NUWS

BUNDANOON WATER SUPPLY

Yield Study Report

Prepared for Wingecarribee Shire Council

Report No. 16001
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NSW Urban Water Services Pty Ltd

Summary

This report provides updated *secure yield* estimates for Bundanoon's water supply headworks system estimated in accordance with NSW Office of Water's[1] Draft *"Assuring future urban water security, Assessment and Adaption guidelines for NSW local water utilities"* (Ref 1).

It is noted ±*secure yield'* is a defined term (see section 1.7) based on accepted methodology.

Table S1 provides the secure yield estimates for Bundanoon Dam only (ie without supply from the Wingecarribee Reservoir) for the main cases examined for the climate experienced over the last 120 years or so and with projected 1°C climate warming.

Table S1: Bundanoon Dam Secure Yield Estimates

Bundanoon Gross Dam Storage Size ML	EFR Releases	Secure Yield ML/a	
		Historic Climate	**1°C Climate Warming**
2046	Up to 1 ML/d*	**1967****	**1695****

* Environmental Flow Requirement (EFR) Subject to Inflow
** Note potential estimate as limited to 1000 ML/a based on licence conditions

It is noted the secure yield estimates are dependent on the operating rules, data and assumptions as discussed in detail in the main body of this Report.

Modelling was also undertaken to estimate transfers required from the Wingecarribee Reservoir to meet a nominated future demand of 9433 ML/a with the aim to maximise the use of Bundanoon Dam and thus minimise the use of transfers from the Wingecarribee Reservoir. The findings are summarised in Table S2.

Table S2: Transfer Estimates

On occasions all the daily demand can be met from Bundanoon Dam, however there are times when all the daily demand needs to be met from the Wingecarribee Reservoir.
For the modelled historic climate, 64 to 62% of demand on average could be supplied from the Bundanoon Dam storage while 36 to 38% of demand on average would need to be supplied from the Wingecarribee Reservoir.
For the modelled 1°C warming scenarios, 55 to 48% of demand on average could be supplied from the Bundanoon Dam storage while 45 to 52% of demand on average would need to be supplied from the Wingecarribee Reservoir.

It was assumed that the 1000 ML/a licence condition limit for Bundanoon Creek did not apply

1. In July 2015 DPI water was formed replacing NSW Office of Water

This report was drafted in June 2016 and instruction to issue as Final Report provided in April 2018.

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1.   Introduction

1.1 Background

Bundanoon's water supply headworks system consists of Bundanoon Dam on Bundanoon Creek with a catchment area of about 52 km^2. The capacity of the dam storage at full supply level is reported to be about 2000 ML. Additional water can be sourced from Wingecarribee Reservoir with a total operating storage of some 24,000 ML which is supplied from the Shoalhaven Scheme.

As part of preparing an IWCM Issues paper, Wingecarribee Shire Council required a *secure yield* analysis to be undertaken for the Bundanoon Dam water supply headworks system in accordance with the requirements of DPI Waters[2] draft guidelines for "*Assuring future urban water security – Assessment and adaption guidelines for NSW local water utilities".*

1.2 Scope of Work

Wingecarribee Shire Council engaged NSW Urban Water Services (NUWS) to:

- Estimate the *Secure Yield* of the existing Bundanoon Dam water supply headworks system.

- Assess the impacts of climate change on the *Secure Yield*.

- Estimate transfers required from *WaterNSW (*Wingecarribee Reservoir) while maximising use of Bundanoon Dam towards minimising volume and frequency of water purchased but still meeting specified future demand on a secure yield basis.

It is noted *Secure Yield* is a defined term as provided by NSW Office of Water (NOW) *Best-Practice Management of Water Supply and Sewerage Guidelines* (Ref 2) and the *NSW Water Supply Investigation Manual* (Ref 3) and more recently by NOW's Draft *"Assuring future urban water security, Assessment and Adaption guidelines for NSW local water utilities"* (Ref 1). Use of Secure Yield provides a practical consistent basis for assessing the yield of a system on a security of supply basis. Details of Secure Yield are provided in Section 1.7 and Appendix A.

1.3 Objectives

This report contains a summary of the modelling undertaken to provide secure yield estimates for specified operating and streamflow conditions for Bundanoon's water supply headworks system.

The outcomes from this modelling were required to assist with planning to meet future water demand.

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2. In July 2015 DPI water was formed replacing NSW Office of Water

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1.4 Methodology

Estimating the yield of a headworks system involves two important stages:

- Streamflow estimation:

    Developing an appropriate sequence of streamflows

- System Behaviour Modelling:

    Modelling the behaviour of the headworks system subject to operating constraints using the streamflows to assess what demand subject to reliability or security criteria can be satisfied.

For this study the required streamflows were obtained using the AWBM rainfall runoff model (Ref 4).

For the behaviour modelling a purposely developed system behaviour model to determine yield in terms of 'secure yield' for the Bundanoon water supply headworks system was used. The underlying methodology used in the model arises from the definition of *Secure Yield* and has been successfully used on many other water supply headworks systems. The model logic has been developed and tested through many uses over the years.

1.5 Climate Change

While secure yield allows for meeting demand with restrictions through a much worse drought than has occurred since about 1890, consideration needs to be given to possible changes from Climate Change.

For this study additional consideration was given by using the approach proposed in NSW Office of Water's (NOW) Draft Proposed Policy[3] for assessing the impact of climate change on non-metropolitan water supplies as informed by (Samra & Cloke, 2010) and provided in Appendix A.

1.6 Qualifications

The work contained in this Report is considered valid within the context of the study purposes, but caution should be exercised if aspects of this report, including data and estimates, are abstracted out of context or are to be used for some other purpose. Hydrology is not an exact science and necessarily involves some uncertainty and the results should be regarded as estimates within the limitations of the study and available data to be used as indications in a much larger decision making process.

The yield of a headworks system is dependent on the assumed streamflows and operating constraints. For this study observed streamflows were provided by others and the operating constraints are as specified. While the yield estimates are based on established methodology, NSW Urban Water Services Pty Ltd does not warrant or accept any liability in relation to the quality or accuracy of the yield estimates which are reliant on provided information and no

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3. *The draft Policy is now also given by way of NOWs Draft Guidelines (Ref 1).*

responsibility is accepted by NSW Urban Water Services Pty Ltd for the accuracy, currency, reliability and correctness of any information in this publication provided by the client or third parties.

1.7 Yield Model

Secure Yield

For the past 25 years or so most urban water supply headworks in country NSW have been sized on a robust Security of Supply basis. This security of supply basis was developed to cost-effectively provide sufficient dam storage capacity to allow the water utility to effectively manage its water supply in future droughts of greater severity than experienced over the past 100 or more years. ±Secure Yieldq is the water demand that can be expected to be supplied with only moderate restrictions during a significantly more severe drought than has been experienced since about 1895 (from when generally reliable rainfall records are available). The required water restrictions must not be too severe, not too frequent, nor of excessive duration. It has been argued that the definition of *Secure Yield* in effect allows meeting demand with moderate restrictions through a severe drought akin to a ±1 in 1000 yearq drought[4].

Under the NSW Security of Supply basis (commonly referred to as the ±5/10/20 ruleq), water supply headworks system were normally sized so that:

a) Duration of restrictions does not exceed 5% of the time; and
b) Frequency of restrictions does not exceed 10% of years (ie 1 year in 10 on average)
c) Severity of restrictions does not exceed 20%. Systems must be able to meet 80% of the unrestricted water demand (ie 20% average reduction in consumption due to water restrictions) through a repetition of the worst recorded drought, commencing with the storage drawn down to the level at which restrictions need to be imposed to satisfy a) and b) above.

±Secure Yieldq was defined as the highest annual water demand that can be supplied from a water supply headworks system while meeting the above ±5/10/20q rule.

Over the last 20 years there has been a significant reduction in residential water consumption per property and thus it is considered it will be difficult to achieve a 20% reduction in consumption as implied by the earlier ±5/10/20q rule . Consequently DPI Water/NSW Office of Water (NOW) recommends that future planning should be based on a 10% reduction in consumption through a repetition of the worst drought commencing with the storage already drawn down to satisfy the 5% duration and 10% frequency criteria. Thus the ±5/10/20q rule has now become a ±5/10/10q rule.

It is also noted that more recently the 10% frequency rule has been slightly refined by NOW from frequency of restrictions occurring 1 in 10 years on average to only being applied in 10% of years. For a sample of test cases this was of little consequence, and was desired to fit in with NOWs requirements for Performance Reporting of restrictions and thus was also based on the financial year.

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4   It is noted that '1 in 1000 year drought' does not mean it only occurs once every thousand years but means it has a 0.1% probability of occurring any year.

The current procedures to determine secure yield are illustrated in Figures 1 and 2 which have been taken from material provided by NOW.

Model

Essentially the model is a computer program that balances continuity equations between all the water sources and demands while incorporating the procedures (as illustrated in Figures 1 and 2) to determine secure yield. The model simulates the behaviour of the system by accounting for and balancing the available water. The hydrological cycle is modelled external to the model and the required hydrometeorological data is provided as input to the system behaviour model. In essence the system model is driven by operating conditions such as the need to meet a particular demand while satisfying constraints and available flow.

2.   Hydrometeorological Data

2.1 Introduction

In general estimates of daily rainfalls, streamflows and daily evaporation and evapotranspiration for as long a historical period as possible is desirable.

Satisfying the $5,10,10q$ rule for determining secure yield requires more than 100 years of daily streamflows to be a sufficiently long data sample for testing the rules and so as to include the significant Federation drought (1895-1903) and other known significant droughts.

In addition to daily streamflows, accompanying daily rainfalls and evaporation are required for input to the system behaviour model for determining the net loss or gain from or to storages water surface area due to evaporation or rainfall.

The daily rainfalls are also required as input to the AWBM rainfall runoff model as well as daily evapotranspiration to obtain streamflows when no observed streamflows are available.
The details of the model are provided in Ref 4 and illustrated in Figure 3.

For this study historic data series were developed to cover the period January 1890 to February 2016.

2.2 Data

Meteorological

The daily rainfall and daily evapotranspiration data were obtained from the SILO Data Drill for 4 grid points as given in Table 2.1 and shown in Figure 4 to cover the catchment area of the dam. The SILO Data Drill is a service provided by the Science Delivery Division of Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA). The Data Drill accesses grids of data at 0.05^{o} intervals derived from interpolation of point Bureau of Meteorology station records. Interpolations are calculated by Splinning and Kriging techniques. Further details of the processes are given in Ref 5.

Daily evaporation and rainfall data to represent losses from the dam storage was also obtained from the SILO Data Drill. For this purpose data from Grid Point 2 being the closest to the dam storage was used.

Table 2.1: SILO Grid Points

Grid Point	Longitude ^{o}	Latitude ^{o}
1	150.40	34.60
2	150.40	34.65
3	150.45	34.60
4	150.45	34.65

Streamflow

An AWBM rainfall runoff model was set up for the Bundanoon Dam catchment. Since no suitable gauging station records were available for Bundanoon Creek, the model parameter values preferably obtained by calibration were estimated from catchment characteristics utilising *Boughton (1993)*(Ref 6) and *Nathan & McMahon (1991)*(Ref 7).

Four sets of model parameter values were considered so as to reflect potential uncertainty in the parameter values so as to assess sensitivity to this uncertainty.

The AWBM model using daily rainfall and daily evapotranspiration data from the SILO Data Drill was run to provide estimated daily inflows to Bundanoon Dam for 1890 to 2016. Four sets of flows were obtained.

Flow duration curves for the four sets of flows are provided in Figure 5.

A water balance of the provided operational data (1/7/2008- 30/11/2015) was undertaken to calculate daily inflows to the dam. The operational data essentially consisted of daily levels for the dam and daily extractions from the dam. However as most of the time the dam was spilling, only relatively short periods of inflows could be obtained. Since these periods of flows were not appropriate for direct model calibration they were used to compare with the four series of flows to assist in selecting the most representative series for secure yield determination.

Figure 6 compares the flows from the AWBM series with the comparable periods of flows from the water balance (*observed*).

Figures 7 and 8 compare the observed storage behaviour with that modelled using the four series of AWBM inflows and the records of daily extractions. The horizontal line at 2046 ML indicates the dam is full and or spilling. Figure 7 shows the drawdown relative to the full storage size however since the drawdowns are relative minor Figure 8 shows it relative to about the top 15% of storage.

From the comparisons of modelled flows with the operational data it was not obvious which was the most appropriate flow series for secure yield modelling. Furthermore it was considered the operational data was very limited, particularly as no significant drawdowns occurred and the high flow comparison may be biased by the spilling. While as shown in Figure 6, the AWBM6 flow series provided the best fit of flows from 20%ile to 100% ile , the modelled drawdowns were more severe than for the other flows and in not so good agreement with the observed drawdown.

3. System Behaviour Modelling

3.1 Introduction

Modelling of the behaviour of the water supply headworks system is required to determine the *secure yield* of that system. The aim of the modelling is to determine the maximum annual demand that satisfies the 5/10/10 rules. This is done using a computer storage and system behaviour model using an iterative process to satisfy all the requirements implied by the rules and available water from the various sources.

A system behaviour model was set up for the headworks system using model logic developed and tested over many years and incorporating refinements to reflect current requirements.

The model is essentially driven by operating conditions such as the need to meet a specified demand whilst satisfying constraints such as available water from streamflows.

In addition to the hydrometeorological data that has to be input into the computer simulation model, other data has to be incorporated into the model. These additional data are detailed in the following sections.

3.2 Headworks System

The existing headworks system modelled essentially consisted of the Bundanoon Dam on Bundanoon Creek from which water was transferred to supply.

3.3 Demand Pattern

Whilst secure yield provides the system annual demand that can be met, the annual demand needs to be broken down into monthly patterns to reflect seasonality. Three demand patterns were used as given in Table 3.1:

- The first pattern was based on the extractions from the dam from Councils operational data for 2008-2015. The pattern was essentially uniform, the differences reflecting the different number of days in the months and reflected how Bundanoon Dam was used in conjunction with Wingecarribee Reservoir. (*Operational*)

- The second pattern was initially used to reflect typical seasonality as considered more appropriate for examining Bundanoon Dams secure yield (*without Wingecarribee Reservoir)*. The pattern was based on that used for the recent Captains Flat yield study. (*Seasonal*)

- The third pattern which was made available later essentially refined the second pattern and was provided from the IWCM work to reflect future demand for unrestricted dry year demand. (*Future*)

Table 3.1: Demand Patterns

Pattern	% of Annual Demand											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Operational	8.535	7.668	8.490	8.217	8.490	8.217	8.487	8.488	8.214	8.488	8.215	8.489
Seasonal	12.2	10.6	10.1	6.6	6.3	6.4	6.4	6.5	6.3	8.1	9.3	11.2
Future	9.83	9.23	9.83	7.39	7.59	6.05	6.70	6.70	6.50	8.94	10.08	11.17

3.4 Storage

Gross dam storage was 2046 ML, and there was insignificant dead storage (about 49 ML) and insignificant leakage.

3.5 Storage Area

Evaporation losses (or rainfall gain) from the dam storage water surface area were modelled as the volume of water in the storage changed. The volume and surface area data for modelling evaporation losses is given in Table 3.2 and was estimated from the storage volume-height curve provided by Council as taken from the recent Dam Surveillance Report.

Table 3.2:   Storage Area Data

RL m	Volume ML	Water Surface Area km²
501.90	80.45	0.0053
505.00	123.76	0.0227
510.00	371.29	0.0762
515.00	878.71	0.1267
520.00	1757.43	0.2248
521.19	2046.00	0.26

3.6 Environmental Flows

Currently Bundanoon Dam is operated without any requirements for environmental flows (EFR) or irrigation and riparian releases. Thus no release requirements were included in the modelling for the initial existing cases.

In addition selected cases were modelled to meet the licence and Water Sharing Plans (WSP) condition that:

> "Water must only be taken if there is visible flow in the water source at the location where water is to be taken".

It was advised by *DPI Water IWCM Manager* that:

- For "visible flow" can assume 1 ML/d or 99%ile flow whichever greater.

- For future case if no augmentation (eg raising of dam etc) then no new EFR will be imposed and only need to satisfy WSP.

For all the flow series the 99%ile flow was less than 1 ML/d. Thus in the model if the daily inflow was greater than or equal to 1 ML/d, then 1 ML/d was released from the Dam. If the daily inflow was less than 1 ML/d then the total daily inflow was released.

3.7 Operating Rules

Water was simply extracted from the Bundanoon Dam to meet demand. To maximise secure yield it was assumed there was no constraint on transfer capacity from the Dam. The results tables provide the maximum daily transfers that occurred for the various secure yield cases modelled.

4. Modelling Results

4.1 Introduction

The secure yield estimates determined from the behaviour modelling for the existing system are presented in this chapter.

Secure Yield determination is based on a defined methodology (see Appendix A) and uses historic climate data and allows for supply to be met through a much more severe drought than has occurred in the last 120 years or so. The results presented in this chapter are based on historic climate. Adjustments to these results can be made to allow for projected climate change scenarios using defined methodology and these results are presented in Chapter 5.

While secure yield is reliant on the available streamflows, it is also dependent on transfer capacities, environmental flow conditions, annual demands and their monthly distribution, level of security expected and the schemes operating rules. The conditions used have been described in Chapter 3.

The expected level of security arises from the 5/10/10 rules which provides for 10% restrictions occurring in 10% of the years for 5% of the time.

4.2 Initial Sensitivity

The initial secure yield results without requirements for dam releases for the different flow series are provided in Table 4.1 for the existing system of Bundanoon Dam only *(ie without Wingecarribee Reservoir transfers)*. The modelled storage behaviour diagram for the case that resulted in the lowest secure yield for a repeat of the historic climate is provided in Figure 9.

Table 4.1: Bundanoon Dam Sensitivity Results (Historic Climate)

Demand Pattern	Run No Set	Flow Series	Secure Yield ML/a	Max Daily Transfer ML/d	Restrictions			CriticalDrought	
					Applied at storage (% full)	Duration (%)	% of Years	From	To
2008-2015 Operational	100	AWBM4	**2424**	6.67	55	1.25	8.66	27/10/1939	13/02/1942
	110	AWBM1	**3071**	8.46	55	0.76	9.45	19/06/2002	10/02/2003
	120	AWBM3	**2821**	7.77	50	0.30	5.51	22/06/2002	10/02/2003
	130	AWBM6	**2232**	6.15	50	0.47	3.94	7/02/1941	13/02/1942
Typical Seasonal	101	AWBM4	**2212**	8.71	50	0.37	3.94	7/02/1941	18/03/1942
	111	AWBM1	**2812**	11.07	59	0.22	6.3	27/06/2002	10/02/2003
	121	AWBM3	**2449**	9.64	50	0.18	3.94	22/10/1904	01/04/1905
	131	AWBM6	**2114**	8.32	50	0.51	9.45	7/02/1941	18/03/1942
No Release Requirements for Dam									

The secure yield results were not that sensitive to the two demand patterns considered. Also the relative differences in the secure yield estimates were not as great as the relative

differences in the low flows from the four AWBM flow series. AWBM6 flow series resulted in the lowest secure yield for the two demand patterns.

Based on the sensitivity testing and the earlier comparison of the modelled inflows from the four AWBM series with limited operational data, it was judged that the AWBM6 flows should be adopted for the secure yield but the AWMB4 flows would still be considered for comparison.

4.3   Additional Sensitivity

Additional secure yield sensitivity results without requirements for dam releases for the AWBM6 flow series are provided in Table 4.2 for the existing system of Bundanoon Dam only *(ie without Wingecarribee Reservoir transfers)* for the typical seasonal demand pattern and the future demand pattern.

Table 4.2   Bundanoon Dam Demand Pattern Results (Historic Climate)

Demand Pattern	Run No Set	Flow Series	Secure Yield ML/a	Max Daily Transfer ML/d	Restrictions			Critical Drought	
					Applied at storage (% full)	Duration (%)	% of Years	From	To
Typical Seasonal	131	AWBM6	**2114**	8.32	50	0.51	9.45	7/02/1941	18/03/1942
Future	232	AWBM6	**2170**	7.82	50	0.56	9.45	7/02/1941	13/02/1942
No Release Requirements for Dam									

There is little difference in the secure yields for the two demand patterns suggesting that the relative differences in secure yields for the initial cases modelled were still relevant.

4.4   Secure Yield With Releases

Secure yield sensitivity results with requirements for dam releases for the AWBM4 and AWBM6 flow series are provided in Table 4.3 for the existing system of Bundanoon Dam only *(ie without Wingecarribee Reservoir transfers)* for the future demand pattern.

Table 4.3   Bundanoon Dam With Releases Results (Historic Climate)

Run No Set	Demand Pattern	Flow Series	Secure Yield ML/a	Max Daily Transfer ML/d	Restrictions			Critical Drought	
					Applied at storage (% full)	Duration (%)	% of Years	From	To
102	Future	AWBM4	**2019**	7.27	55	0.97	9.45	27/10/1939	18/03/1942
132	Future	AWBM6	**1967**	7.09	50	0.58	8.66	7/02/1941	13/02/1942
Release Requirements (up to 1 ML/d) for Dam									

The imposition of the release requirements has reduced the secure yield estimates by about 10%.

The modelled storage behaviour diagram for the case of future demand pattern based on the AWBM6 flow series (*Run set132*) for a repeat of the historic climate is provided in Figure 10.

# 5.	Climate Change

## 5.1	Background

While secure yield allows for meeting demand with restrictions through a much worse drought than has occurred since about 1890, consideration needs to be given to possible changes from Climate Change.

For this study additional consideration was given by using the approach[5] proposed in NSW Office of Waters (NOW) Draft Proposed Policy for assessing the impact of climate change on non-metropolitan water supplies as given in (Samra & Cloke, 2010) and provided in Appendix A. However for this study data for projections based on 1^oC warming scenario, about Year 2030 for A1B mid-range emissions, were used. The Pilot Study was based on 0.9^oC warming, for A1B mid-range emissions scenario, at the time thought to be about a Year 2030 projection but now considered to be some years earlier.

## 5.2	Data

The required Climate Change data to follow the proposed approach were provided by DPI Water. Daily values of rainfall and evapotranspiration were provided by DPI Water using the methodology developed for their 2008 data sets (Vaze et al, 2008) (Ref 8) for the 15 global climate models (GCMs) and the corresponding historic data for the four nominated catchment representative SILO grid points. The climate change data are for projected ~2030 and were obtained by Vaze et al (Ref 8) by scaling the historical 1894-2008 daily rainfall and evapotranspiration data using the methods detailed in Chiew et al, 2008 (Ref 9). The climate change data were based on the Years 2030 A1B warming scenarios, mid-range emissions scenarios.

The daily data from the 15 GCMs and the corresponding historic base data were input into the AWBM rainfall runoff model using the two sets of model parameter values, AWBM4 and AWBM6 to produce two sets of 16 series of inflows to Bundanoon Dam for the 1^oC warming scenario.

## 5.3	Modelling

The modelling essentially involved:

- The 16 series of daily flows, (and daily rainfalls and daily evaporation) were input into the headworks storage behaviour model to determine 16 corresponding secure yield estimates. (*The required daily evaporation for the offstream storage was obtained from relations developed between historic evapotranspiration and historic evaporation and then applied to the climate change evapotranspiration daily values*).

It is noted the modelling period due to data availability was 1/1/1895 to 31/12/2008 which was slightly shorter to that used for the secure yield modelling without climate change.

5	*This complies with NOWS draft guidelines "Assuring future urban water security" (Ref 1).*

5.4   Results

Table 5.1 summarises the key results for determining the factors to apply to the *traditional* secure yield estimates for the nominated cases modelled to allow for Climate Change using the same approach[6] as provided by NOWs draft policy as given in %NSW Response for Addressing the Impact of Climate Change on the Water Supply Security of Country Towns+, (Samra & Cloke, 2010).

Table 5.1: Climate Change Factors

Case for 1°C Warming		Secure Yield Estimates ML/a				Relevant Case in terms of NOW Draft Policy	Adopted Factor to be Applied for Climate Change
Model Parameter Values	Demand Pattern	Historic from Climate Change data Base	Median from GCMs (5/10/10)	Lowest from GCMs (5/10/10)	Lowest from GCMs rerun with (10/15/25)*		
		A	B	C	D		
AWBM4	Future	1860	1804	1397	1639	D/A	0.8812
AWBM6	Future	1872	1789	1413	1613	D/A	0.8616
Release Requirements (up to 1 ML/d) for Dam							

* Subsequent to Samra & Cloke, 2010, the Technical Steering Committee revised 5/10/25 to 10/15/25

It is noted that the secure yields in column A are different than the original historic secure yields. This was a common finding of the pilot study due to differences in data sets including period of data.

Table 5.2 provides the secure yield estimates adjusted for climate change in accordance with the above proposed approach.

Table 5.2: Secure Yield Adjusted for Climate Change

Case		Secure Yield Estimates ML/a			
Model Parameter Values	Demand Pattern	Run No for Original Historic Case*	Original Historic (5/10/10)	Adjustment factor for Climate Change	With Climate Change**
AWBM4	Future	*Set102*	2019	0.8812	1779
AWBM6	Future	*Set132*	1967	0.8616	1695
Release Requirements (up to 1 ML/d) for Dam					

*   see Table 4.3

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6   *This complies with NOWS draft guidelines "Assuring future urban water security" (Ref 1).*

6. Transfers

6.1 Introduction

The required transfers from the Wingecarribee Reservoir determined from the behaviour modelling for the existing system are presented in this chapter.

Behaviour modelling was undertaken to aim to maximise the use of Bundanoon Dam and thus minimise the use of transfers from the Wingecarribee Reservoir.

The modelling was undertaken to provide Councils nominated future annual demand of 9433 ML/a. The modelling was based on the adopted AWBM6 model parameter values, with the dam release requirements (up to 1 ML/d) and using the future demand pattern.

It was assumed that whenever Bundanoon Dam could not meet supply, the deficit in supply would be met from the Wingecarribee Reservoir, thus in effect the 9433 ML/a would be met on the secure yield basis.

6.2 Results

Historic Climate

Two cases were modelled to examine transfers required to provide a demand of 9433 ML/a for a repeat of the historic inflows:

- Use Wingecarribee transfers whenever Bundanoon Dam storage below 20% full.
- Use Wingecarribee transfers whenever Bundanoon Dam storage below 30% full.

The 20% and 30% full criteria were examined as it was considered that it would not be desirable to go too close to emptying Bundanoon Dam storage. The resulting amount of transfers required did not appear that sensitive to whether 20 or 30% level was used as the trigger to transfer. For the 20% trigger on average 64% of demand could be supplied from Bundanoon Dam and with the 30% trigger on average 62% of demand could be supplied from Bundanoon Dam.

Climate Change

To assess the impact of climate change on the amount of transfers required to provide a demand of 9433 ML/a two cases were modelled:

- Using the GCM flow series that resulted in the median secure yield for the 1 $^{\circ}$C warming scenario.
- Using the GCM flow series that resulted in the lowest secure yield for the 1 $^{\circ}$C warming scenario.

Both these cases were modelled assuming Wingecarribee transfers occurred whenever Bundanoon Dam storage level was below 30% full.

Results

Table 6.1 summarises the transfers required for the above four cases modelled. The results show that on occasions all the daily demand can be met from Bundanoon Dam, however there are times when all the daily demand needs to be met from the Wingecarribee Reservoir.

For the modelled historic climate 64 to 62% of demand on average could be supplied from the Bundanoon Dam storage while 36 to 38% of demand on average would need to be supplied from the Wingecarribee Reservoir.

For the modelled 1°C warming scenarios 55 to 48% of demand on average could be supplied from the Bundanoon Dam storage while 45 to 52% of demand on average would need to be supplied from the Wingecarribee Reservoir.

Table 6.1: Transfer Results

Inflow Case	Bundanoon Storage Trigger level for Wingecarribee Transfer	Peak Transfer From ML/d		Average* Transfer From ML/d	
		Bundanoon	Wingecarribee	Bundanoon	Wingecarribee
Historic Climate (1890-2016)	<20%	34	34	**16.50**	**9.33**
Historic Climate (1890-2016)	<30%	34	34	**16.01**	**9.82**
Climate Change Median GCM Secure Yield (1895-2008)	<30%	34	34	**14.16**	**11.67**
Climate Change Lowest Median GCM Secure Yield (1895-2008)	<30%	34	34	**12.47**	**13.35**

* Over simulation period

Figures 11 and 12 show the variation in the annual transfers required for the historic climate and Figure 13 shows the daily transfers required as duration curves.

7. Discussion

7.1 Previous Study

There do not appear to be any previous studies with estimates of *secure yield* that can be compared with the current study estimates.

7.2 Extractions

For the last 7 years Council has extracted about 450 to 800 ML/a from Bundanoon Dam without significant Dam drawdown and with the dam spilling most of the time. Table 7.1 provides the annual extractions.

Table 7.1: Bundanoon Dam Extractions

Financial Year	Annual Extraction ML/a
2008/09	672
2009/10	530
2010/11	443
2011/12	453
2012/13	794
2013/14	*Incomplete*
2014/15	515

7.3 Validation

Due to the lack of appropriate data to validate the modelling it was considered prudent to adopt the more conservative results.

7.4 Low Flows

Table 7.2 compares the low flows from the four sets of historic flows resulting from the four sets of AWBM model parameter values and compares them to the 1 ML/d adopted for visible flow and thus the release requirement for Bundanoon Dam storage.

Table 7.2: Low Flows Comparison

| Flow	AWBM1	AWBM3	AWBM4	AWBM6
95%ile	1.26 ML/d	0.41 ML/d	0.73 ML/d	0.19 ML/d
99%ile	0.5 ML/d	0.09 ML/d	0.28 ML/d	0.04 Ml/d
1 ML/d	96.6 %ile	89%ile	92.3 %ile	81.8%ile

8.   Recommendations

The results presented in this report should be used keeping in mind the assumptions on which the estimates are based.

9. References

1. NSW Department of Primary Industries, Office of Water (2013), "Assuring future urban water security, Assessment and adaption guidelines for NSW local water utilities", Draft-December 2013.

2. NSW Department of Water and Energy (2007), "Best-Practice Management of Water Supply and Sewerage, Guidelines", August 2007.

3. NSW Public Works (1986), "Water Supply Investigation Manual" (Amended 1990).

4. CRC for Catchment Hydrology (2004), "Rainfall Runoff Library V1.05, AWBM Catchment Water Balance Model"

5. Jeffrey, S.J., Carter,J.O.,Moudie, K.M., and Beswick, A.R.(2001), "Using Spatial Interpolation to construct a Comprehensive archive of Australian Climatic data", Environmental Modelling and Software, Vol 16/4 pp309-330,2001.

6. Boughton, W.C.(1993), "A Hydrograph-Based Model for Estimating the Water Yield of Ungauged Catchments", Institution of Engineers Australia, Hydrology and Water Resources Symposium, Newcastle 1993.

7. Nathan, R.J. and McMahon, T.A. (1990), "The estimation of low flow characteristics and yield from small ungauged rural catchments", AWRAC Research Project Report No.85/105.

8. Vaze, J., Post D., Chiew F., Perraud J-M. and Kirono D. (2008), "Future climate and runoff projections (~2030) for New South Wales and Australian Capital Territory, NSW Department of Water and Energy, Sydney.

9. Chiew F., Teng J., Kirono D., Frost A.J., Bathols J.M., Vaze J., Viney N.R., Young W.J., Hennessy K.J., and Cai W.J., (2008), "Climate data for hydrologic scenario modelling across the Murray-Darling Basin", A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Sydney.

10. Figures
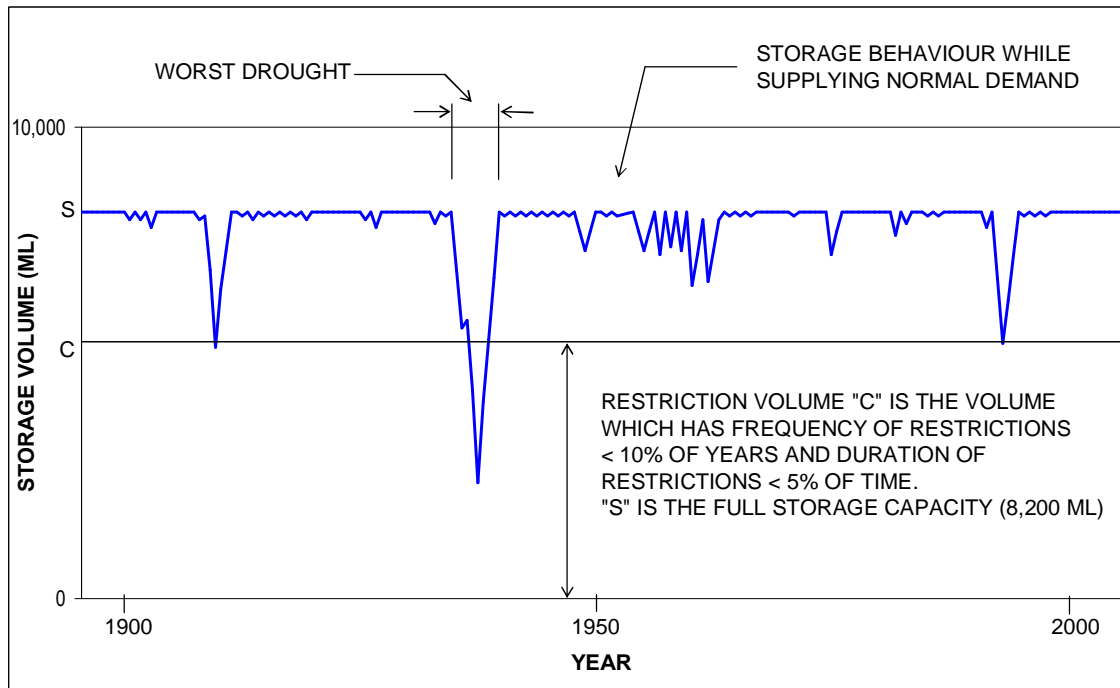
Figure 1: Duration and Frequency of Restrictions

Figure 1 shows the results of simulating an example utility's storage behavior for 120 years of daily streamflow, rainfall and evaporation data and shows that:

- Unrestricted water demand can be supplied for over 95% of the time and over 90% of years (ie. whenever the storage volume is above the **restriction volume C**). In order to satisfy the 5/10/10 rule, restrictions must be imposed whenever the volume of water in storage falls below the **restriction volume C**.

- A 10% reduction in demand is applied when the storage falls below **restriction volume C**

- The worst drought shown in Figure 1 is for approximately the 5-year period January 1939 to December 1943

- The minimum simulated storage volume is approximately 30% of the full storage capacity.
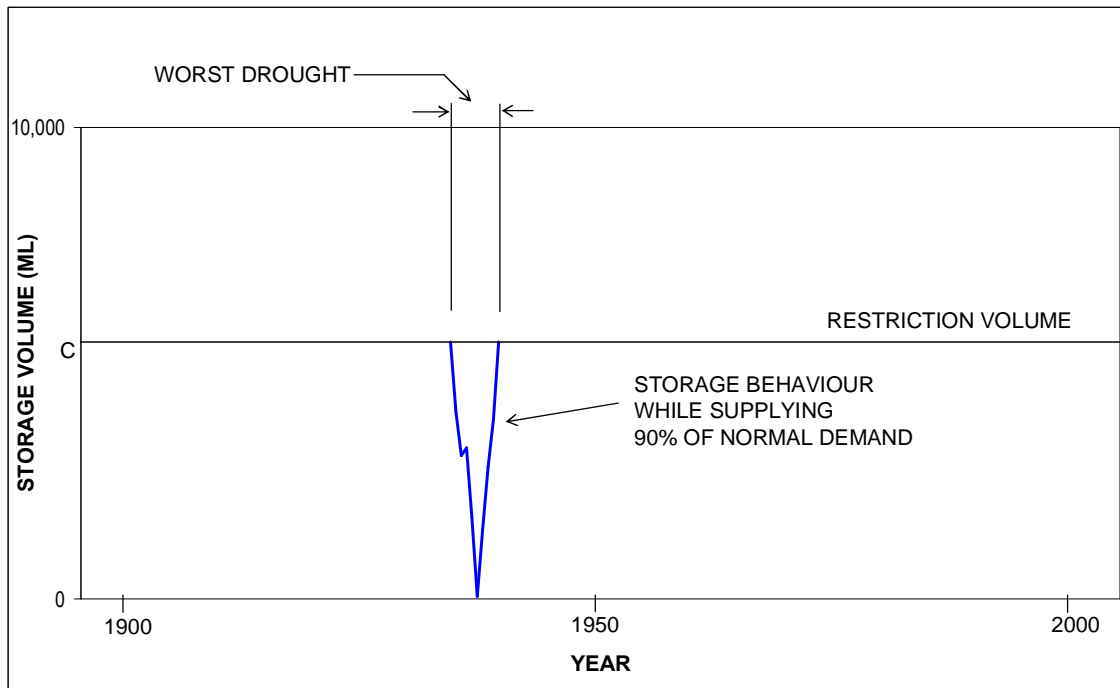
Figure 2: Severity of Restrictions

Figure 2 shows the results of simulating storage behaviour for the worst drought identified in Figure 1 (5-year drought from January 1939 to December 1943) on the following basis:

- A 10% reduction in demand for the full 5-year drought as the storage volume is below the Restriction volume C

- The commencing storage volume for this simulation is the **restriction volume C** and the resulting minimum simulated storage volume is approximately 2% of the full storage capacity.

Comment

Imposition of the requirements of the 5/10/10 rule approximates the severity of a ≜1 in 1000 yearq drought and is necessary in order to enable a utility to manage its system in a drought more severe than the worst drought in the 120 year historical record, with only moderate drought water restrictions.

As the first year of the worst drought for this example utility is simulated in **both Figure 1 and Figure 2**, the water supply system must be able to cope with effectively a 6-year drought, rather than the 5-year worst drought in Figure 1 as it takes about 1-year to drawdown to **restriction volume C.**

It is important to note that the analytical process for the 5/10/10 rule is iterative and that a solution is identified only when all 3 requirements have been met.

A refinement that the NUWS model undertakes and as practiced by NSW Public Works Hydrology Group is to test all droughts for criticality when testing the critical drought with the storage already drawdown at the start of the drought. This is done as it was occasionally found in previous studies that the drought that is critical for the full storage was not necessarily the drought that was critical for in effect a smaller (ie drawdown) storage. This is achieved by modelling the full flow series with the reduced storage size and the restricted demand. This also arises from the "1 in 1000 year" security concept.
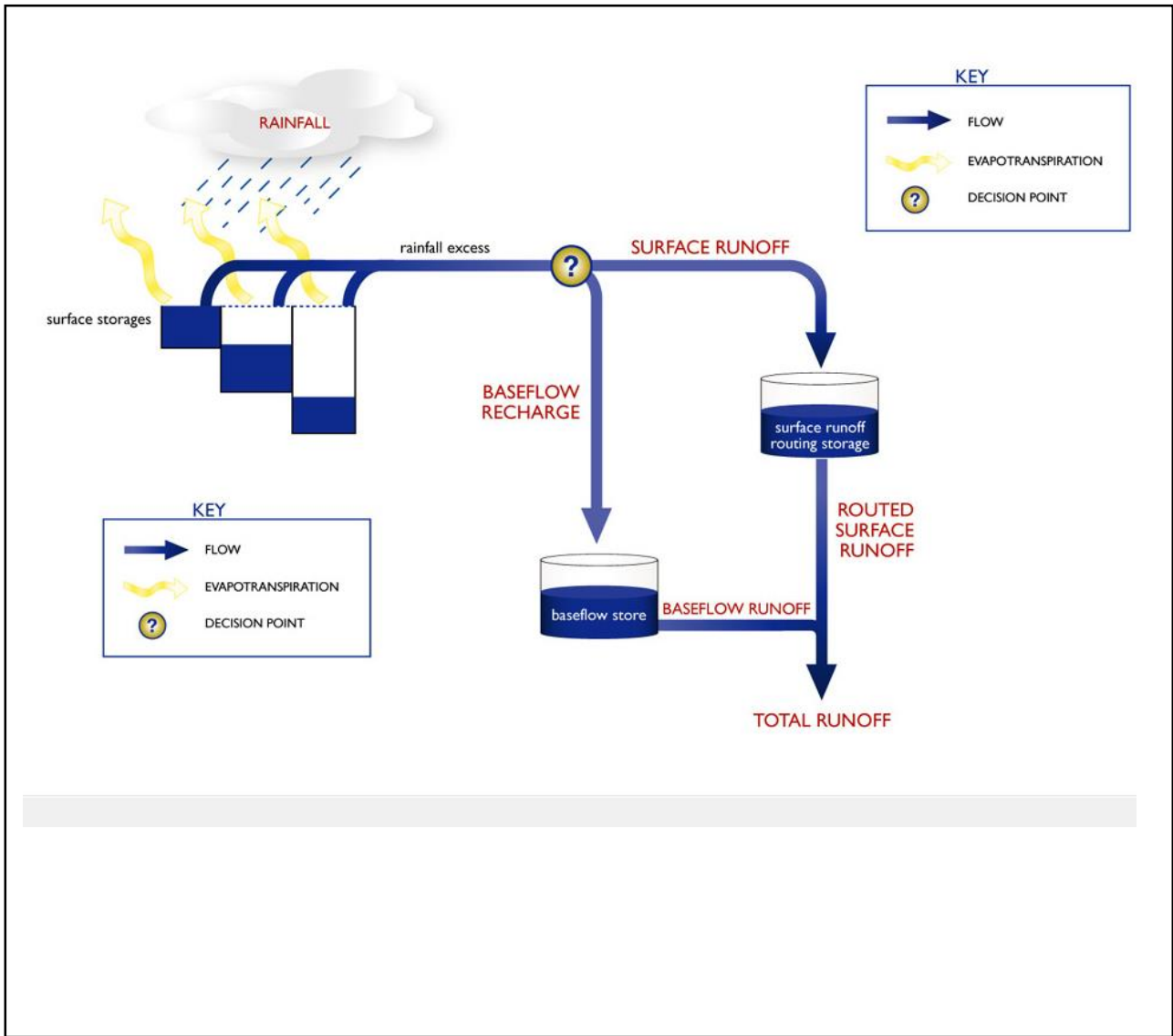
Source Reference 5

Figure 3: AWBM Model
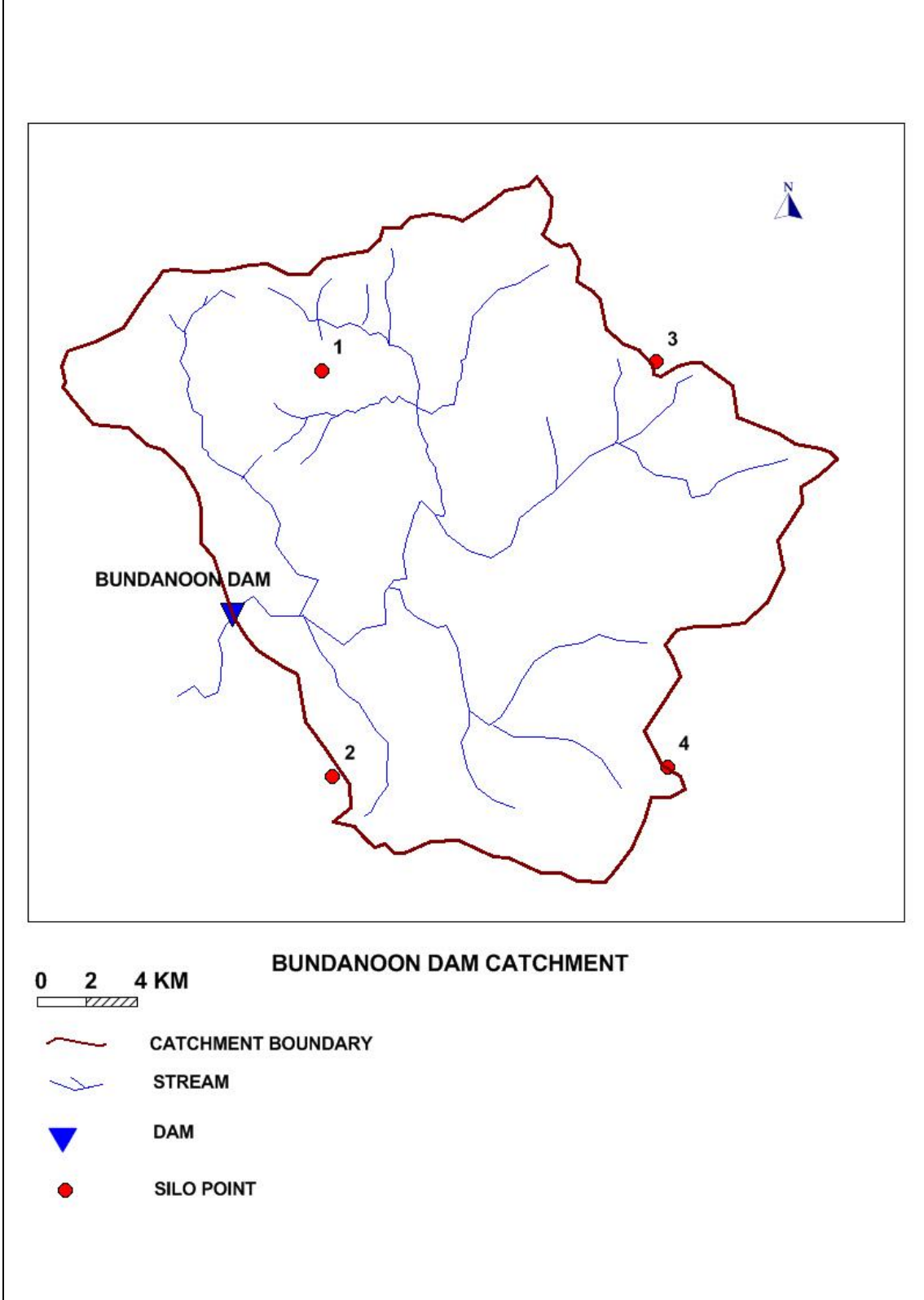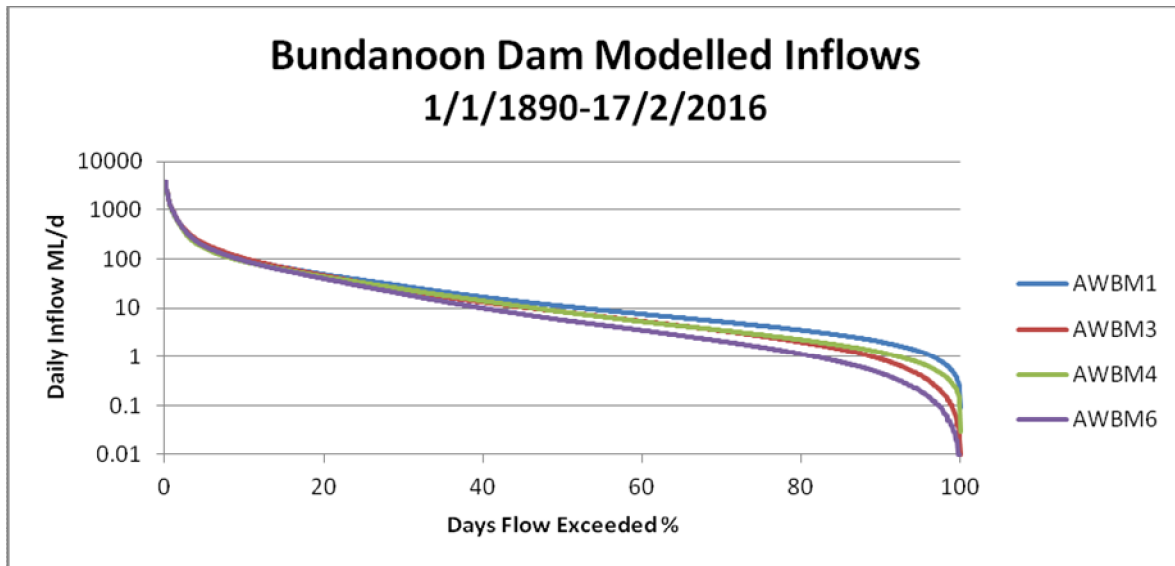
Figure 4: Model Catchment and Water Supply Scheme
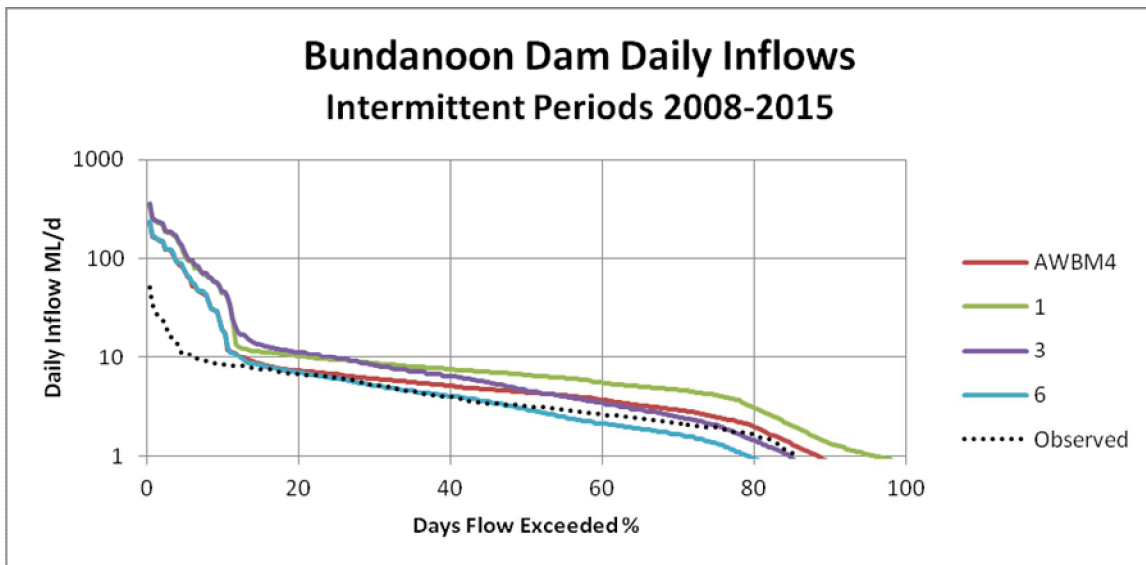
Figure 5: Modelled Inflow Duration Curves

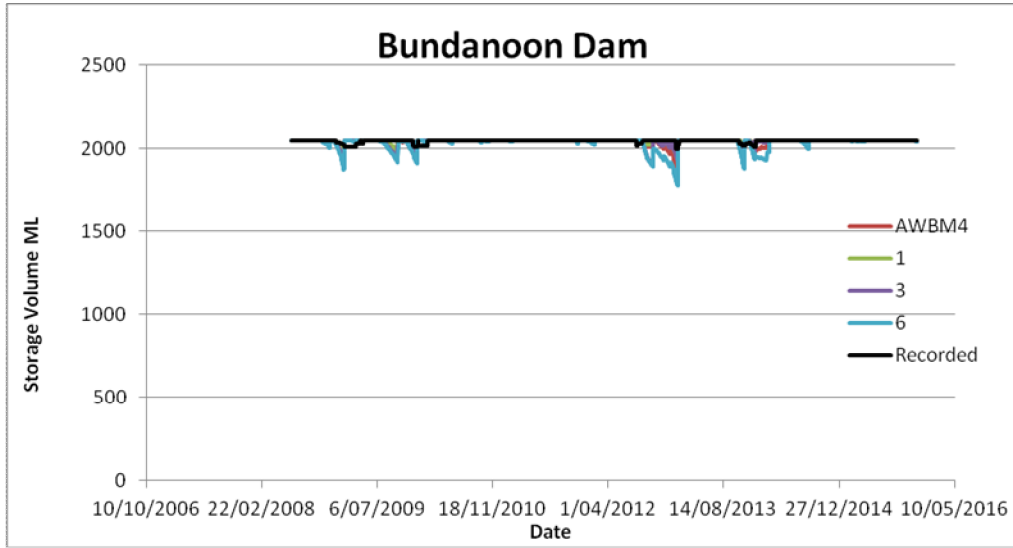**Figure 6: Flows Comparison**

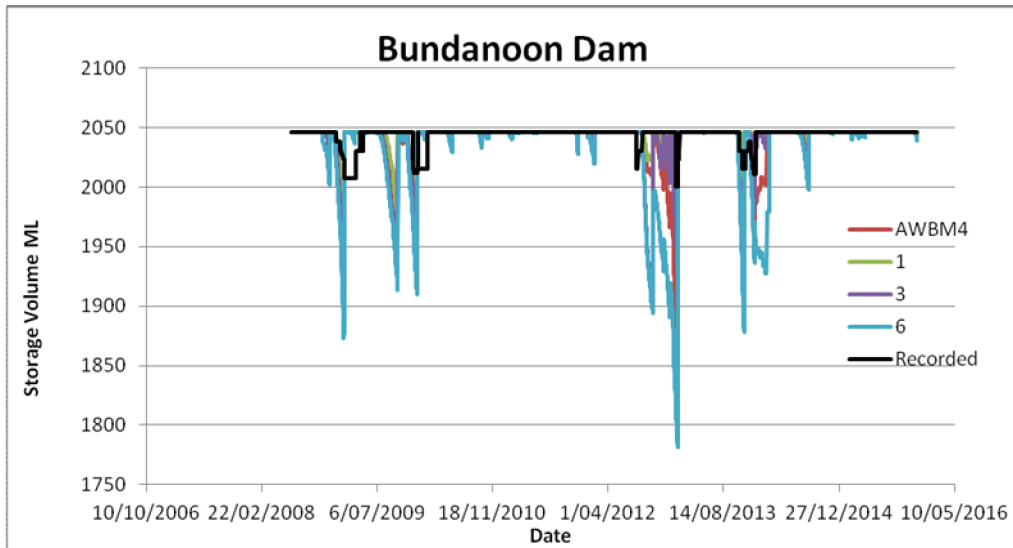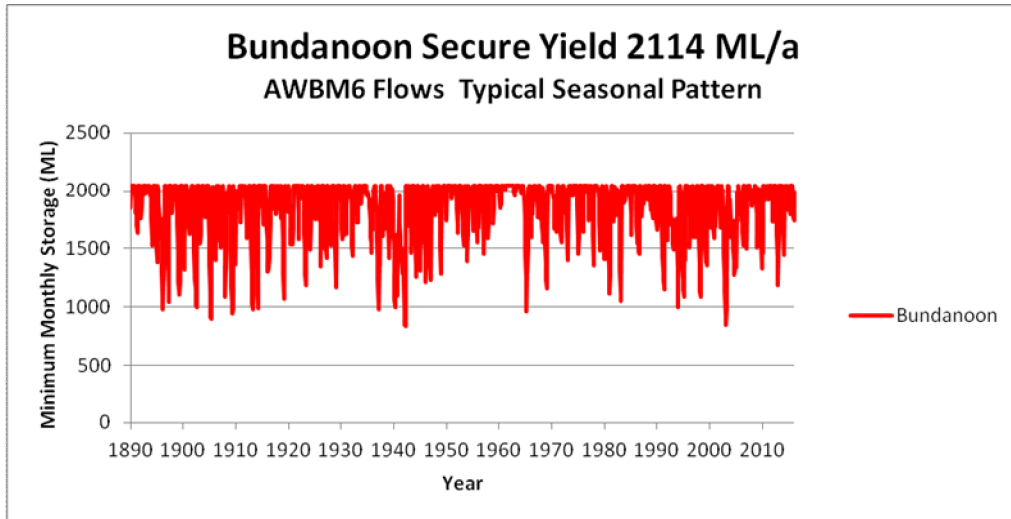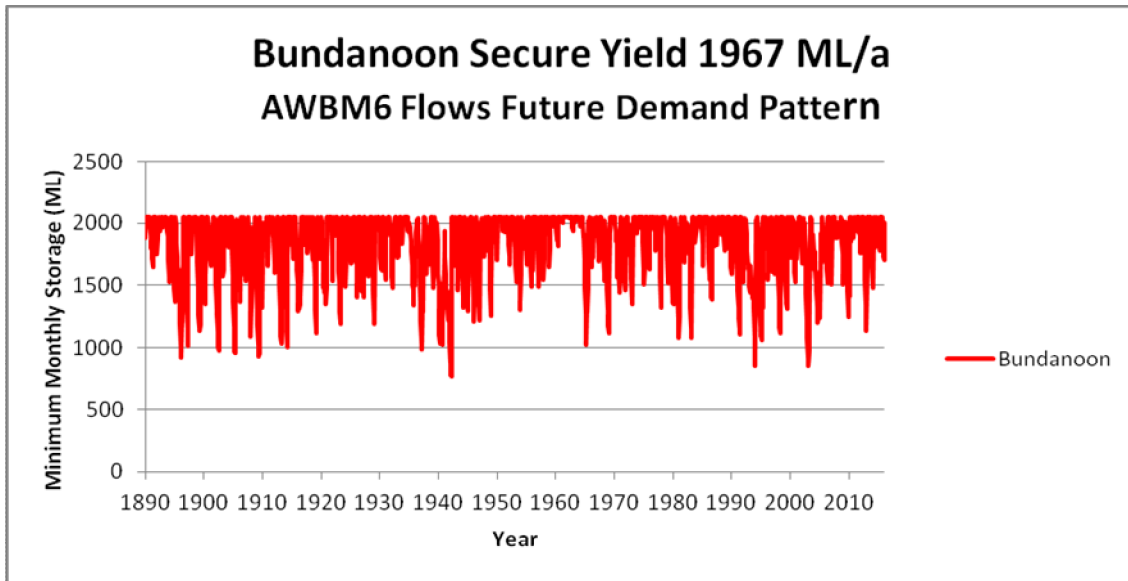**Figure 7: Storage Behaviour Comparison**

Figure 8: Storage Behaviour (above 1750 ML) Comparison

No Dam Release Requirements

Figure 9: Storage Behaviour Diagram (Run Set131)

Up to 1 ML/d Dam Release Requirement

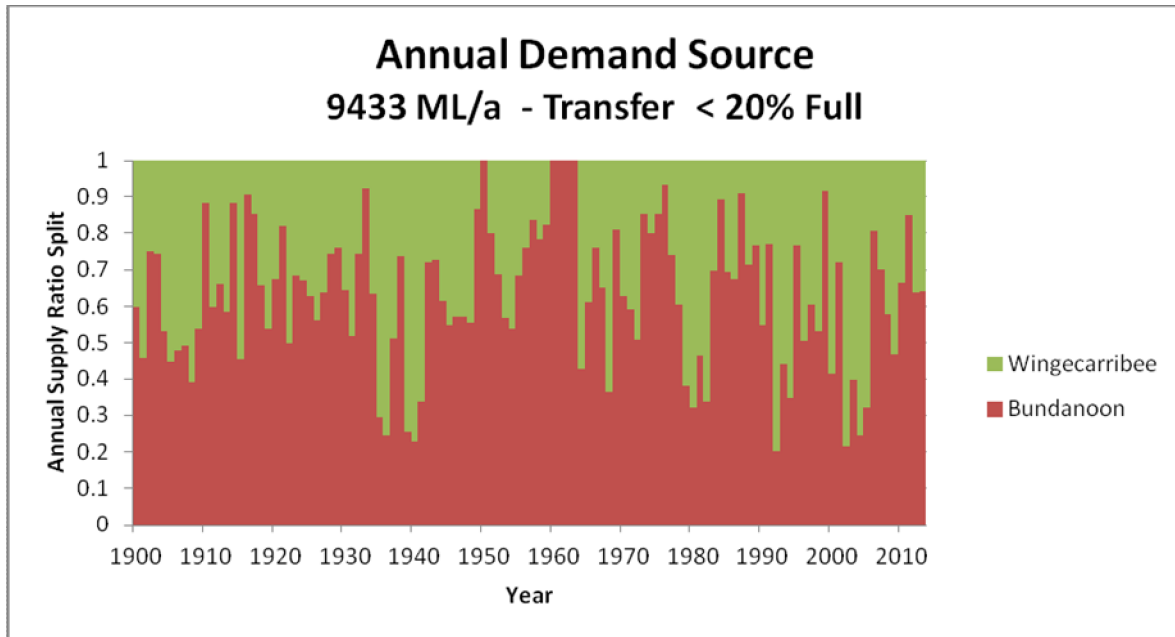**Figure 10: Storage Behaviour Diagram (Run Set132)**

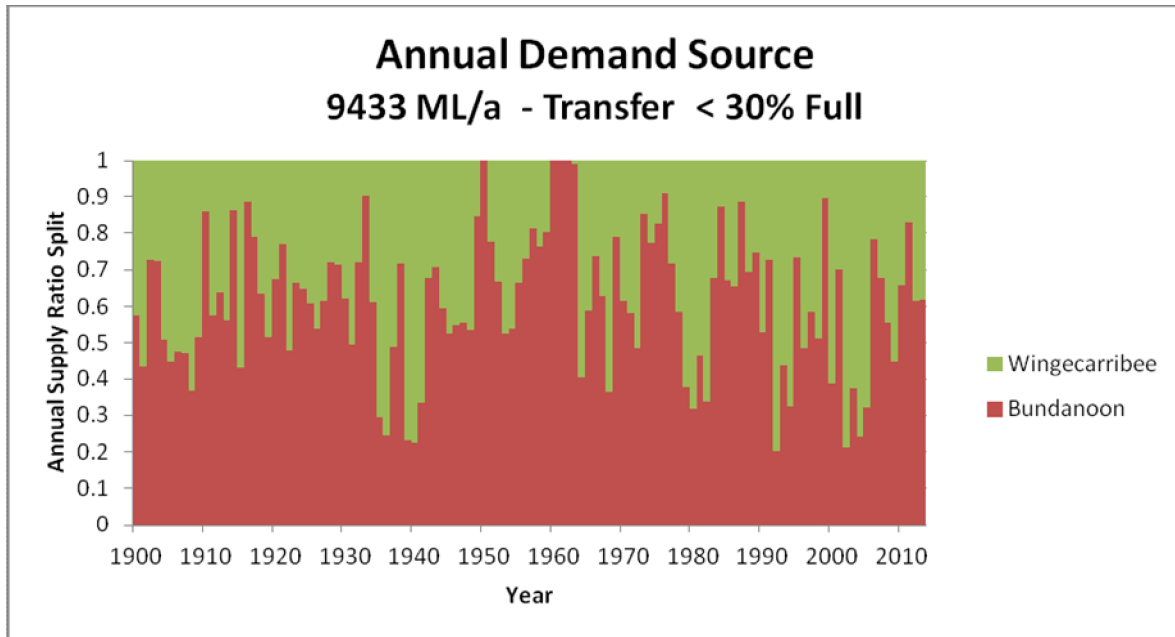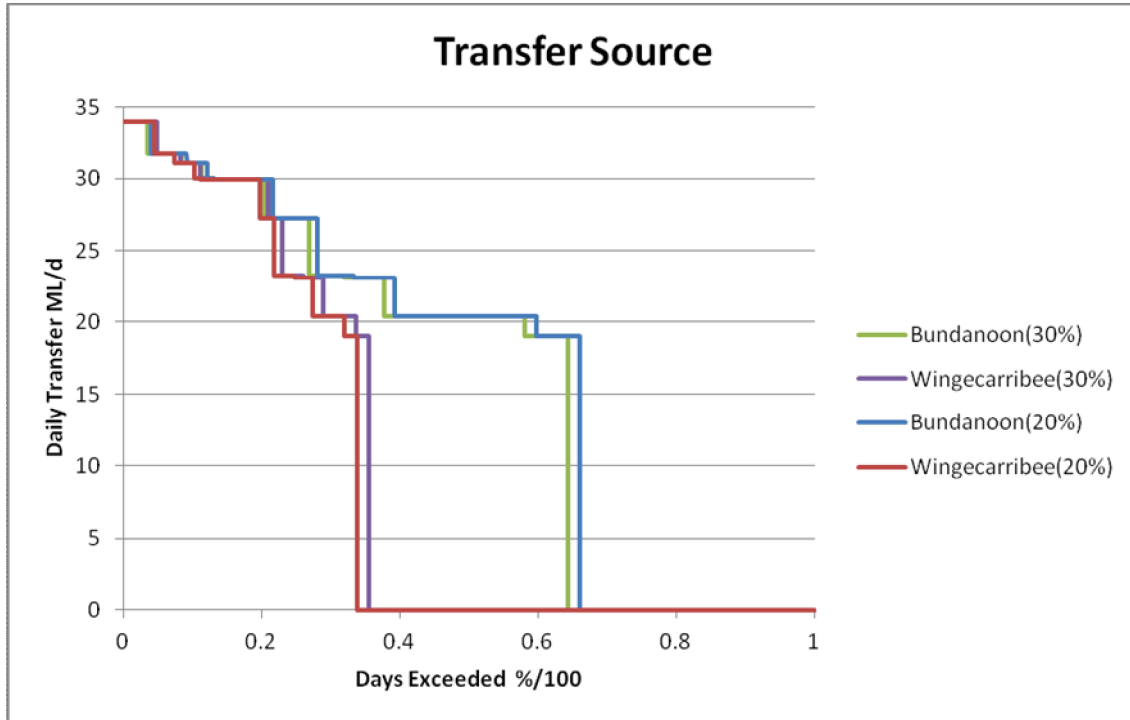**Figure 11: Annual Demand Source (Transfer < 20% Full)**

Figure 12: Annual Demand Source (Transfer < 30% Full)

Trigger levels transfer from Wingecarribee when Bundanoon less than 20 or 30% full

Figure 13: Daily Supply Duration Curves

11   Appendices

Appendix A – Climate Change Paper

Paper from 'Practical Responses to Climate Change' National Conference 2010, Melbourne, Institution of Engineers Australia.

NSW RESPONSE FOR ADDRESSING THE IMPACT OF CLIMATE CHANGE ON THE WATER SUPPLY SECURITY OF COUNTRY TOWNS

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ABSTRACT

Under the NSW Government's *Best-Practice Management of Water Supply and Sewerage Guidelines*, local water utilities in non-metropolitan NSW are required to prepare and implement a comprehensive 30-year integrated water cycle management (IWCM) strategy. The IWCM strategy is prepared for the utility's water supply, sewerage and stormwater businesses, including the water supply headworks, and is effectively a 30-year rolling strategy, which must be reviewed and updated by each utility every 6 years.

For the past 25 years most urban water supply headworks in country NSW have been sized on a robust Security of Supply basis. This security of supply basis has been designed to cost-effectively provide sufficient dam storage capacity to allow the water utility to effectively manage its water supply in future droughts of greater severity than experienced over the past 100 or more years. 'Secure Yield' is the water demand that can be expected to be supplied with only moderate water restrictions during a significantly more severe drought than had been experienced historically. The required water restrictions must not be too severe, not too frequent, nor of excessive duration. Recent analysis for the severe 2001-2007 drought has confirmed the continuing robustness of the NSW Security of Supply basis.

To understand the potential impact of climate change on the security of urban water supplies, results are presented from a pilot study for 11 non-metropolitan NSW water supplies utilising 112 years of downscaled daily hydrometeorological data from 15 global climate models for climate change projections for the year 2030 using the A1B medium warming emissions scenario. This analysis enabled determination of the impact of climate change on the Year 2030 secure yield for each water supply.

Future 30-year IWCM strategies in NSW will need to include assessment of the secure yield of the utility's water supply in accordance with the analysis reported for the pilot study. Implementation of these strategies, together with the required 6-yearly updates, will address future water security.

INTRODUCTION

The NSW Government is tackling the challenge of the impact of climate change on non-metropolitan urban water utilities in a multi-pronged approach through comprehensive best practice management requirements, as noted below.

The key element of the NSW response to climate change is that the utilities will be required to determine their urban water supply security along the lines of the analysis reported in this paper for the pilot study for 11 NSW water supplies. Reporting of such water supply security analysis will need to be documented in each utility's 30-year IWCM strategy.

Background

The NSW Government's *Best-Practice Management of Water Supply and Sewerage Guidelines* (Dept Water and Energy, 2007) is the key driver for reform of planning and management and performance improvement in non-metropolitan NSW. 106 NSW local water utilities provide piped water supply and sewerage services to the 1.8 million people in NSW country towns (97.9% water supply coverage). The 19 requirements of the guidelines include:

- Annual performance monitoring by each utility;
- Current 20 year strategic business plan and financial plan;
- Regulation of water supply, sewerage and trade waste (including pay-for-use water pricing, full cost recovery, commercial sewer usage, trade waste and developer charges, trade waste approvals for all dischargers and a sound trade waste regulation policy by each utility);
- Demand management;
- Drought management ; and

- Integrated Water Cycle Management (IWCM) - comprehensive 30 year strategy required for the utility's water supply, including headworks, sewerage, and where cost-effective, stormwater businesses. A full range of scenarios must be evaluated on a rigorous triple bottom line (TBL) basis, with extensive community involvement. The IWCM Strategy is effectively a 30-year rolling strategy, which must be reviewed and updated by each utility every 6 years.

The non-metropolitan NSW utilities have annual revenue of $950 million and an asset base with a current replacement cost of almost $20 billion (NSW Office of Water, 2010 (1) : vii). Overall, the utilities had met 82% of the requirements of the *Best-Practice Management Guidelines* by June 2009. The Best-Practice Management Guidelines, the IWCM Guidelines, the 7 IWCM Information Sheets and the annual NSW Water Supply and Sewerage Performance Monitoring Reports and Benchmarking Reports are available on the NSW Office of Water website (www.water.nsw.gov.au).

NSW Security of Supply Basis
45 local water utilities have surface water supplies with storage dams in non-metropolitan NSW. Such utility storages have in the main been sized on the NSW Security of Supply basis since the mid–1980s (NSW Public Works, 1986; Samra & French, 1988 and Cloke, 1995).

The purpose of the NSW Security of Supply basis is to determine the cost-effective storage volume and transfer capacities required to enable each water utility to operate its system with only moderate water restrictions in the event of occurrence of droughts of similar severity to those in the historical record, generally back to at least 1895. The utility would also be able to cope with significantly more severe droughts albeit with more severe water restrictions. Effectively, each water supply system would be able to cope with approximately a '1 in 1000 year drought' (Cloke & Samra, 2009 :13).

Under the NSW Security of Supply basis (commonly referred to as the '5/10/20 rule'), water supply headworks systems are normally sized so that:

a) Duration of restrictions does not exceed 5% of the time; and

b) Frequency of restrictions does not exceed 10% of years (ie. 1 year in 10 on average); and

c) Severity of restrictions does not exceed 20%. Systems must be able to meet 80% of the unrestricted water demand (ie. 20% average reduction in consumption due to water restrictions) <u>through a repetition of the worst recorded drought</u>, commencing with the storage drawn down to the level at which restrictions need to be imposed to satisfy a) and b) above.

This enables the utilities to operate their systems without restrictions until the volume of stored water approaches the trigger level determined by a) and b) above (typically about 50% to 60% of the storage capacity). If at this trigger level, the utility imposes drought water restrictions which reduce demand by 20%, the system would be able to cope with a <u>repeat</u> of the worst recorded drought, commencing at that time, without emptying the storage.

'Secure yield' is defined as the highest annual water demand that can be supplied from a water supply headworks system while meeting the above '5/10/20 rule[1]'.

The robustness of the NSW Security of Supply basis has been demonstrated by Cloke & Samra (2009 :7) who showed that for the 10 NSW urban water supplies studied, the very severe 2001 to 2007 drought resulted in a reduction in the secure yield of up to 7% for 7 of the water supplies and a reduction of about 15% for the other 3 supplies.

The first paragraph in footnote 2 below[2], which is a quote from page 3 of the *2008-09 NSW Water Supply and Sewerage Performance Monitoring Report* shows that for the 15 years from 1986, the frequency of drought water restrictions by the non-metropolitan NSW water utilities was consistent with the implied target of no restrictions in 90% of years in b) above.

The *2008-09 NSW Water Supply and Sewerage Benchmarking Report* shows each utility's drought water restrictions over each of the last 6 years (page 56).

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[1] As noted at the top of page 3, this has been superseded by a '5/10/10 rule' since February 2009.

[2] 'For the 15 years from 1986 to 2000/01, on average, the NSW utilities did not apply any drought water restrictions for 87% of the years, which include the severe 1993 to 1994 drought. This is consistent with the implied target of no restrictions in 90% of years in the NSW Security of Supply basis (commonly referred to as the '5/10/10 rule').

For the 23 years from 1986 to 2008/09, on average, the NSW utilities did not apply any drought water restrictions for 75% of the years. However, this period includes both the above 1993 to 1994 drought and the very severe 2001 to 2008/09 drought.'

The *2008-09 Performance Monitoring Report* (page 8) also shows 'there has been a 47% reduction in the volume of average annual residential water supplied per property in non-metropolitan NSW over the last 18 years (from 330 to 175kL per connected property)'. It is therefore considered that it will now be much more difficult to achieve a 20% reduction in consumption than it was 20 years ago as there has been a large reduction in outdoor water use. Accordingly, in February 2009 the NSW Office of Water agreed to basing future planning in non-metropolitan NSW on being able to achieve an average of only a 10% reduction in consumption through a repetition of the worst drought commencing with the storage already drawn down to satisfy the restriction duration and frequency criteria in a) and b) on page 2. Thus the NSW '5/10/20 rule' has been superseded by a '5/10/10 rule'.

Accordingly, a pilot study has been undertaken to examine the impacts climate changed hydrometeorological data has on water security for 11 surface water supplies and to develop a methodology suitable for application for this purpose by the other NSW water utilities.

PILOT STUDY

A Climate Change Steering Group has been formed to oversee a climate change pilot study for 11 urban NSW water supplies and development of NSW guidelines for local water utilities on assessing the impact of climate change on the secure yield of their water supplies. The Steering Group members are:

- Peter McLoughlin (National Water Commission)

- Jai Vaze (NSW Office of Water/CSIRO)

- Peter Cloke (NSW Public Works - commissioned to carry out the pilot study)

- Sascha Moege (Local Government and Shires Associations)

- Wayne Franklin (NSW Water Directorate)

- Sam Samra, Mike Partlin, Peter Ledwos (NSW Office of Water)

As indicated above, the purpose of the pilot study was to provide insights on the impacts of climate changed hydrometeorological data on the water security of the 11 water supplies in the pilot study and to then develop a suitable methodology and guidelines for application by the other NSW water utilities.

The pilot study (Samra & Cloke, 2010 :10) involved undertaking hydrological and system modelling to determine the impact of climate change on secure yield. The pilot study incorporates the scientific logic of the CSIRO's Murray Darling Basin Sustainable Yields Project (Chiew et al, 2008), which used daily historical data from 1895 to 2006 and applied the relevant global climate models (GCMs) to provide projected (~2030) climate changed data for each GCM for this period.

The pilot study uses daily values of rainfall and evapotranspiration from the NSW Office of Water's 2008 data sets[3] (Vaze et al, 2008) for 15 GCMs. These future climate change series for ~2030 were obtained by Vaze et al by scaling the historical 1895-2006 daily rainfall and evapotranspiration data using the methods detailed in Chiew et al ,2008.. These data sets involve extension of the CSIRO data for the Murray Darling basin to cover all of NSW and are based on the Year 2030 A1B warming scenario[4]; a mid range emissions scenario.

The study essentially involved two modelling steps:

- Daily rainfall and evapotranspiration data were inputted into existing calibrated rainfall-runoff models to produce climate changed daily streamflows[5]

- The daily climate changed streamflows, rainfall and evapotranspiration were inputted into water supply system simulation models[6] to determine climate changed secure yields.

The climate changed secure yields were compared with the secure yields for a repeat of the historical data set as noted on page 5.

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[3] This comprehensive data set provides projections of down scaled daily climate changed data for the Year 2030 for all of NSW. It is the best such data set available at present, and was therefore used for the pilot study. As noted on page 10 this data set now covers all of NSW, Victoria and the Murray Darling Basin, including Adelaide. As noted on page 10 improved and longer term projections of climate changed data are expected to be developed in the future and these should be applied by water utilities when they become available.

[4] It is noted that there is little difference in the impacts of the various warming scenarios considered by the IPCC for the Year 2030. Such impacts diverge in longer term projections such as for the Year 2050 or 2070.

[5] Use of a locally calibrated daily rainfall-runoff model for each water supply is essential. The analysis carried out in the pilot study demonstrated that use of generalised streamflow estimates available from the NSW Office of Water data sets is inappropriate for security of water supply analysis. In NSW, such a local daily rainfall-runoff model is routinely developed for any water supply secure yield study.

[6] Similarly, a suitable system simulation model is routinely developed in NSW for any water supply secure yield study.

Table 1 lists the 15 GCMs that were used to produce the data sets

Table 1: The 15 Global Climate Models

| Climate Data Series	GCM	Modelling Group	Country
1	CCCMA T47	Canadian Climate Centre	Canada
2	CCCMA T63	Canadian Climate Centre	Canada
3	CNRM	Meteo-France	France
4	CSIRO-MK3.0	CSIRO	Australia
5	GFDL 2.0	Geophysical Fluid Dynamics Lab	USA
6	GISS-AOM	NASA/Goddard Institute for Space Studies	USA
7	IAP	LASG/Institute of Atmospheric Physics	China
8	INMCM	Institute of Numerical Mathematics	Russia
9	IPSL	Institut Pierre Simon Laplace	France
10	MIROC-M	Centre for Climate Research	Japan
11	MIUB	Meteorological Institute of the University of Bonn,	Germany
		Meteorological Institute of KMA	Korea
12	MPI-ECHAMS	Max Planck Institute for Meteorology, DKRZ	Japan
13	MRI	Meteorological Research Institute	Japan
14	NCAR-CCSM	National Center for Atmospheric Research	USA
15	NCAR-PCMI	National Center for Atmospheric Research	USA

It is noted that to maintain relativity and ensure consistency in the pilot study, modelled streamflow data was used throughout. However in practice in determining 'historical' secure yield, best use is made of the observed data for each utility. Thus the historical estimates in Table 2 differ slightly from the current best estimates of secure yield, which include consideration of the observed data. Thus the Steering Group recommends applying the percentage change in secure yield in column (9) of Table 2 to the utility's current best estimate of secure yield in order to obtain the climate changed secure yield estimate.

Table 2: Comparison of Secure Yield Estimates[#]

Water Utility	Estimated Secure Yield (ML)				% Change in Secure Yield From Historical Data Set			
	Historical Data Set*	Median of 15 Global Climate Models (GCMs)	Lowest GCM	Lowest GCM with 25% severity	Median of 15 GCMs $[(3) - (2)] \times 100$ / (2)	Lowest GCM $[(4) - (2)] \times 100$ / (2)	Lowest GCM with severity of 25% $[(5) - (2)] \times 100$ / (2)	Adopted % Change in Year 2030 Secure Yield due to Climate Change [lesser of (6) & (8)] (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	21,500	20,000[14]	17,500 [9]	19,500	-7%	-19%	-9%	**-9%**
2	3,400	3,500 [1]	3,200 [9]	3,600	+3%	-6%	+6%	**+3%**
3	12,400	12,200 [1]	11,400 [6]	12,600	-2%	-8%	+2%	**-2%**
4	7,700	7,200 [13]	6,700 [3]	7,200	-6%	-13%	-6%	**-6%**
5	5,200	4,900 [4]	4,500 [9]	4,800	-4%	-13%	-8%	**-8%**
6	495	450 [12]	400 [3]	435	-9%	-19%	-12%	**-12%**
7	4,850	4,150 [4]	3,250 [3]	3,600	-14%	-33%	-26%	**-26%**
8	3,600	3,600 [8]	2,900 [3]	3,400	0%	-19%	-6%	**-6%**
9	480	360 [8]	220 [4]	240	-25%	-54%	-50%	**-50%**
9+	1500	1260 [7]	880 [4]	1060	-16%	-41%	-29%	**-29%**
10	185	175 [4]	115 [9]	135	-5%	-38%	-27%	**-27%**
11	16,900	15,300 [4]	14,300 [13]	15,700	-9%	-15%	-7%	**-9%**

On the basis of '5/10/10 rule' in ML/a, except for columns (5) and (8), which involve a severity of 25% (ie. a '5/10/25 rule').
* 111 years of data (1896 to 2006) from the "Future climate and runoff projections (in 2030) for NSW and ACT" Database.
+ Enlarged storage for proposed augmentation.
In columns (3) and (4), the relevant GCM is shown within square brackets, eg. for Utility 10 the secure yield shown in column (3) is based on GCM 4.

Figure 1 shows the general location of the 11 NSW water supply systems examined which covered a range of attributes: large, small, on-stream storage, off-stream storage, coastal, inland and multi-sources.`
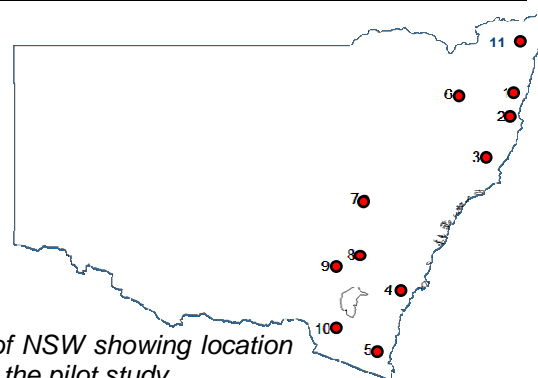
Figure 1: Map of NSW showing location of the utilities in the pilot study

RESULTS OF THE PILOT STUDY
Climate Change

The projected impacts of climate change in ~2030 on the average annual rainfall, streamflow and evapotranspiration for each utility's water supply, in comparison with the historical data sets are shown in Figures 2, 3 and 4 respectively. Note that there is a tendency towards drying in NSW.

Following determination of the average annual rainfall for each of the 15 GCMs for each utility, the GCM with the highest average annual rainfall is shown as 'Highest' in Figure 2, expressed as a percentage change in comparison with the historical average annual rainfall. Similarly, the GCM with the lowest average annual rainfall for a utility is shown as 'Lowest' and the GCM with the median average annual rainfall from the 15 GCMs is shown as 'Median' in Figure 2.
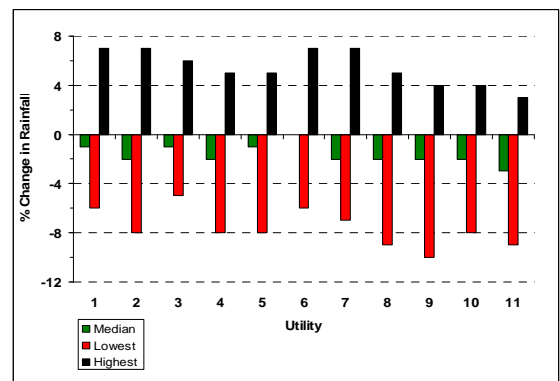
Figure 2: % Change in the Average Annual Rainfall for the Global Climate Models (GCMs) shown compared with the result for the Historical Data Set
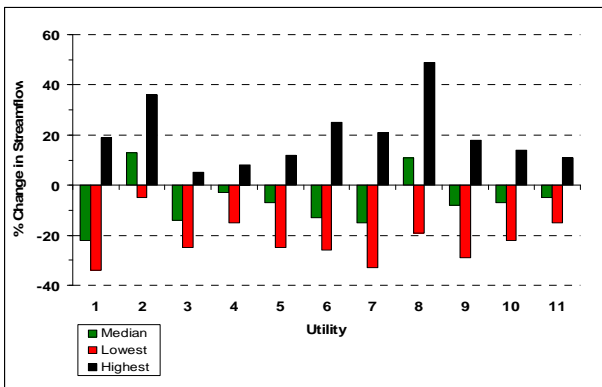

Figure 3: % Change in the Average Annual Streamflow for the Global Climate Models (GCMs) shown compared with the result for the Historical Data Set
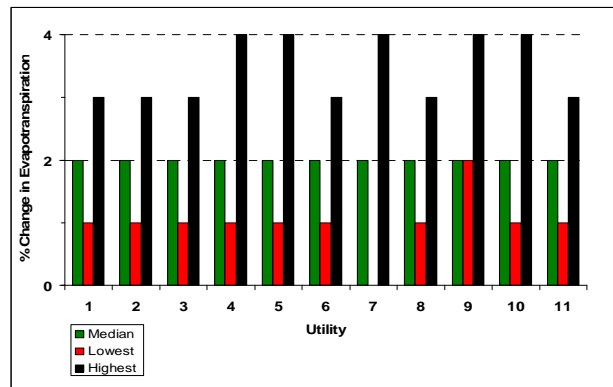

Figure 4: % Change in the Average Annual Evapotranspiration for the Global Climate Models (GCMs) shown compared with the result for the Historical Data Set

Figure 2 shows that the changes in the average annual rainfall for the GCM with the median change range from no change (Utility 6) to a reduction of 3% (Utility 11) (median is a 2% reduction). For the GCM with the lowest change, the range is reductions of 5% (Utility 3) to 10% (Utility 9) (median is an 8% reduction). For the GCM with the highest change, the range is increases of 3% (Utility 11) to 7% (Utilities 1, 2, 6 and 7) (median is a 5% increase).

Figure 3 shows that the changes in the average annual streamflow for the GCM with the median change range from an increase of 13% to a reduction of 22% (median is a 7% reduction). For the GCM with the lowest change, the range is reductions of 5% to 34% (median is a 25% reduction). For the GCM with the highest change, the range is increases of 5% to 49% (median is an 18% increase).

Figure 4 shows that for the GCM with the median change, the change in the average annual evapotranspiration is a 2% increase in each case. For the GCM with the lowest change, the range is increases of nil to 2% (median is a 1% increase). For the GCM with the highest change, the range is increases of 3% to 4% (median is a 3% increase).

Secure Yield

The results of the pilot study with respect to secure yield are shown in Table 2. Columns (2), (3) and (4) show the secure yield for each of the 11 utilities in the pilot study for the historical data, the median of 15 GCMs and the lowest GCM on the basis of the '5/10/10 rule'.

Columns (6) and (7) show the changes in secure yield for the median of 15 GCMs and the lowest GCM in percentage terms. For the median GCM (column (6)) the change in secure yield varies from an increase of 3% (Utility 2) to a reduction of 25% (Utility 9). For the lowest GCM (column (7)) the change in secure yield varies from a 6% reduction (Utility 2) to a reduction of 54% (Utility 9).

As discussed in Samra & Cloke (2010 :5) the Steering Group considers that a balanced approach to determining the secure yield after climate change would be to adopt the lesser of:

a) secure yield for the median of 15 GCMs on the basis of the '5/10/10 rule'

b) secure yield for the GCM with the lowest secure yield on the basis of a '5/10/25 rule'; the 25% severity of restrictions under this rule amounts to being able to 'survive' occurrence of the lowest GCM, albeit with relatively harsh water restrictions to cope with the reduced availability of water.

Thus a utility's core planning under a) above would be on the basis of the '5/10/10 rule'. However, under b) above, the utility would also need to ensure its system would be able to survive the lowest GCM under the severe restrictions involved in a '5/10/25 rule'.

Column (5) of Table 2 shows the secure yield of the lowest GCM on the basis of 25% severity of restrictions (ie. a '5/10/25 rule'). For comparison purposes, the percentage change in secure yield is shown in column (8).

The above approach is considered to provide a reasonable balance between avoiding excessive capital expenditure by the utilities and avoiding very harsh future drought water restrictions. The 25% severity for the GCM with the lowest secure yield is considered to be acceptable in view of the low probability of occurrence of such a GCM and is informed by the outcomes of at least 35% reduction in consumption achieved by several NSW utilities in the current drought, including Goulburn, Orange and the Central Coast (Samra & Cloke, 2010: 5).
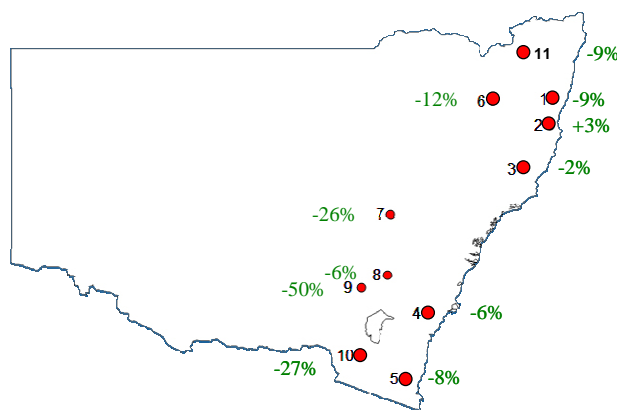

Figure 5: Map of NSW showing adopted % change in Year 2030 Secure Yield due to climate change for each utility in the pilot study

Note:
For Utility 9, the changes in secure yield for the existing small storage dam and for the proposed enlargement of the dam were -50% and -29% respectively.

The adopted change in the Year 2030 secure yield due to climate change for each utility is shown in column (9) of Table 2 and Figure 5. This is identical with the values shown in column (6), for 4 utilities (2, 3, 4 *and 11). The adopted changes for the other 7 utilities are on the basis of 25% severity of restrictions for the* lowest GCM, and are up to 25 percentage points lower than for the median GCM.

The 3 utilities with a reduction in the adopted secure yield of over 25% are inland utilities in mid and southern NSW. This finding is consistent with the Victorian expectation of increasing drought severities.

Storage behaviour diagrams for each utility are shown in Figures A1 to A12 in Appendix A on page 11. These show the storage behaviour (expressed as % of full storage capacity) while delivering an annual demand[7] equivalent to the secure yield determined for the historical data for a repeat of:

• the historical climate conditions and

• for a repeat of the climate changed conditions that produced the

   o highest,
   o median and
   o lowest climate changed secure yield for each utility.

Using the climate changed inflows, Figures A1 to A12 show that except for Utility 10 (Figure A11), the storages did not empty while supplying a demand equivalent to the historic secure yield for each utility. This includes the results in Figures A9 and A10 for Utility 9 which had the largest reduction in secure yield. It is important to note that the existing small storage capacity for Utility 9 results in a 50% reduction in secure yield (column 9 of Table 2). However after the proposed augmentation of the storage dam, there would be only a 29% reduction in the secure yield, which demonstrates that the impact of climate change is system dependent.

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[7] Unrestricted demand was supplied until the storage volume fell to the restriction volume for each utility (typically about 50% to 60% of full capacity). Thereafter 90% of the demand was supplied until there was a significant recovery in the storage volume, when the unrestricted demand was resumed. As it was necessary to use the first year of each dataset to initialise the daily rainfall-runoff models, each simulation was generally carried out with the remaining 111 years of daily hydroclimate data.
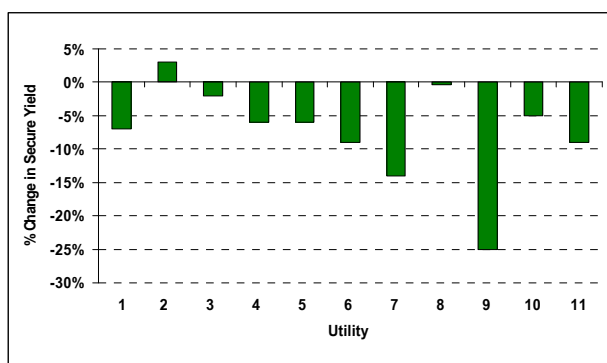
Figure 6: Median % Change in the Secure Yield from the 15 Global Climate Models compared with the result for the Historical Data Set
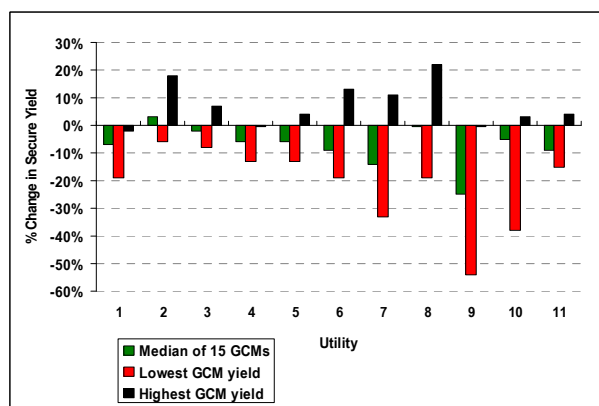

Figure 7: % Change in the Secure Yield for the Global Climate Models (GCMs) shown compared with the result for the Historical Data Set

Figure 6 provides a graphical representation of the percentage change in secure yield for the GCM with the median secure yield, in comparison with the historical data set. These results are as shown in column (6) of Table 2 and range from an increase of 3% to a reduction of 25%.

Figure 7 also provides a graphical representation of this percentage change for the GCM with the lowest secure yield (from column (7) of Table 2) and that for the GCM with the highest secure yield, in comparison with the historical data set. As also noted above, the results for the GCM with the lowest secure yield range from a reduction of 6% to a reduction of 54% (column (7) of Table 2). The results for the GCM with the highest secure yield range from an increase of 22% to a reduction of 2%.

The GCMs which provided the median, lowest and highest changes in the average annual rainfall, streamflow and evapotranspiration[8] (refer to Figures 2 to 4) are not necessarily those which resulted in the median, lowest and highest changes in secure yield (refer to Figure 7).

A report on the pilot study will be published on the NSW Office of Water website in 2010 in order to disseminate the results and findings of the study.

Tables 3 and 4 show the key characteristics of the 4 simulations shown for each utility in Figures A1 to A12 on page 12, Table 3 provides a comparison of the resulting minimum storage volume for each simulation and indicates that the minimum storage volume for the historical data set ranges from 31% to 49% of the full storage capacity (column (3)). For the median of GCMs, the minimum storage volume ranges from 23% to 49%, with 3 utilities having a minimum storage volume of 23% to 25% of capacity (column (4)). However, for the lowest GCM, 4 utilities have a minimum storage of under 15% of capacity (Utilities 7, 9, 10 and 11), with the storage volume for the small Utility 10 emptying for a period of 6 months (column (5)). For the highest GCM, the minimum storage volume ranges from 32% to 51% of capacity (column (6)).

Table 3: Comparison of Minimum Storage Volumes

Water Utility	Storage Capacity (ML)	Minimum Storage Volume (%) while supplying the Historical Secure Yield			
		Historical Data Set	Median of 15 Global Climate Models (GCMs)	Lowest GCM	Highest GCM
(1)	(2)	(3)	(4)	(5)	(6)
1	35,600	39	30	20	40
2	5,500	31	33	27	41
3	4,500	43	49	31	51
4	4,900	46	44	42	46
5	3,780	49	34	24	37
6	460	34	31	22	42
7	22,500	37	23	10	43
8	15,500	38	38	23	46
9	850	37	25	9	37
9+	2,470	37	30	14	42
10	100	31	29	0 for 6 months	32
11	14,800	33	23	14	39

+ Enlarged storage

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[8] Eg. for Utility 1, the median rainfall, streamflow, evapotranspiration and secure yield resulted from GCMs 5, 5 , 9 and 14 respectively.

Table 4: Comparison of Storage Drawdowns

Water Utility (1)	% of the time storage is drawn down below volumes shown while supplying the Historical Secure Yield											
	Historical Data Set (2)			Median of 15 Global Climate Models (GCMs) (3)			Lowest GCM (4)			Highest GCM (5)		
	60%	40%	20%	60%	40%	20%	60%	40%	20%	60%	40%	20%
1	1.4	0.1	0.0	1.5	0.5	0.0	3.1	0.7	0.1	1.2	0.0	0.0
2	3.7	0.8	0.0	2.8	0.7	0.0	5.0	0.8	0.0	1.1	0.0	0.0
3	0.7	0.0	0.0	0.8	0.0	0.0	1.3	0.1	0.0	0.5	0.0	0.0
4	1.5	0.0	0.0	2.1	0.0	0.0	2.9	0.0	0.0	1.6	0.0	0.0
5	0.2	0.0	0.0	1.1	0.2	0.0	2.1	0.3	0.0	0.7	0.0	0.0
6	1.4	0.2	0.0	1.1	0.2	0.0	2.3	0.4	0.0	0.7	0.0	0.0
7	5.0	0.4	0.0	9.5	1.4	0.0	18	5.2	0.8	2.5	0.0	0.0
8	7.0	0.2	0.0	6.1	0.3	0.0	16	2.9	0.0	1.0	0.0	0.0
9	1.4	0.2	0.0	1.7	0.6	0.0	2.5	0.8	0.2	0.8	0.1	0.0
9+	1.4	0.2	0.0	1.5	0.4	0.0	2.4	0.5	0.1	1.0	0.0	0.0
10	2.0	0.5	0.0	2.7	0.8	0.0	4.3	1.4	0.7	1.5	0.4	0.0
11	1.5	0.3	0.0	3.4	0.7	0.0	4.9	1.3	0.4	1.6	0.1	0.0

+ Enlarged storage

In summary, Table 3 shows that for the median GCM, the minimum resulting storage volume for most of the utilities is a little lower than that for the historical data, indicating slightly more severe droughts than had been experienced historically. For the lowest GCM, all the minimum storage volumes are much lower than the historical data set. This indicates the occurrence of much more severe droughts, with 5 of the utilities experiencing a minimum storage volume of under 15% of full capacity, in comparison with the historical data set, where the minimum storage volume was 31% of full capacity.

For the 4 simulations for each utility discussed in Table 3 above, Table 4 provides a comparison of the percentage of time each storage is drawn down below 60%, 40% and 20% of full capacity. These draw downs indicate the relative vulnerability of each water supply to supply failure due to emptying of the storage. For the historical data set (column (2)) of Table 4 shows that the percentage of time the storage volume falls below 60% of full capacity exceeds 5% only for Utility 8, where restrictions are implemented at a storage capacity of 55% under the '5/10/10 rule'. Column (3) of Table 4 shows that for the median of GCMs, 2 utilities (Utilities 7 & 8) have storage volumes under 60% of capacity for more than 5% of the time. Only these 2 utilities have such storage volumes for more than 5% of the time for the lowest GCM, but the duration now extends to 16% to 18% of the time for this GCM (column (4)). For the highest GCM, the duration of such storage volumes does not exceed 2.5% of the time for any utility (column (5)).

Table 4 also shows that for the historical data set (column (2)), the percentage of time the storage volume falls below 40% of full capacity, which could be expected in a severe drought, does not exceed 0.8% for all the utilities. Column (3) of Table 4 shows that for the median of GCMs, only Utility 7 has such storage volumes exceeding 0.8% of the time. However, for the lowest GCM only 7 utilities have such storage volumes not exceeding 0.8% of the time, with the other 4 utilities (Utilities 7, 8, 10 and 11)) experiencing durations of 1.3% to 5.2% of the time (column (4)). For the highest GCM, the duration of such storage volumes does not exceed 0.4% of the time (column (5)).

In addition, Table 4 shows that for the historical data set (column (2)), the median of GCMs (column (3)) and the highest GCM (column (5)), the storage volume never falls below 20% of full capacity, which could be expected to occur only in an extreme drought. However, for the lowest GCM, 5 utilities (Utilities 1, 7, 9, 10 and 11) have a storage volume below 20% of capacity for at least 0.1% of the time (column (4)).

As previously noted, the *Best-Practice Management Guidelines* require each NSW water utility to prepare a comprehensive 30-year IWCM Strategy. The IWCM strategies will need to include assessment of the secure yield of the utility's water supply on the basis of new NSW guidelines proposed for release in late 2010. The utilities will be able to soundly plan for the security of their water supply for climate change by developing and implementing their 30-year IWCM strategy on the basis of the climate changed secure yield determined along the lines of the pilot study for 11 NSW water supplies.

As noted on page 3, the pilot study has focused on climate change projections for the Year 2030 based on predictions for the A1B mid range warming emissions scenario. This is not only due to the availability of the daily database but because there is only a small difference in the climate change projections between different emissions scenarios for the year 2030. These differences will be magnified for longer-term projections, such as year for the year 2050 or 2070.

DISCUSSION
The 1895-1902 Federation Drought
The severe 2001-2007 drought has been claimed as the worst drought since records began in Australia and has resulted in questioning of the reliability of several major water supplies in Australia. Fortunately NSW country town water supplies that had been planned on the basis of the NSW security of supply basis (ie. 5/10/20 rule) have been able to maintain the expected supply. It is hypothesised that this is because the 5/10/20 rule incorporates the very severe Federation drought of 1895-1902 and allows for maintaining a 20% restricted supply through in effect a '1 in 1000 year' drought (Cloke & Samra, 2009 :13).

It is understood consideration of Perth's and Melbourne's water supply reliability was until recently based on flow records post the Federation drought, as shown in their plots of inflows (*from 1911 for Perth and from 1913 for Melbourne*) (Gill, 2008 and Rhodes et al, 2010). The plot of inflows to Perth's water supply headworks has been repeatedly shown as an example of a shifting climate.
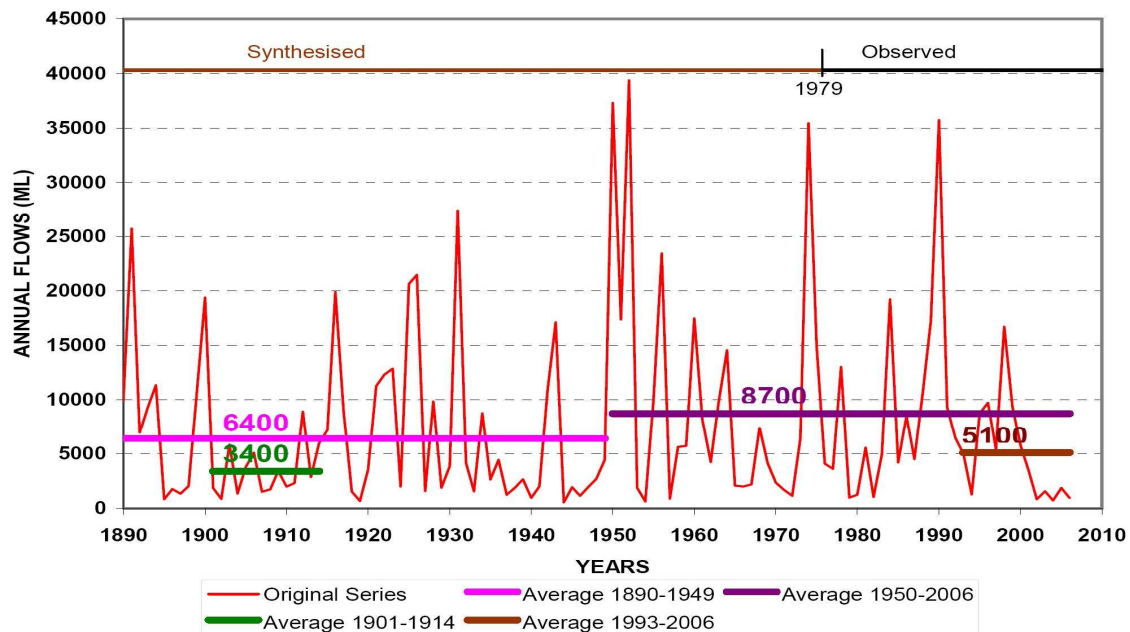
Figure 8: Annual Historic Flows Periodic Comparison

An equivalent plot of inflows for a Tablelands water utility in central NSW [catchment area 100 km^2] is shown in Figure 8. With the inclusion of the Federation drought it suggests that the 2001-2007 drought was more likely to be due to climate variability rather than climate change and in terms of water supply headworks was not the worst drought on record.

If the Federation drought and pre 1915 droughts had not been incorporated in the water supply planning, secure yields for many NSW water supplies would have been determined to have been much higher and may have then been impacted by the 2001-2007 drought. **For example for Utility 7, post the Federation drought, the secure yield would have been determined as some 25% higher and post 1915, some 50% higher than the historical secure yield.** This highlights the importance of including the Federation Drought in any security of supply simulation studies to avoid such over-estimation of secure yield.

Accordingly, it is considered that the robustness of the NSW security of supply basis, combined with analysis for climate change as developed in the pilot study, will continue to provide reliable and cost-effective water supply security for NSW country towns.

Reducing uncertainty in climate models
The overall summary of the **Ozwater '10 Workshop on Climate Change Impacts on the Water Sector** (Claydon, et al., 2010: 3) includes:

> 'Reducing uncertainty in climate models is an active area of research – in particular coupled ocean-atmosphere general circulation models (GCMs). There have already been (published) steps made to provide this more refined (downscaled) output in Bureau of Meteorology and CSIRO climate projections, especially for drought. However, the core aspects of how best to apply these various models using sophisticated integrated modelling procedures remains an ongoing interesting research and operational issue.'

It is acknowledged that reducing uncertainty in climate models and how best to apply them is an area of ongoing research.

However, water supply planning and decision making requires assessment of the impact of climate change on water supply security. At present, the best available downscaled daily hydrometeorological data in Australia is for 15 GCMs along the lines developed by the Murray Darling Basin Sustainable Yields Project. Such data is now available for all of NSW and Victoria, as well as for all of the Murray Darling Basin, including Adelaide. It is therefore considered that the analysis carried out in this pilot study could be used to assess the Year 2030 climate change impacts for urban water utilities in the areas with such downscaled data which have surface water supplies with storage dams.

In addition, there are some major research activities such as the research in SEACI[9] Theme 2 which focus on improving hydroclimate change projections for south-eastern Australia. They are specifically investigating

(i) GCM assessment and selection for hydrological application and

(ii) assessing the relative merits of different downscaling methods and relative uncertainties in various components in estimating climate change impact on runoff (GCM projections, downscaling methods and hydrological modelling) (Vaze J., 2010).

The above research includes consideration of dynamic downscaling, which has the potential to improve the projections of drought persistence for severe droughts.

Accordingly, as such better hydroclimate change data becomes available in the future, it should be applied in future planning. In this regard, where a utility has sufficient supply capacity to enable it to defer a major capital investment decision for additional surface water supplies for 5 or more years, it should do so, as the better hydroclimate change data likely to be available by that time would enable the utility to make a more robust investment decision.

CONCLUSIONS

1   A sound basis has been developed for non-metropolitan urban water utilities to assess the impact of climate change for the Year 2030 on the secure yield of their urban water supply. This is an adaptive management approach which enables utilities to carry out sound climate change planning and decision making immediately, using the existing 112 years of downscaled daily hydrometeorological data sets for 15 GCMs. As better hydroclimate change projections become available in the future, these will need to be applied in future planning by the utilities.

2   The results for the 11 utilities in the pilot study are shown in Figure 5 on page 6. These indicate that the main impacts on Year 2030 secure yield are:

- no greater than a reduction of 9% for the 7 coastal and tablelands utilities

- reductions of almost 30% for the 3 inland utilities in mid and southern NSW, after allowing for the proposed augmentation of the existing small storage capacity for Utility 9.

3   Future utility 30-year IWCM strategies in NSW will need to include assessment of the secure yield of the utility's water supply in accordance with the analysis reported for the pilot study. Implementation of these strategies, together with the required 6-yearly updates, will address the future water security of these utilities.

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Chee Chen and Dr Liz Chen of NSW Public Works Hydrology Group who carried out the detailed modelling required to produce the results provided in the pilot study.

The many NSW Councils which have engaged NSW Public Works over the years to carry out yield studies, thus enabling use of the study models for the analysis reported in the pilot study.

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[9] SEACI – South-East Australian Climate Initiative

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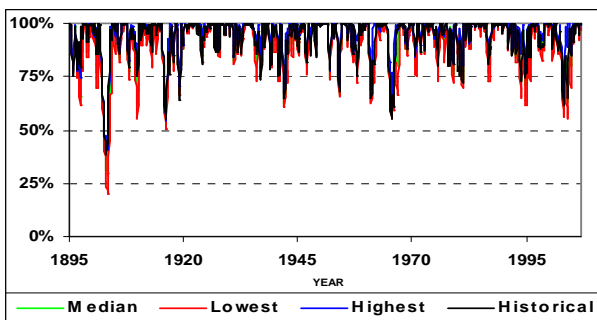
APPENDIX A

Figure A1: Storage Behaviour Diagram for repeat of years 1895 to 2006 for different climate conditions for Utility 1
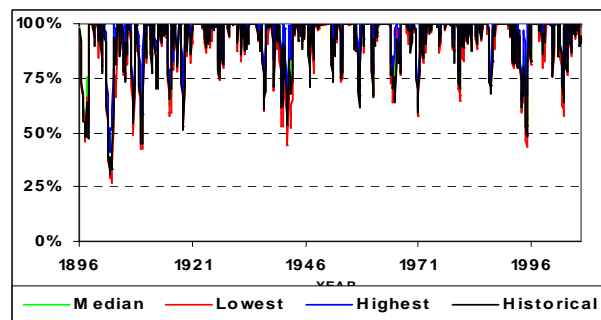

Figure A2: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 2
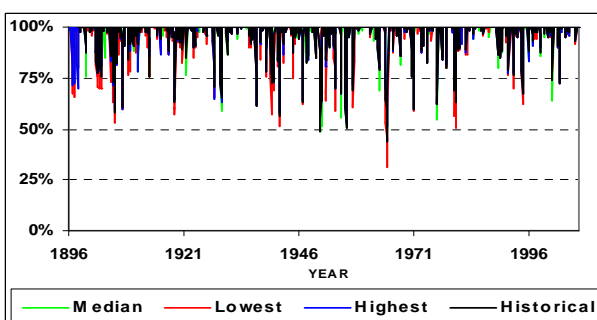

Figure A3: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 3
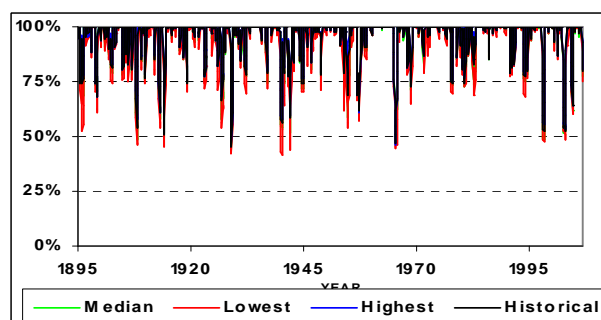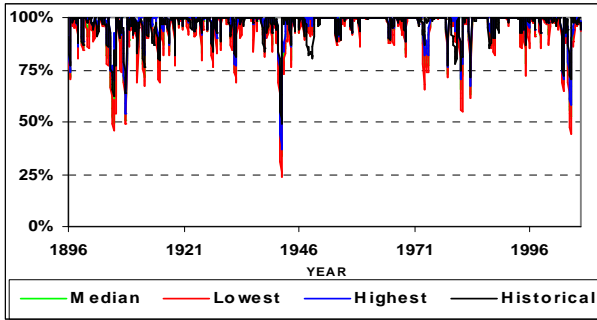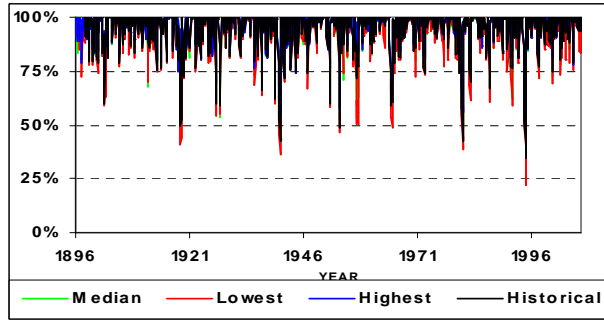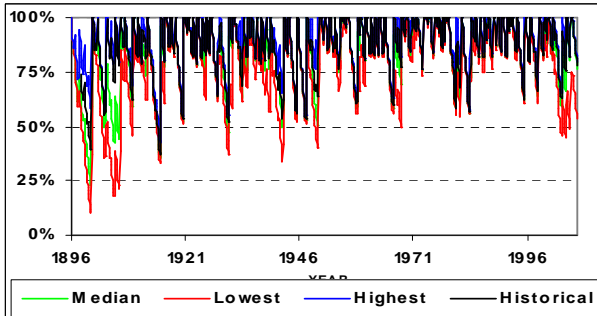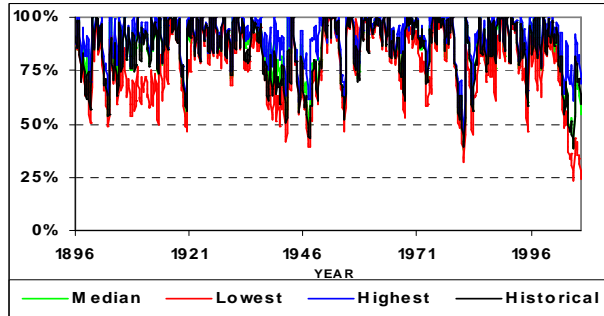

Figure A4: Storage Behaviour Diagram for repeat of years 1895 to 2006 for different climate conditions for Utility 4

Figure A5: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 5
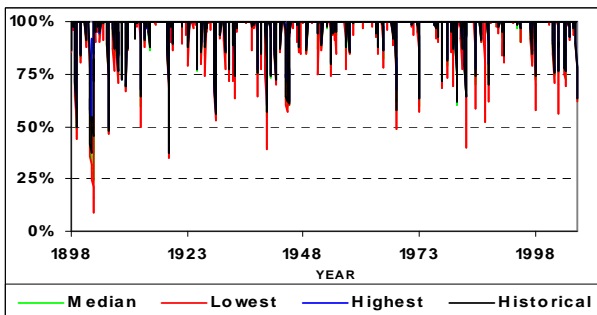

Figure A6: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 6

Figure A7: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 7

Figure A8: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 8

Figure A9: Storage Behaviour Diagram for repeat of years 1898 to 2006 for different climate conditions for Utility 9 – Existing Storage
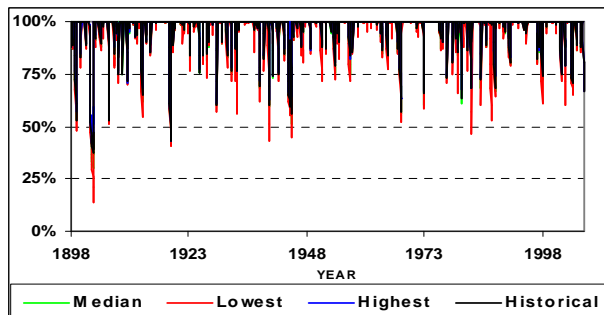

Figure A10: Storage Behaviour Diagram for repeat of years 1898 to 2006 for different climate conditions for Utility 9 – Enlarged Storage
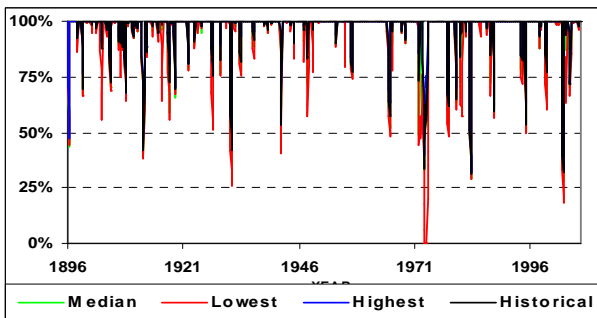

Figure A11: Storage Behaviour Diagram for repeat of years 1896 to 2006 for different climate conditions for Utility 10
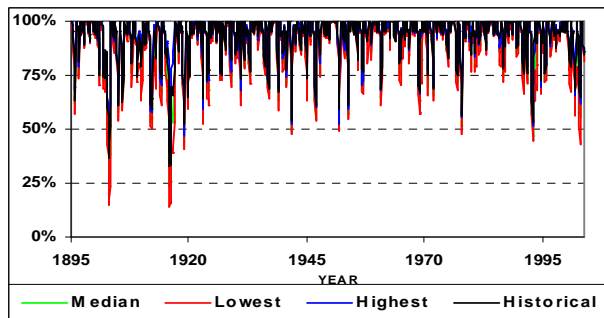

Figure A12: Storage Behaviour Diagram for repeat of years 1895 to 2003 for different climate conditions for Utility 11