APPENDIX C

WATER SECURITY MODELLING

KEY TERMS

TERM	DEFINITION
Aquifer	An underground layer of soil, rock or gravel able to hold and transmit water. Bores, spear-points, springs and wells are used to obtain water from aquifers.
Catchment	The area of land drained by a river and its tributaries.
Hydrology	The study of the distribution and movement of water.
Recharge	Water that infiltrates through the soil surface to the watertable.
WATHNET	Bulk water supply model used to estimate bulk supply levels and security, based on changes in climate and water consumption.

C.1 HYDROLOGY

The hydrologic assessment of water security in the CENTROC region was undertaken by Pavel Kozarovski and Associates with contributions from Bonacci Water and Chris Jewel and associates.

C.2 INTRODUCTION

Hydrological practice in Australia is characterised by a wide range of methodologies from the simple to those employing the latest innovations. The need for simulation of water resource systems is brought about by the natural variance in systems. Australia is subject to high levels of climate and hydrological variability in comparison to Europe and North America. The accuracy and usefulness of mathematical simulation of these demand, supply and storage systems is determined by how well they simulate the variance in systems.

The key to good hydrological assessment is understanding and simulating that variance. Traditionally, hydrological assessments for urban water systems have been undertaken using a single historical rainfall and evaporation time series to generate streamflows and determine storage evaporation and a fixed seasonal pattern for demands. The stochastic modelling approach used in the current study offered a number of improvements to that approach:

1. The inclusion of climate driven town water demands;
2. The use of stochastically generated streamflow and demand sequences. Using stochastic simulation, hundreds and thousands of different potential climate sequences (called replicates) can be generated.

One of the benefits of the multiple replicate modelling approach is the ability to model gradually changing climate regimes over time, rather than the need to simulate climate scenarios at discrete points in the future. These improvements in current hydrological modelling practices are essential for the assessment of the water supply security benefits of options. In addition, network systems analysis using continuous simulation and climate replicates can also provide robust information about the probability of a range of system responses (such as water shortages).

The goals of the hydrological assessment for the study were:

- To provide a water security context for the examination of options;
- To understand the impact on urban water security of options;
- Conservation, transfer links, restrictions policies;
- To understand the benefits to other users (irrigation, mining, environment);
- Maximise the knowledge held in IQQM models within scope and time frame available.

Importantly, it is not the intention of the modelling undertaken for the study to replace or replicate the IQQM modelling underlying Water Sharing Plans.

C.3 OUTLINE OF METHODOLOGY

Integrated Water Resource Planning (IWRP) efforts of the type being undertaken for this study generally have a data analysis component and a forecasting/modelling component. An integrated compendium of models was used to undertake:

- The analysis of historical water demands;
- The preparation of forecasts;
- The simulation of climate influences on demand; and

- The simulation of water supply system operation.

An overview of the models used and their interactions is shown in Figure C-1. A brief description of each model is provided in the text to follow.

Figure C - 1: CENTROC Water Security Modelling Framework

C.3.1 THE BULK WATER TREND TRACKING MODEL (WATERTRAC)

The Bulk Water Trend Tracking Model (WaterTrac) is used to provide a detailed understanding of the drivers of daily water demand and wastewater flows. It uses daily records of bulk water production and wastewater flow and generates a correlation with climate influence and other demand drivers. Model outputs include:

- Regression calibration statistics;
- The long-term Hindcast of calibrated model demands and flows through the full climate record;
- Climate corrected demands/flows (including upper and lower 95% confidence intervals); and
- Historical peak to climate corrected average demands.

WaterTrac uses a unique non-linear multi-variable regression analysis approach to explain the day to day climate influences on water demands. Once this climate influence has been established the influence of other drivers (such as water pricing changes and water restrictions) can be estimated. The WaterTrac model was used to establish the climate-normalised starting point for demand projections. More information on the demand forecasting component of the study can be found in Appendix B.

C.3.2 THE DEMAND SIDE MANAGEMENT DECISION SUPPORT SYSTEM (DSM DSS)

The DSM DSS has a set architecture for generating demand forecasts and assessing the impact of demand management and source substitution initiatives.

The model starts with the generation of a baseline or "business as usual" forecast, which is the reference case for the demands to follow. The baseline forecast represents the demand that would occur in the event that there was no demand management or source substitution intervention.

The DSM DSS has a number of modules that are used to assess the impact of different types of demand management and source substitution measures. These include:

- The water pricing module which provides a framework for the assessment of changes in water prices;
- The fixture and appliance market intervention model where the impact of retrofit and rebate programs relative to the natural market trends can be estimated;
- The general conservation/source substitution module which estimates the impact of measures that include recycled and rainwater use;
- The Water Loss and Infiltration/Inflow Reduction modules where the impact on reducing system water losses and wet weather wastewater system inflows can be estimated.

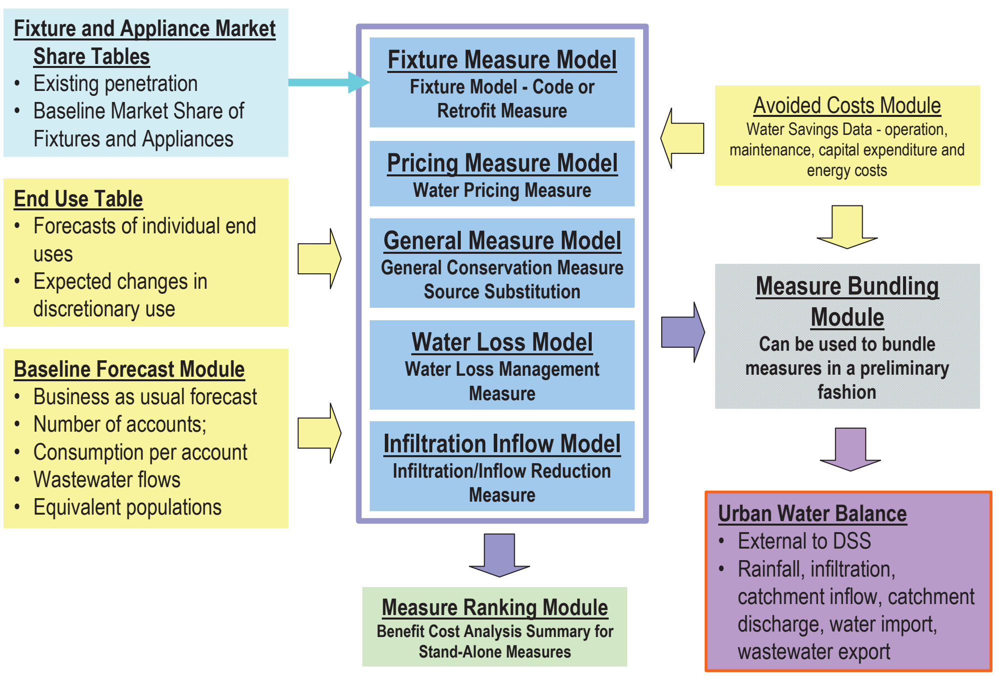


Figure C - 2: Evaluation of Demand Management Options Using the DSM DSS Model

C.3.3 THE PROBABILISTIC URBAN RAINWATER AND WASTEWATER RE-USE SIMULATOR (PURRS)

PURRS is a unique model for simulating the impacts of rainwater tanks, water efficient appliances, stormwater harvesting and wastewater recycling on water demands (Coombes, 2006). The PURRS suite of models includes climate and socioeconomic dependent water demand algorithms and the capability to analyse a wide range of climate change scenarios. In its simulations, rather than utilise the performance of a single connection extrapolated to approximate large numbers of connections, it is designed to simulate the collective performance of large numbers of different customer types servicing a large number of different demand regimes. It is a truly probabilistic simulation undertaken at a 6 minute time step and is an ideal engine for generating climate-driven demand regimes for use in hydrological simulations, even if there is no consideration of rainwater tanks and recycling.

C.3.4 WATHNET - WATER SUPPLY HEADWORKS SIMULATION

WATHNET is a suite of Windows programs for simulating water supply headworks systems which allows analysis of a wide range of water resource options at multiple scales. It uses network linear programming to intelligently allocate water from multiple sources to competing demands making allowance for capacity and operational constraints. Data entry and output are based on a graphical schematic of the headworks system. Full support is provided for Monte Carlo analysis including generation of multi-site hydroclimatic data and probabilistic assessment of future performance.

A schematic of the WATHNET model for used in the study is shown in Figure C - 3.

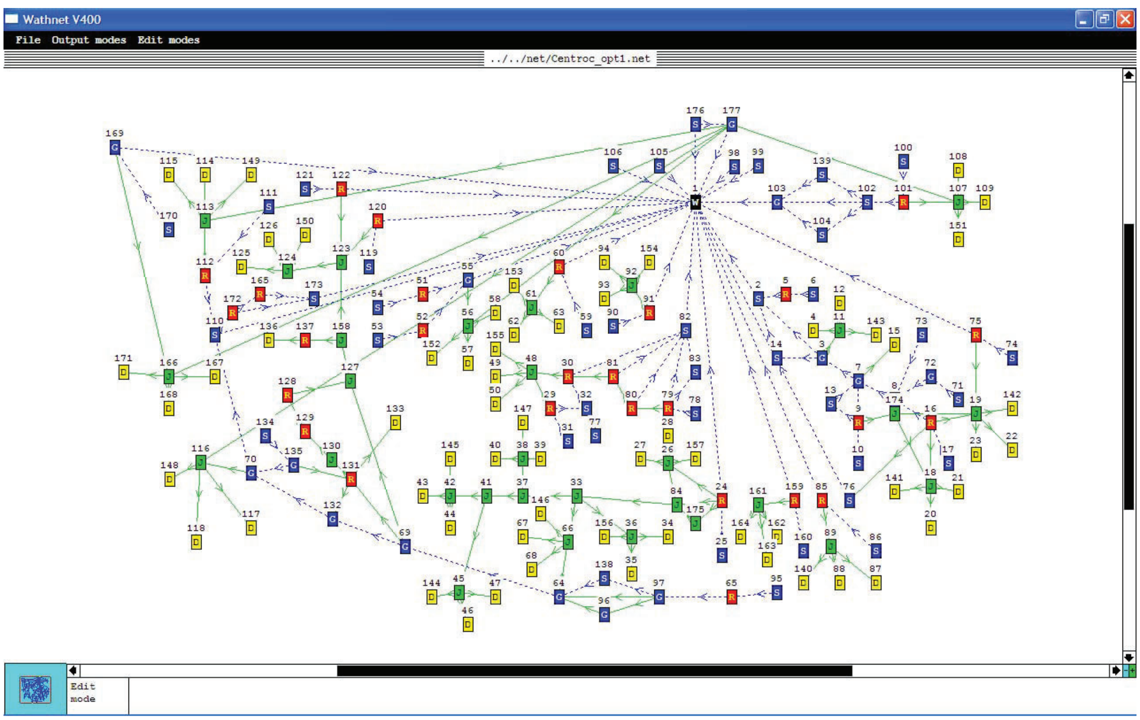


Figure C - 3: WATHNET Model Schematic

C.4 THE SIMULATION OF SURFACE WATER SUPPLIES

The hydrologic modelling undertaken for the CENTROC security study necessarily requires the simulation of the operation of a number of surface water supply storages. A summary of the simulation data used for each storage is shown in Table C - 1. Most storages utilised rainfall-genereated runoff data in the simulations with the exception of the major storages of Wyangala and Lake Burrendong. The inflows to these storages was generated using inflows from IQQM model data sets using multi-site Markov Chain Model, where:

- annual totals – mean, std dev., serial correlation and cross-correlation consistent with original data set; and

- Daily totals generated by the method of fragments.

An example of simulated inflows to Wyangala Dam from a single simulation replicated is shown in Figure C - 4.

Table C - 1: Simulation of Surface Water Supply Storages

OWNERSHIP	ASSET	CAPACITY (ML - FSL)	INFLOWS MODELLED USING	EVAPORATION STATION
Bathurst Regional Council	Chifley Dam	30,800	Bathurst 63004	Synthetic model based on SILO data for Bathust
	Winburndale Dam	1,700	Bathurst 63004	Synthetic model based on SILO data for Bathurst
	Macquarie River Weir	10	Bathurst 63004	Synthetic model based on SILO data for Bathurst
Boorowa Shire Council	Boorowa Dam	335	Murrumburrah – Harden 73029	Wyangala Dam
Cabonne Shire Council	Molong Creek Dam	1,000	Molong 65023	Orange 63065
	Borenore Creek Dam	230	Molong 65023	Orange 63065
Central Tablelands Water	Lake Rowlands	4,500	Blayney 63010	Blayney 63010
Lithgow City Council	Farmers Creek No. 1	77	Lithgow 63224	Lithgow 63224
	Farmers Creek No. 2	440	Lithgow 63224	Lithgow 63224
Orange City Council	Suma Park Dam	18,000	Orange 63065	Orange 63065
	Spring Creek Dam	4,500	Orange 63065	Orange 63065
Parkes Shire Council	Lake Endeavour	2,400	Parkes 65024	Parkes 65024
	Beargamil Dam (Lake Metcalfe)		Parkes 65024	Parkes 65024
State Water Corporation	Burrendong Dam	1,188,000	Replicated Historical IQQM Inflows	Burrendong Dam
	Wyangala Dam	1,220,000	Replicated Historical IQQM Inflows	Wyangala Dam
	Oberon Dam	45,400	Bathurst 63079	Synthetic model based on SILO data for Bathurst
	Duckmaloi Weir	20	Bathurst 63079	Synthetic model based on SILO data for Bathurst
Upper Lachlan Shire Council	Crookwell Dam	450	Crookwell 70025	Wyangala Dam

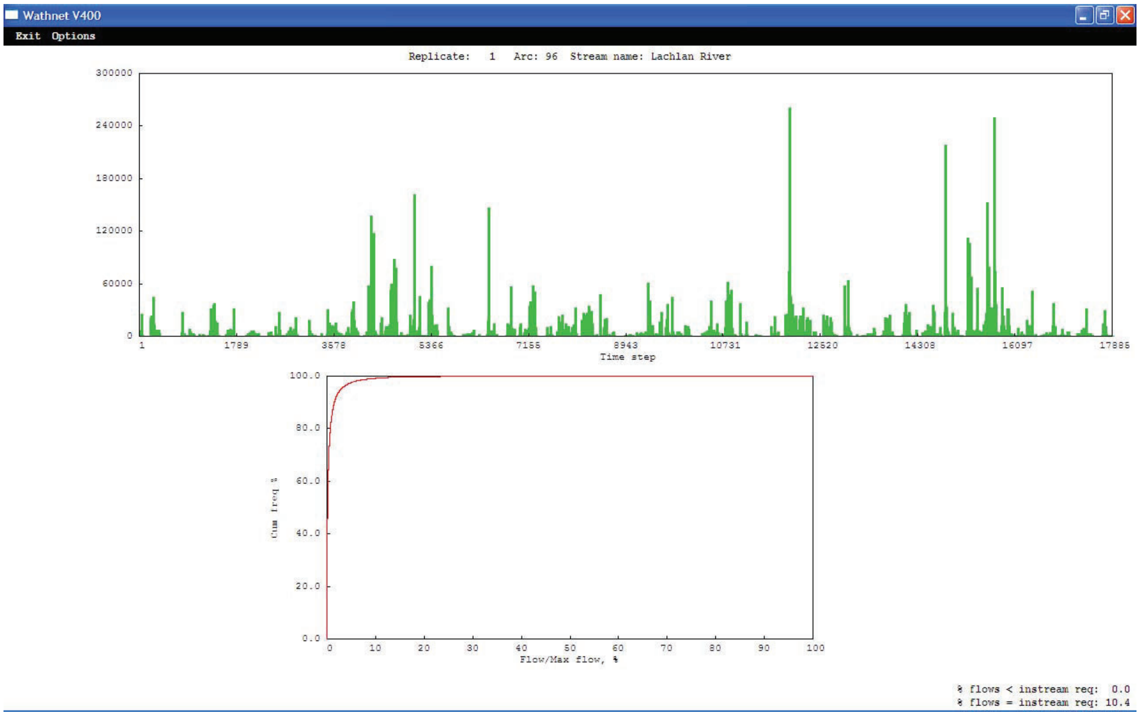


Figure C - 4: Example of Simulated Inflows to Wyangala Dam

Modelling Releases from Major Storages

An important consideration in the modelling of the major storages was the releases from both Wyangala and Lake Burrendong. The data from IQQM model runs contained releases for high, and general security users in addition to special releases. The time series also included the level of allocation. For the purpose of ascertaining the reliability of urban supplies, a "full" allocation time series for general security users was generated using the following equation:

$$U = \frac{R}{(1 - p + xp)}$$

Where: *U* = unrestricted demand;

R = Restricted demand;

p = % General security in unrestricted demand;

x = General security allocation.

Once the full allocation data was generated, replicates were generated using the multi-site Markov Chain Model. A general security allocation regime was generated using a line of best fit over historical data (Figure C - 5 and Figure C - 6). The wide scatter in the Lake Burrendong data set is the result of the carry-over provisions used in the regulation of the Macquarie River below Lake Burrendong.

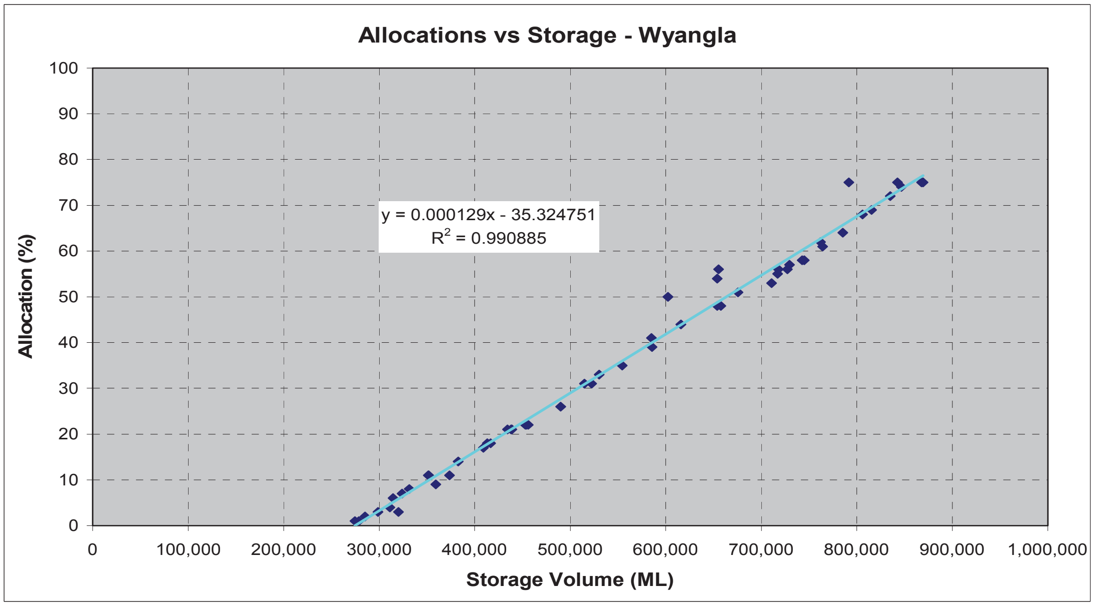


Figure C - 5: Relationship Between Years Starting Storage and Allocation - Wyangala Dam

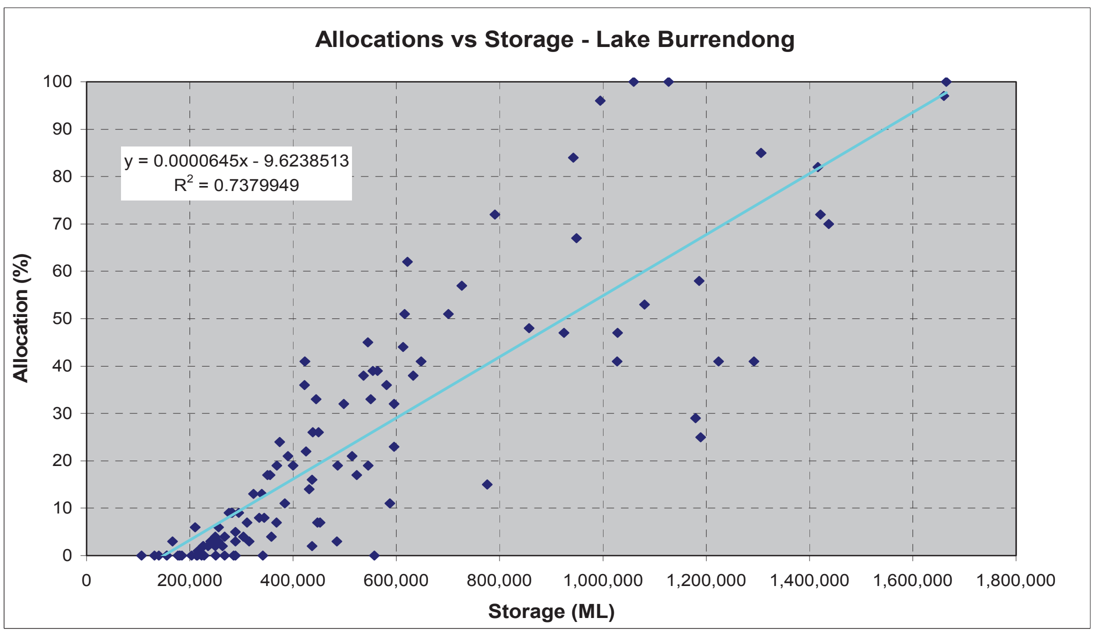


Figure C - 6: Relationship Between Years Starting Storage and Allocation - Lake Burrendong

An example of the unrestricted and restricted release time series are shown in Figure C - 7 and Figure C - 8.

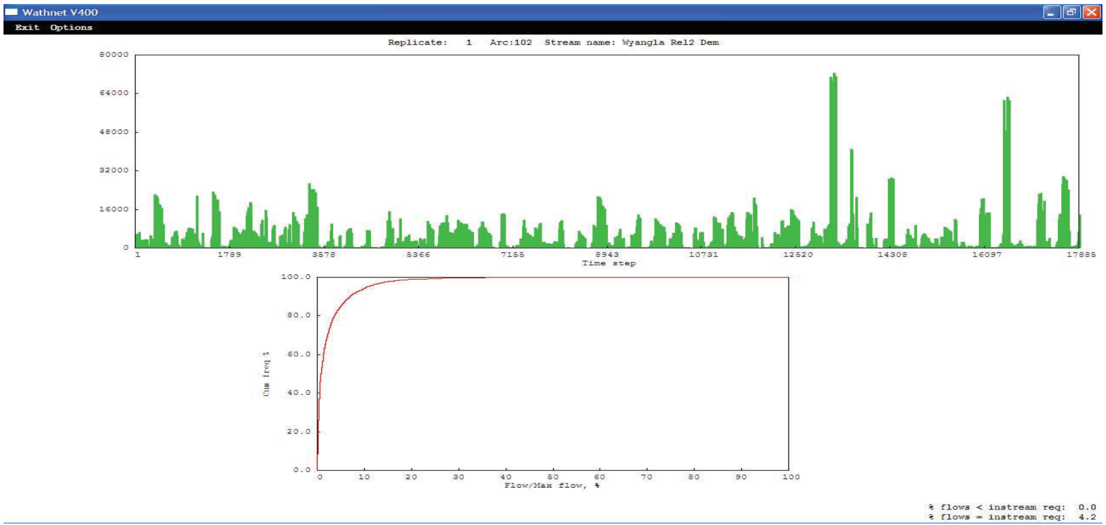


Figure C - 7: Unrestricted Release Time Series - Wyangala Dam

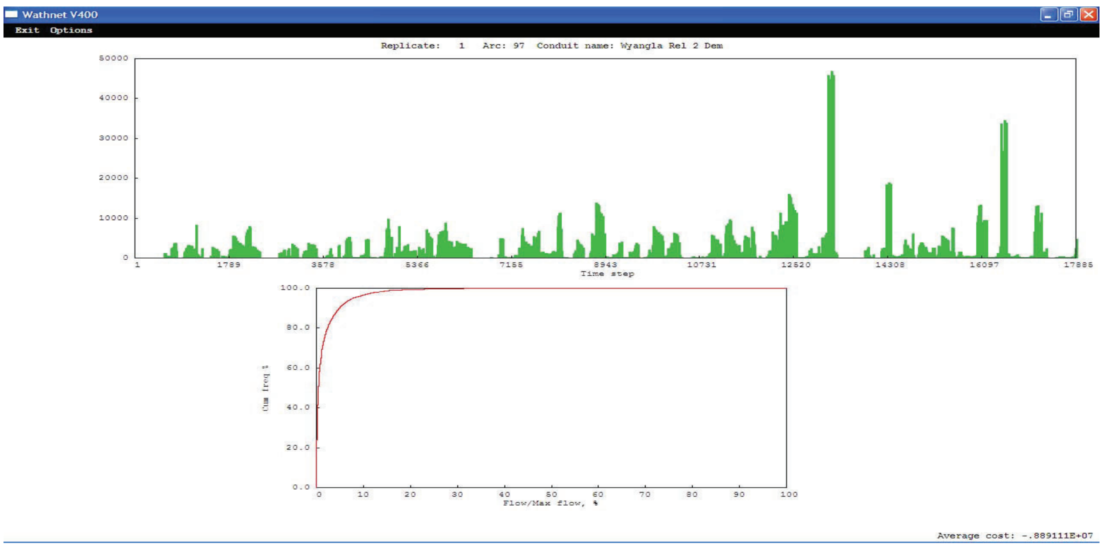


Figure C - 8: Restricted Release Time Series - Wyangala Dam

Stochastic Generation of Climate and Streamflow Data

Even when the water supply system is stationary in the sense that average annual demand is not changing over time and system configuration remains static, historic climate and streamflow records are frequently too short to permit accurate assessment of steady-state system performance; this is particularly true for systems with a low probability of experiencing demand shortfalls. When assessment of transient system performance is required, the time series of historical data is often inadequate.

In such instances, reliable assessment requires the use of stochastically generated streamflow and demand data. The idea is to make better use of the historical data by fitting a probability model and then randomly sampling from that model. Sufficient data should be sampled to reduce sampling errors in performance statistics (such as probability of restrictions on water use), to acceptable levels.

The flowchart in Figure C - 9 shows the procedure used to generate stochastic data. First a multi-site probability model is fitted to annual climate and/or streamflow data. From the model, estimates of the probability model parameters are obtained as well as their distributions (which describe the uncertainty about the parameters). For each replicate a check is made whether parameter uncertainty is to be allowed for. If so, the probability model parameters are randomly sampled from their distributions; otherwise, the original estimates are used. Then a specified number of years of data are generated using the probability model and disaggregated into seasonal flows using the method of fragments. This procedure is repeated until the desired number of replicates have been generated. Each replicate represents an equally likely sequence of future climate or streamflows.

The lag-one multi-site model was proposed by Matalas (1967). It can be applied to both climate, streamflow and demand data provided the annual means are **stationary**. Suppose there are k sites. Let q_{it} be the annual flow for site i, i=1,..,k, and year t. We transform these annual flows using the Box-Cox transformation (Box and Cox, 1964) to obtain the transformed flows.

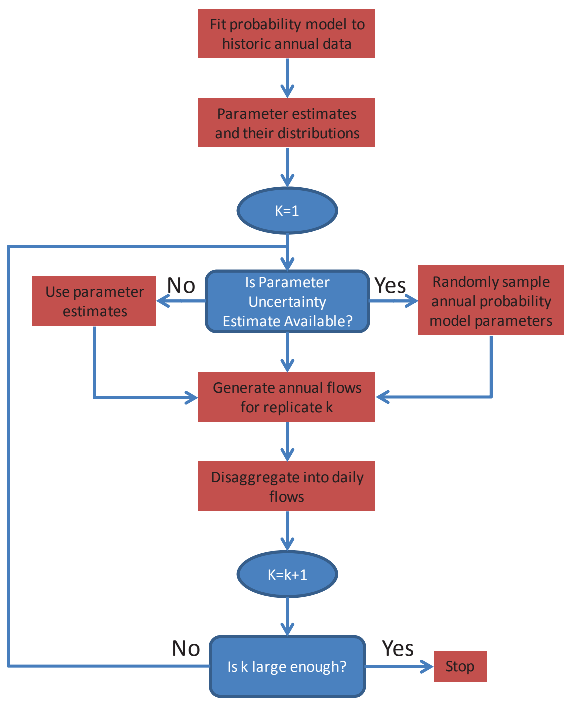


Figure C - 9: Flowchart of Data Generation Procedure

$$Q_{it} = [q_{it}^{\lambda_i} - 1] / \lambda_i \quad \text{if } \lambda_i \neq 0$$

$$= \log_e (q_{it}) \quad \text{otherwise} \quad i = 1,...,k \quad (1.1)$$

The transformation ensures that Q is approximately normally distributed. Let $\mathbf{Q_t}$ and μ be k-vectors of the transformed annual flows for year t and transformed annual flow means respectively. The multi-site lag-one model assumes the following probability model:

$$Q_t - \mu = A (Q_{t-1} - \mu) + \varepsilon_t \quad (1.2)$$

where $\boldsymbol{\varepsilon_t}$ is a k-vector of disturbances assumed to be normally and independently distributed with mean **0** and covariance matrix Σ, which describes the spatial correlation between sites, and **A** is a (k,k) matrix of parameters which accounts for correlation between flows in years t and t-1.

The transformation parameter λ is estimated for each site independently by computing the skew of Q for different values of λ and selecting that value which has a skew closest to zero. The parameter matrices Σ and **A** are estimated using the method of maximum likelihood (Kuczera, 1987). This avoids the occasional inconsistency problems encountered with the estimation procedure proposed by Matalas.

Generation of annual flows for year t involves three steps. First the vector of disturbances ε_t is randomly sampled from a multi-normal distribution with mean **0** and covariance Σ. Then $\mathbf{Q_t}$ is computed using eqn. (5.2). Finally the back-transformation

$$q_{it} = [\lambda_i Q_{it} + 1]^{1/\lambda i} \qquad \text{if } \lambda_i Q_{it} + 1 > 0 \text{ and } \lambda_i \neq 0$$

$$= \exp(Q_{it}) \qquad \text{if } \lambda_i = 0 \qquad (1.3)$$

is employed to generate annual flows at the k sites. If $\lambda \neq 0$, the constraint in eqn. (1.3) is sometimes violated. If this occurs, it is necessary to return to the first step and start over. In fact, the distribution of Q can never be exactly normal, rather it follows a truncated normal distribution.

Seasonal Disaggregation Using Method of Fragments

Once annual flows have been generated, a simple scheme called the method of fragments (Svanidze, 1960) is used to disaggregate annual flow into seasonal flows. Provided a sufficient number of historical data are available, this method will reproduce reasonably well gross seasonal flow statistics (except start-of-year lag-one autocorrelation which is always 0).

Suppose there are n years of historical data at m sites. Let q_{ijk} be the flow for season i, year j and site k, and q_{jk} be the annual flow for year j and site k. The fragment for season i, year j and site k is defined as

$$f_{ijk} = \frac{q_{ijk}}{q_{jk}} \qquad (1.4)$$

Now suppose the annual flow vector $\mathbf{q^*_t}$ was generated for year t by the lag-one annual flow model. Select a key site. Find the historical annual flow at the key site closest to the one generated for the key site. Let this year be u. Then the disaggregated seasonal flows for year t are

$$q^*_{itk} = f_{iuk}\ q^*_{tk} \qquad i = 1,..,12, \quad k = 1,...,m \qquad (1.5)$$

Inflows to Minor Storages

Hydrologic assessment of the reliability of water supply systems requires the use of long records of streamflows to understand the reliability over time. In most places there is a much shorter record of streamflows than there is of rainfall. The use of a rainfall runoff model to convert rainfall into a synthetic record of streamflow is an important first step in the hydrological assessment process.

Many of the urban centres in the study area make use of surface water supply storages that are not connected to the major regulated storages of Lake Burrendong and Wayangla Dam. To assess the water security of these unregulated water supplies, hydrological models of their catchments had to be developed. These were developed using a Monash rainfall runoff model. A description of the model input parameters is provided in Table C - 2 and the parameters used in the study, including any stream flow sites used in calibration is shown in Table C - 3.

Table C - 2: Monash Model Calibration Parameters

PARAMETER	DESCRIPTION	UNITS
Coeff	Infiltration coefficient	mm/day
SMS	Conceptual soil moisture store in mm	mm
DS	Depression store	mm
EM	Maximum evapotranspiration rate	mm/day
ADS	Depression store infiltration rate or ratio	no.
Sub	Interflow coefficient	no.
Crak	Ground water seepage factor	no.
CINS	Interception store on grass, leaves etc	no.
SQ	Exponent in soil moisture.	no.

PARAMETER	DESCRIPTION	UNITS
CPDay1	Multiplier on ground water baseflow function 1	no.
Zday1	Exponent on ground water baseflow function 1	no.
CPDay2	Multiplier on ground water baseflow function 2	no.
Zday2	Exponent on ground water baseflow function 2	no.
CO	Surface runoff delay parameter	no.

Table C - 3: Monash Model Parameters - Minor Storage Catchments

PARAMETER	CHIFLEY DAM	WINBURNDALE DAM	SUMA PARK	SPRING CK	FARMERS CREEK	OBERON DAM	LAKE ENDEAVOUR	BEARGAMIL DAM	LAKE ROWLANDS	CROOKWELL	BOOROWA	BELL RIVER AT CUMNOCK	BUCKINBAH CREEK	MOLONG	BORENORE C
Water Supply	Bathurst	Bathurst	Orange	Orange	Lithgow	Fish River	Parkes	Parkes	Central Tablelands Water	Crookwell	Boorowa	Cumnock	Yeoval	Molong	Molong
Gauging Station	421101 Campbells River at U/S Ben Chifley Dam	421101 Campbells River at U/S Ben Chifley Dam	421103 Emu Swamp Creek @ Llewelyh	421103 Emu Swamp Creek @ Llewelyh	421101 Campbells River at U/S Ben Chifley Dam	421101 Campbells River at U/S Ben Chifley Dam	412086 Goobang Creek @ Parkes	412086 Goobang Creek @ Parkes	412092 Coombing Creek @ Lake Rowlands near Neville		412029 Boorowa River at Processors Crossing	421050 Bell River at Molong	421050 Bell River at Molong	421050 Bell River at Molong	421050 Bell River at Molong
GS Catchment Area (km2)	901	901	84	84	901	901	670	670	132		1530	365	365	365	365
Catchment area @ dam site	960	88	116	63	12	143	143	32	197	24.6	680	490	350	70	22
Infiltration Coeff (mm/day)	50	50	100	100	50	50	55	55	60	40	30	70	70	70	70
Soil Moisture Store (mm)	100	100	150	150	100	100	220	220	150	60	120	90	90	90	90
Depression store (mm)	5	5	20	20	5	5	20	20	10	10	20	20	20	20	20
Max. Evaporation (mm)	20	20	10	10	20	20	30	30	7	6	9	11	11	11	11
ADS	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Interflow coeff Sub	0.18	0.18	0.28	0.28	0.18	0.18	0.45	0.45	0.5	0.5	0.25	0.35	0.35	0.35	0.35
Infiltration to deep ground water Crak	0.2	0.2	0.12	0.12	0.2	0.2	0.12	0.12	0.2	0.5	0.1	0.25	0.25	0.25	0.25
CINS	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1
SQ	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GW recession coeff CPDay1	0.04	0.04	0.09	0.09	0.04	0.04	0.15	0.15	0.075	0.075	0.04	0.05	0.05	0.05	0.05
GW recession exponent Zday1	1.3	1.3	2	2	1.3	1.3	2	2	2	2	2	2	2	2	2
Surface flow routing CO (hrs)	6	6	1	1	6	6	1	1	1	1	1	1	1	1	1
GW recession coeff 2 CpDay2	0.055	0.055	0.09	0.09	0.055	0.055	0.018	0.018	0.155	0.1	0.06	0.07	0.07	0.07	0.07
GW recession coeff 2 Zday2	0.5	0.5	0.72	0.72	0.5	0.5	0.55	0.55	0.7	0.7	0.7	0.7	0.7	0.7	0.7

C.5 INTEGRATION OF GROUNDWATER MODELS

There was limited coverage of groundwater systems by models in the study area. The one exception was the Lachlan River Aquifer in the vicinity of Parkes. The results of the Modflow model, developed by Chris Jewel and associates, of this aquifer was used to generate a groundwater response model within WATHNET for the Parkes Integrated Water Cycle Management Study. This integrated groundwater and surface water model was used when considering the water security of Parkes and Peak Hill in the current study.

C.6 IMPACTS OF CLIMATE CHANGE

When examining the impact of climate change on water supply security, there needs to be a consideration of the change in rainfall, temperature and evaporation regimes. These changes are forecast and then the impact on streamflows and demand sequences are inputs to supply security estimates. There are two possible approaches used for estimating the impact of climate change on rainfall, temperature and evaporation regimes:

1. Global Climate Models and translate those changes into changes in water demand and runoff; and
2. The sampling of the historical record for given increases in temperature using a key site.

The driving force behind the climate change forecast is the increase in temperature. The question is what would be the response of other variables such as rainfall and evaporation to the increase in temperature? Sampling from the historical record (option 2 above) has the advantage that it is simpler, although the inherent assumption is that the relationships in the past are maintained into the future. The application of GCM results have the advantage that they are theoretically trying to model the integrated climate system (thus modelling the new relationship between temperature, evaporation and rainfall). A major drawback is that GCM models produce such a variety of results, particularly when it comes to predicting changes in rainfall.

For this study, the second of the two options has been used to model the impacts of climate change.

The key site chosen to generate climate change estimates was the daily maximum temperature at Bathurst. The sorted annual sums of daily temperature measured at Bathurst are shown on Figure C - 10. The lowest sum was recorded in 1992 and the highest in 1919. The lowest and the highest 10 annual temperature sums are given in Table C - 4.

Table C - 4: Years with Lowest and Highest Annual Temperatures

YEARS WITH LOWEST TEMP. SUMS	1992	1943	1989	1984	1981	1974	1971	1956	1978	1968
YEARS WITH HIGHEST TEMP. SUMS	1944	1899	1940	1915	1957	1898	1902	1897	1914	1919

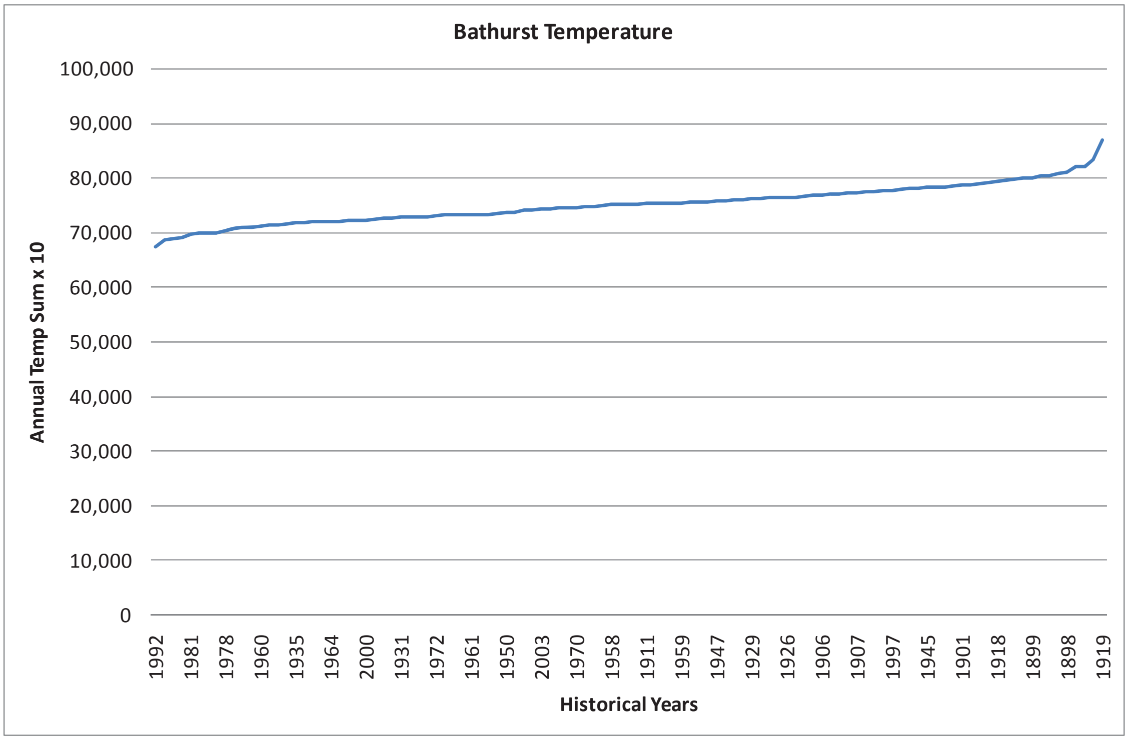


Figure C - 10: Bathurst Annual Temperature Sums in Ranked Order

The annual sums of daily rainfall for Blayney corresponding to the sorted temperature are shown on Figure C - 11. There is a clear negative trend in annual rainfall as the annual temperature sums increase.

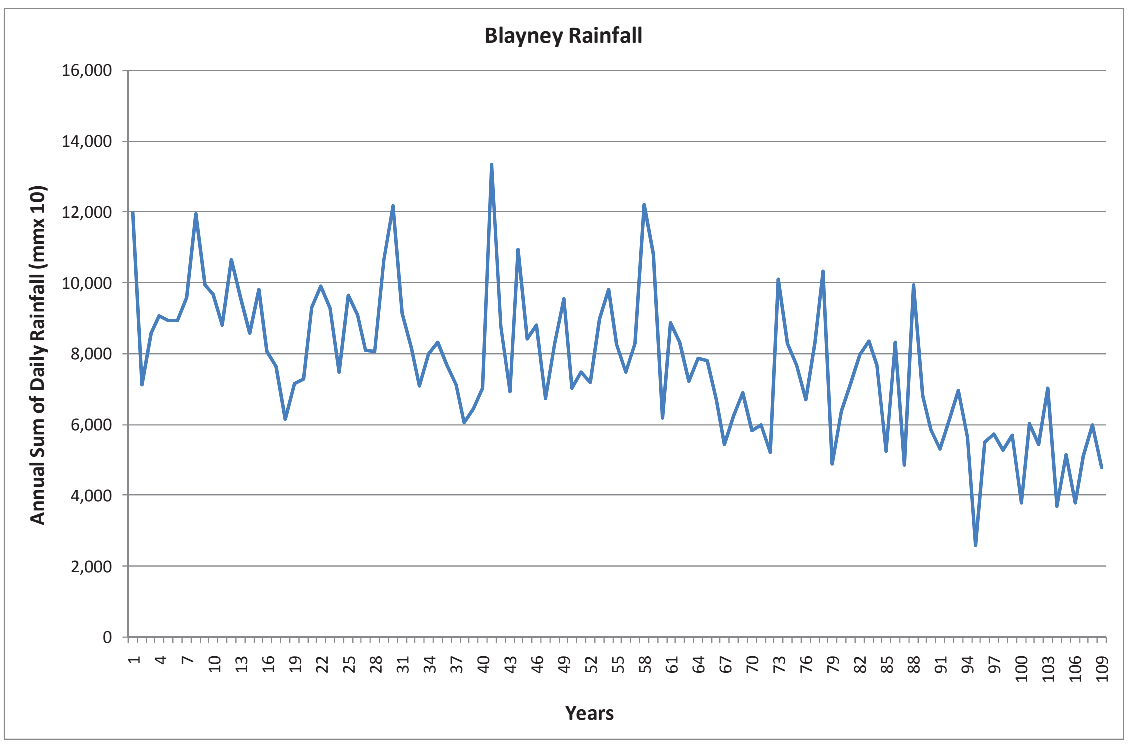


Figure C - 11: Annual Rainfall Sums Corresponding to Ranked Annual Temperatures - Blayney

If we generate stochastic data using the stationary model as described above with a trend in annual temperature only, then the generated annual rainfall and evaporation data contains the same trend evident in the historical data. Disaggregation into daily values using the method of fragments uses the temperature as the key site.

Equation 1.2 can be re-arranged to include an annual trend in temperature data aiming at the forecasted increase:

$$Q_t - \mu = A[(Q_{t-1} - \mu) + \Delta t] + \varepsilon_t \qquad (1.6)$$

It must be noted that Δt is zero for all sites but for the key temperature site.

The resulting trend in annual temperature sum at Bathurst (average of 1,000 climate replicates) is shown in Figure C - 12. Examples of the resulting average annual rainfall and evaporation forecasts are shown on Figure C - 13 and Figure C - 14. The results show that, given the assumption that historical sampling provides an estimate of the impacts of changing temperature regimes, then rainfall will decrease and evaporation will increase across the region.

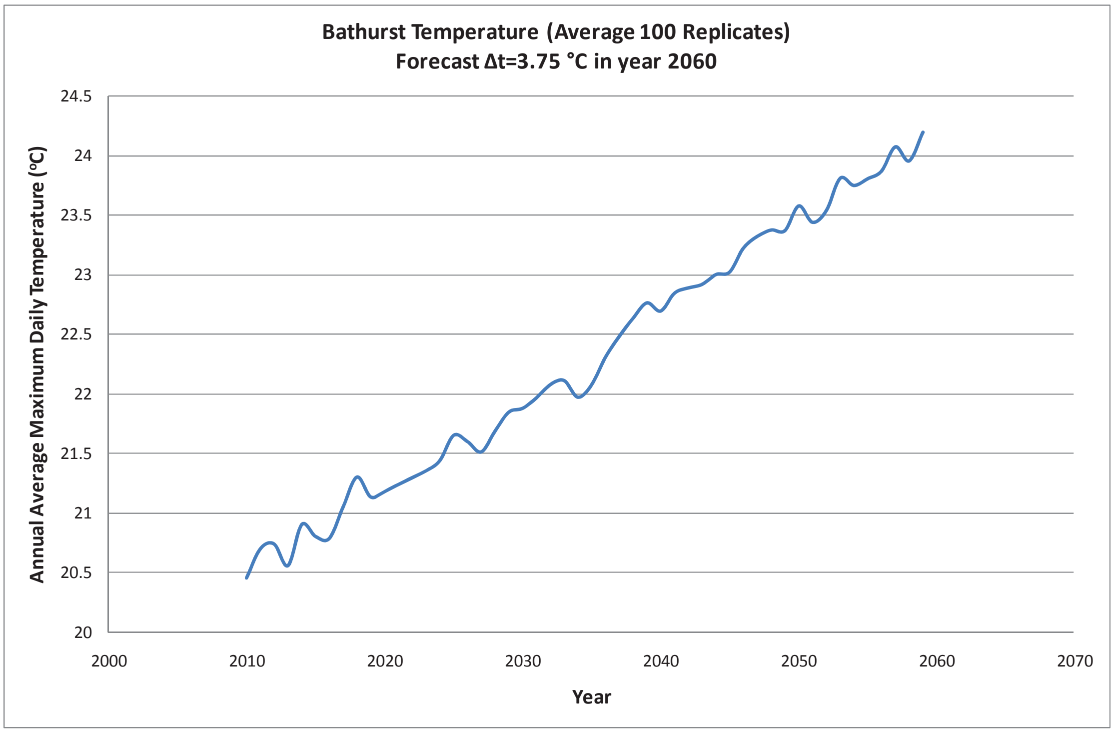


Figure C - 12: Annual Trend in Sum of Daily Temperatures - Bathurst

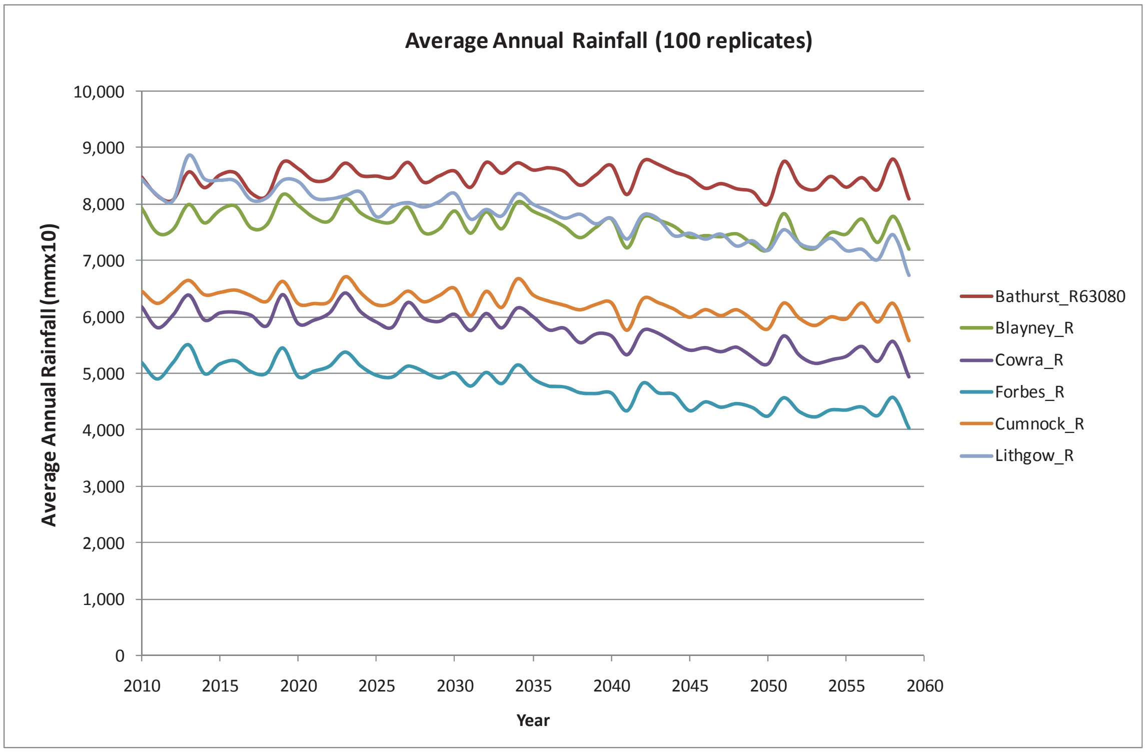


Figure C - 13: Examples of Changes in Annual Rainfalls - CENTROC Region

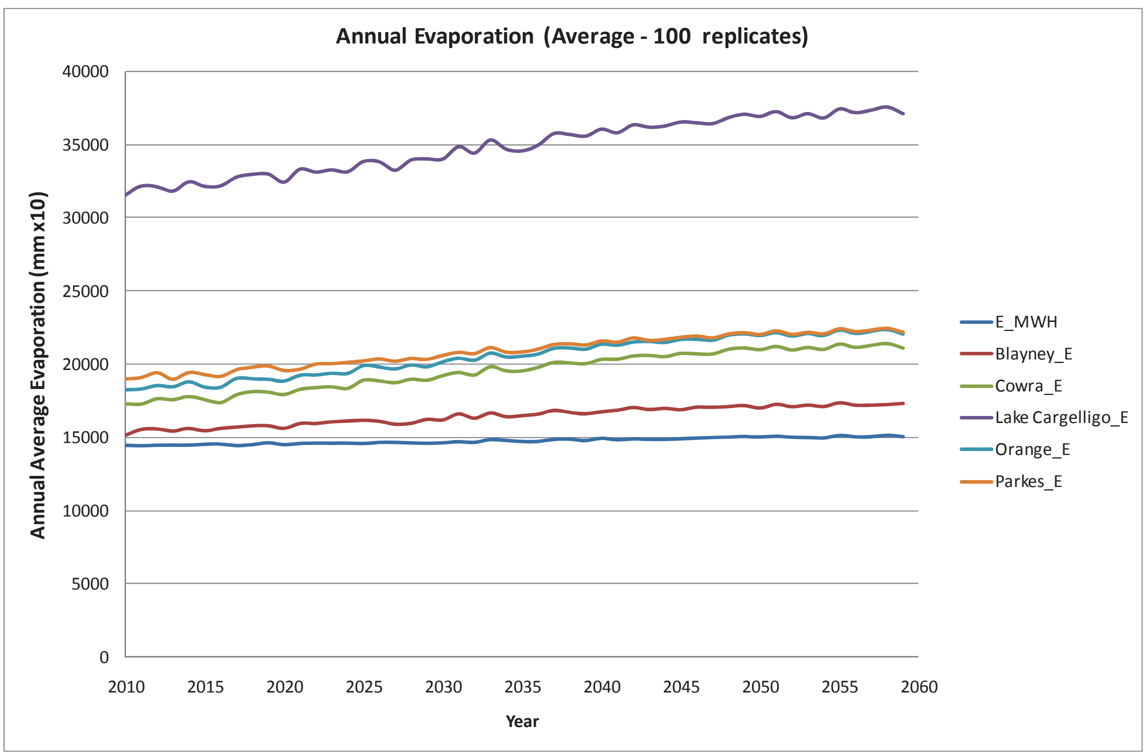


Figure C - 14: Examples of Changes in Annual Evaporation - CENTROC Region

The impact on inflows into and releases (unrestricted) from the major storages in Lake Burrendong and Wyangala Dam can also be assessed. Under the climate change regime modelled, releases (unrestricted) can be expected to increase and inflows decrease (Figure C - 15).

It can be seen from the figure that inflows to Wyangala are expected to decrease from the average 700 GL/a to 600 GL/a, while unrestricted releases are expected to increase 600 GL/a to 800 GL/a. It should be noted that the above trends are generated directly using the historical sampling of IQQM-based inflows and releases. Climate-change related inflows generated using climate data and the source catchment models may generate different results to those generated here.

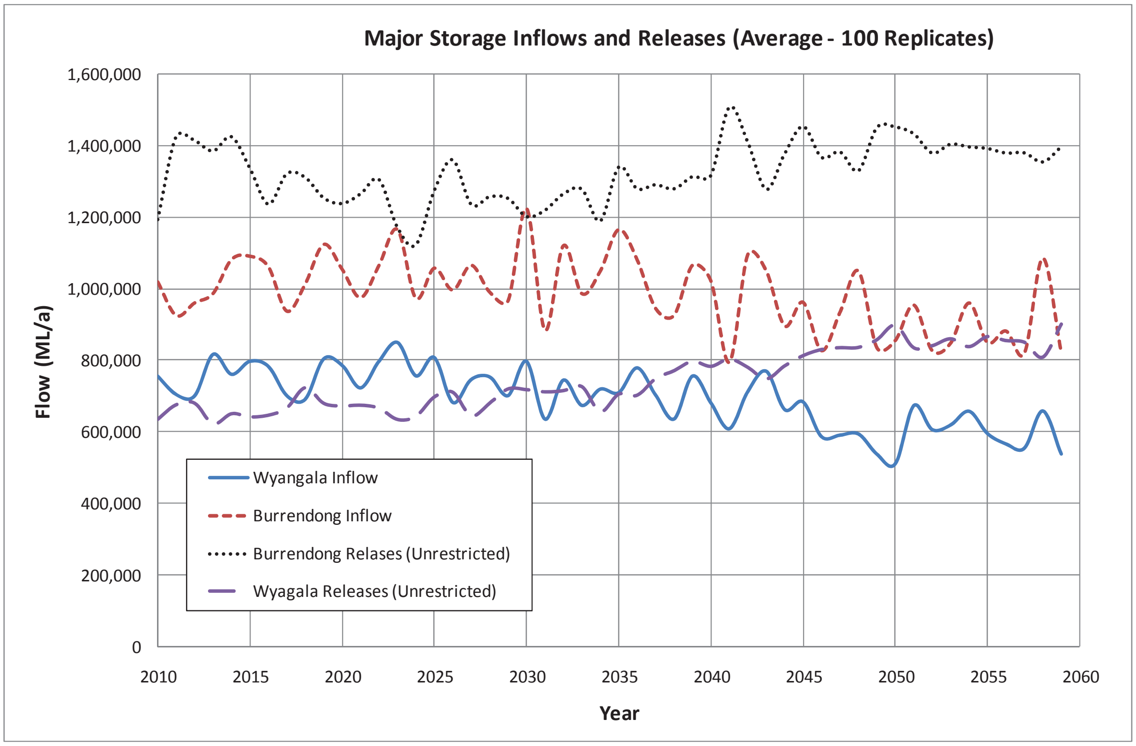


Figure C - 15: Forecast Inflows and Releases - Major Storages

The generated rainfall and evaporation time series were also used to generate the corresponding streamflows for minor storages in the region. An example of the changes in flow regimes (Chifley Dam, Suma Park Dam and Lake Rowlands) are shown on Figure C - 16, Figure C - 17 and Figure C - 18. Interestingly the Suma Park Dam shows a slight increase in flows under the climate change scenario.

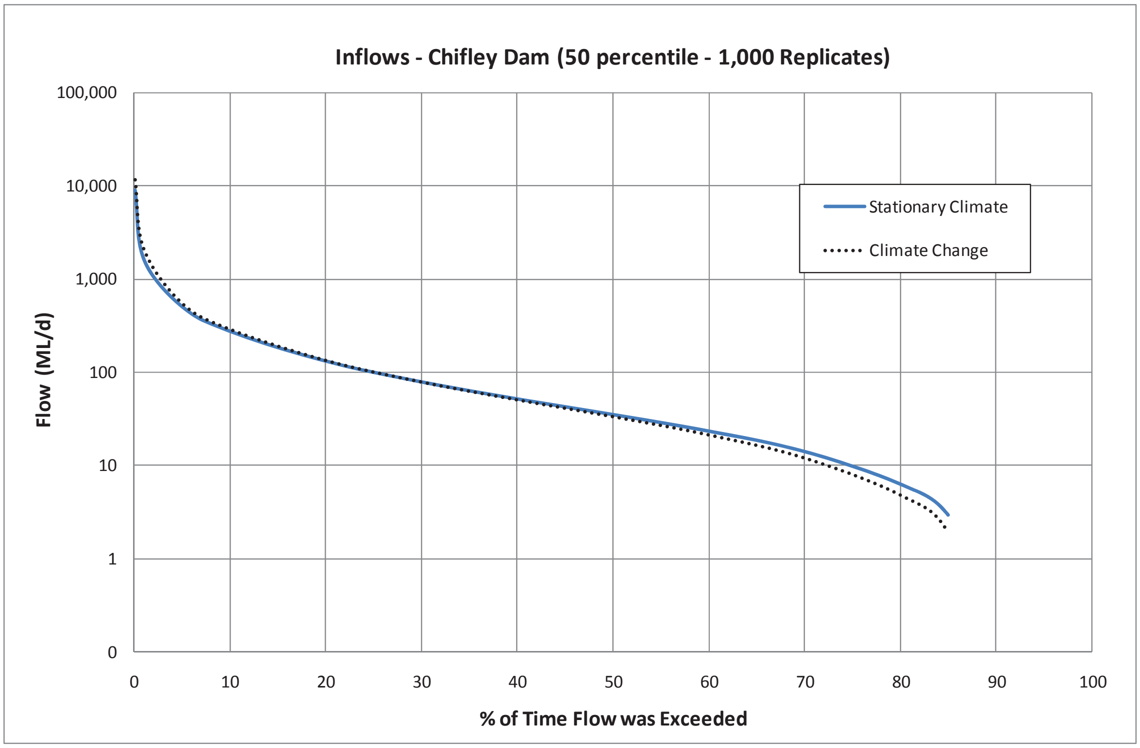


Figure C - 16: Change in Median Flow Duration Curve - Chifley Dam Inflows

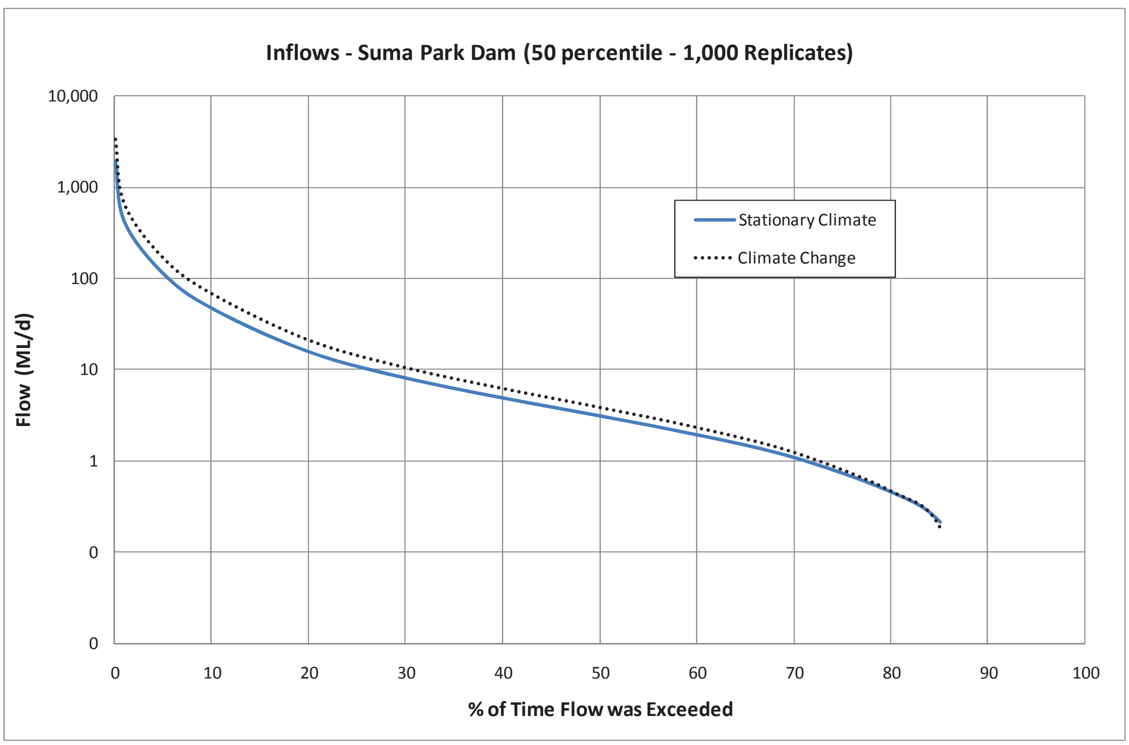


Figure C - 17: Change in Median Flow Duration Curve – Suma Park Dam Inflows

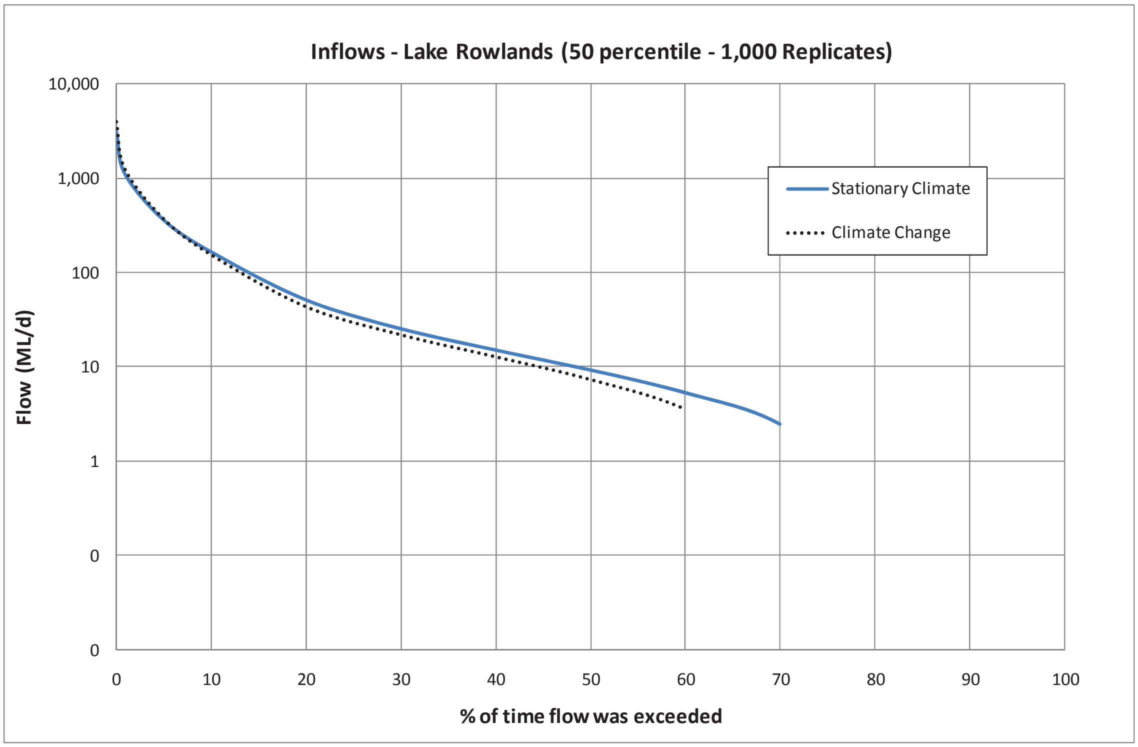


Figure C - 18: Change in Median Flow Duration Curves – Lake Rowlands

C.7 DEFINING THE SECURITY OF SUPPLY

In assessing the security of water supply, two criteria were used:

1. The percentage of years that water restrictions (of any duration) were in place; and
2. The percentage of total simulation replicates showing a total failure of the water supply system (i.e. storage levels fall to zero).

When planning water supplies, it is typically assumed that water restrictions should not be in place in any more than 10% of years and that there be no replicates in 1,000 showing total supply system failure (<0.01% failure probability).

In a simulation where each replicate represents an equally possible climate future for the planning period, a supply system failure in a single replicate is a replicate where, due to prolonged periods of hot and dry conditions, the flow in supplying streams is reduced to the extent that the water supply storage cannot be replenished – even where there are restrictions on supply. In this situation an emergency water supply (generally water cartage or groundwater) is required. For anything other than the smallest urban centres, water cartage is prohibitively expensive and generally infeasible. A failed water supply will put local industry and jobs at risk and is generally viewed as unacceptable.

C.8 MODELLING RESULTS

C.8.1 BUSINESS AS USUAL DEMAND CASE – EXISTING INFRASTRUCTURE

The first case to be modelling in the assessment of supply security under existing demand management regimes and infrastructure. The results (Table C - 5) show that there are a variety of supply securities across the region. The risk of supply failure for urban centres on the regulated river supplies are the estimate of the likelihood of total supply failure for Lake Burrendong and Wyangala Dam. These estimates have not been generated using approximate modelling of these systems and are for town water supply security purposes only. They should not be regarded as an estimate of supply reliability of the regulated river supplies as a whole.

Table C - 5: Summary of Water Security Under Current Conditions

DEMAND NODE	TOWNS	SOURCE SUPPLYING	PROBABILITY OF LEVEL 1 RESTRICTIONS IN ANY YEAR	PROBABILITY OF TOTAL SYSTEM FAILURE
Bathurst	Bathurst	Chifley Dam Macquarie River Weir	1.45%	<0.1%
Blayney - Carcoar	Blayney, Millthorpe, Carcoar, Lyndhurst, Mandurama, Garland	Lake Rowlands	0.03%	<0.1%
Boorowa	Boorowa	Boorowa Dam	Less than 0.5%	<0.1%
Canowindra	Canowindra, Woodstock	Lake Rowlands	Less than 0.5%	<0.1%
Condobolin	Condobolin	Goobang Creek Weir	10%[1]	0.4%
Cowra - Koorawatha	Cowra, Koorawatha, Bendick Murrell, Brundah, Greenethorpe, Mogongong, Wattamondara	Wyangala Dam	10%[1]**Error! Bookmark not defined.**	0.4%
Crookwell	Crookwell	Crookwell (Kentgrove) Dam	Less than 0.5%	<0.1%
Cudal/ Cargo/ Manildra	Cudal, Cargo, Manildra	Lake Rowlands	Less than 0.5%	<0.1%
Cumnock - Yeoval	Cumnock, Yeoval	Bell River and Buckinbah Creek Weir	18% Cumnock[2] Up to 32% Yeoval	14% Cumnock Up to 27% Yeoval
Forbes	Forbes	Wyangala Dam Lachlan River Weir	10%[1]	0.4%
Gooloogong-Eugowra	Gooloogong, Eugowra	Lake Rowlands	Less than 0.5%	<0.1%
Grenfell	Grenfell	Lake Rowlands	Less than 0.5%	<0.1%
Lake Cargelligo	Lake Cargelligo, Murrin Bridge, Tullibigeal	Terminal Lake 15 ML (Located within Lake Cargelligo)	10%[1]	0.4%
Lithgow - Portland[3]	Lithgow and Portland	Farmers Creek Dam (Lithgow No.1)	Up to 100%	0.4%
Molong	Molong	Molong Creek Dam Borenore Creek Dam	Less than 0.5%	0.0%
Oberon[1]	Oberon, Oberon timber industry	Oberon Dam	Up to 100%	0.9%
Orange	Orange, Clifton Grove	Suma Park Dam Spring Creek Dam (limited use)	10%[1]	0.6%

[1] While Town Security water users theoretically have no water restrictions under water sharing plans, it is a recommendation of this study that water restrictions should be in place in 10% of years. This would involve initiating restrictions at the ten percentile water level in Lake Burrendong and Wyangala Dam.

[2] Water supplies for Cumnock and Yeoval are assumed to service the full urban demand for both centres.

[3] The Fish River has been modelled as a single supply scheme with shared security for all users. At the current time, the water supply to Lithgow does not contribute to the security of the Fish River Water Supply. Fish River system water security has been estimated with the licenced offtake by Sydney Water to the Upper Blue Mountains Scheme included.

DEMAND NODE	TOWNS	SOURCE SUPPLYING	PROBABILITY OF LEVEL 1 RESTRICTIONS IN ANY YEAR	PROBABILITY OF TOTAL SYSTEM FAILURE
Parkes	Parkes, Peak Hill, NorthParkes Mine	Bogan River Weir @ Peak Hill Lake Endeavour Beargamil Dam (Lake Metcalfe) Parkes Borefield	11%	<0.1%
Wellington - Geurie	Wellington, Geurie, Nanima	Burrendong	10%[1]	4.4%

C.8.2 BASE CASE – ENHANCED DEMAND MANAGEMENT PROGRAMS WITH EXISTING INFRASTRUCTURE

One of the underlying assumptions in the Centroc water security study is that all urban water utilities will adopt and enhanced series of cost effective conservation measures consistent with best practice demand management. These measures will complement existing measures already in place. The impact on supply security associated with enhanced demand management approaches is shown in Table C-6. They show for many towns a small improvement in supply security can be obtained by additional demand management efforts. For urban centres with supply from regulated river sources, reductions in urban water use will no significant impact on overall supply security.

Table C - 6: Summary of Water Security Under Current Conditions

DEMAND NODE	TOWNS	SOURCE SUPPLYING	PROBABILITY OF LEVEL 1 RESTRICTIONS IN ANY YEAR	PROBABILITY OF TOTAL SYSTEM FAILURE
Bathurst	Bathurst	Chifley Dam Macquarie River Weir	0.82%	<0.1%
Blayney - Carcoar	Blayney, Millthorpe, Carcoar, Lyndhurst, Mandurama, Garland	Lake Rowlands	0.03%	<0.1%
Boorowa	Boorowa	Boorowa Dam	Less than 0.5%	<0.1%
Canowindra	Canowindra, Woodstock	Lake Rowlands	Less than 0.5%	<0.1%
Condobolin	Condobolin	Goobang Creek Weir	10%	0.4%
Cowra - Koorawatha	Cowra, Koorawatha, Bendick Murrell, Brundah, Greenethorpe, Mogongong, Wattamondara	Wyangala Dam	10%	0.4%
Crookwell	Crookwell	Crookwell (Kentgrove) Dam	Less than 0.5%	<0.1%
Cudal/ Cargo/ Manildra	Cudal, Cargo, Manildra	Lake Rowlands	Less than 0.5%	<0.1%
Cumnock - Yeoval	Cumnock, Yeoval	Bell River and Buckinbah Creek Weir	17% Cumnock Up to 30% Yeoval	14% Cumnock Up to 25% Yeoval
Forbes	Forbes	Wyangala Dam Lachlan River Weir	10%	0.4%
Gooloogong- Eugowra	Gooloogong, Eugowra	Lake Rowlands	Less than 0.5%	<0.1%
Grenfell	Grenfell	Lake Rowlands	Less than 0.5%	<0.1%

DEMAND NODE	TOWNS	SOURCE SUPPLYING	PROBABILITY OF LEVEL 1 RESTRICTIONS IN ANY YEAR	PROBABILITY OF TOTAL SYSTEM FAILURE
Lake Cargelligo	Lake Cargelligo, Murrin Bridge, Tullibigeal	Terminal Lake 15 ML (Located within Lake Cargelligo)	10%	0.4%
Lithgow - Portland[4]	Lithgow and Portland	Farmers Creek Dam (Lithgow No.1)	Up to 100%	0.4%
Molong	Molong	Molong Creek Dam Borenore Creek Dam	Less than 0.5%	0.0%
Oberon[1]	Oberon, Oberon timber industry	Oberon Dam	Up to 100%	0.9%
Orange	Orange, Clifton Grove	Suma Park Dam Spring Creek Dam (limited use)	10%	0.6%
Parkes	Parkes, Peak Hill, NorthParkes Mine	Bogan River Weir @ Peak Hill Lake Endeavour Beargamil Dam (Lake Metcalfe) Parkes Borefield	11%	<0.1%
Wellington - Geurie	Wellington, Geurie, Nanima	Burrendong	10%	4.4%

C.8.3 IMPROVED WATER SECURITY WITH STATIONARY CLIMATE REGIME

A number of options were explored with the goal of improving water security in the region. Under the preferred Final Strategy (2a), water will be supplied from an augmented Lake Rowlands to Cowra, Forbes, Orange and Parkes, plus provide water for expanded mining operations. The impact on urban water security of the proposed water security measures is shown in Table C-7. Overall, the results show that an augmented Lake Rowlands has the capacity to improve the water security to all towns that are proposed for connection.

It is important to note that for all communities that continue to rely solely on regulated river sources in the Preferred Strategy (Wellington, Lake Cargelligo and Condobolin), the planned measures will not reduce the probability of water restrictions in any year. The restriction trigger levels will remain tied to operation levels in the major storages. In these communities, the water security improvement options are to reduce the probability of system failure to below the 0.1% threshold.

Table C-7: Summary of Water Security Under the Preferred Final Strategy

DEMAND NODE	TOWNS	SOURCE SUPPLYING	PROBABILITY OF LEVEL 1 RESTRICTIONS IN ANY YEAR	PROBABILITY OF TOTAL SYSTEM FAILURE
Bathurst	Bathurst	Chifley Dam Macquarie River Weir	0.88%	<0.1%
Blayney - Carcoar	Blayney, Millthorpe, Carcoar, Lyndhurst, Mandurama, Garland	Lake Rowlands	Less than 0.5%	<0.1%

[4] The Fish River has been modelled as a single supply scheme with shared security for all users. At the current time, the water supply to Lithgow does not contribute to the security of the Fish River Water Supply. Fish River system water security has been estimated with the licenced offtake by Sydney Water to the Upper Blue Mountains Scheme included.

DEMAND NODE	TOWNS	SOURCE SUPPLYING	PROBABILITY OF LEVEL 1 RESTRICTIONS IN ANY YEAR	PROBABILITY OF TOTAL SYSTEM FAILURE
Boorowa	Boorowa	Boorowa Dam	Less than 0.5%	<0.1%
Canowindra	Canowindra, Woodstock	Lake Rowlands	Less than 0.5%	<0.1%
Condobolin	Condobolin	Goobang Creek Weir	10%	<0.1%
Cowra - Koorawatha	Cowra, Koorawatha, Bendick Murrell, Brundah, Greenethorpe, Mogongong, Wattamondara	Wyangala Dam	Less than 0.5%	<0.1%
Crookwell	Crookwell	Crookwell (Kentgrove) Dam	Less than 0.5%	<0.1%
Cudal/ Cargo/ Manildra	Cudal, Cargo, Manildra	Lake Rowlands	Less than 0.5%	<0.1%
Cumnock - Yeoval	Cumnock, Yeoval	Bell River and Buckinbah Creek Weir	<10% Cumnock <10% Yeoval	<0.1%
Forbes	Forbes	Wyangala Dam Lachlan River Weir	Less than 0.5%	<0.1%
Gooloogong-Eugowra	Gooloogong, Eugowra	Lake Rowlands	Less than 0.5%	<0.1%
Grenfell	Grenfell	Lake Rowlands	Less than 0.5%	<0.1%
Lake Cargelligo	Lake Cargelligo, Murrin Bridge, Tullibigeal	Terminal Lake 15 ML (Located within Lake Cargelligo)	10%	<0.1%
Lithgow - Portland[5]	Lithgow and Portland	Farmers Creek Dam (Lithgow No.1)	Less than 0.5%	<0.1%
Molong	Molong	Molong Creek Dam Borenore Creek Dam	Less than 0.5%	0.0%
Oberon[1]	Oberon, Oberon timber industry	Oberon Dam	Less than 0.5%	<0.1%
Orange	Orange, Clifton Grove	Suma Park Dam Spring Creek Dam (limited use)	Less than 0.5%	<0.1%
Parkes	Parkes, Peak Hill, NorthParkes Mine	Bogan River Weir @ Peak Hill Lake Endeavour Beargamil Dam (Lake Metcalfe) Parkes Borefield	Less than 0.5%	<0.1%
Wellington - Geurie	Wellington, Geurie, Nanima	Burrendong	10%	<0.1%

[5] The Fish River has been modelled as a single supply scheme with shared security for all users. At the current time, the water supply to Lithgow does not contribute to the security of the Fish River Water Supply. Fish River system water security has been estimated with the licenced offtake by Sydney Water to the Upper Blue Mountains Scheme included.

C.8.4 IMPROVED WATER SECURITY WITH CLIMATE CHANGE

Under the climate change scenario used in the modelling, those communities with supply sourced from either Chifley Dam or the enlarged Lake Rowlands maintained high water security levels with probabilities of water restrictions in any one year below the 10% level. The risk of supply failure remained below 0.1%. These findings suggest that that under the climate change scenarios modelled, rainfall and runoff in the upper reaches of the Macquarie and Lachlan catchments were less likely to affected by climate change than the mid reaches.

In the communities of Condobolin, Lake Cargelligo, Cumnock and Yeoval that are reliant on either run of river or local storages, the climate change scenarios indicated that an adjustment in the size of the proposed storages may be advisable. These changes in storage size are set out in Table C-8, below.

Table C-8: Changes to Proposed Storage Sizes Under Climate Change Scenarios

URBAN CENTRE	RECOMMENDED STORAGE SIZE UNDER STATIONARY CLIMATE REGIME	RECOMMENDED STORAGE SIZE UNDER MODELLED CLIMATE CHANGE
Condobolin	100 ML	150 ML
Cumnock	32 ML	33 ML
Lake Cargelligo	150 ML	150 ML
Yeoval	38 ML	40 ML

At the current time there is considerable uncertainty over the operating regimes for the regulated Lachlan River upon which supply to Condobolin and Lake Cargelligo is sourced. For the purposes of the costings prepared for this report, the storages for these two communities have been increased to 3 months supply for both communities. Losses from evaporation in both locations was substantial. Additional investigation should identify the trade-offs between storage size and the cost of covering the storages to reduce evaporation.

C.9 HYDROGEOLOGY

Hydrogeological or groundwater assessment of the Centroc region was conducted by C.M. Jewell & Associates Pty Ltd for the purpose of this study.

Groundwater is stored within, and moves through, the pore-spaces between the grains that make up sediments such as gravels, sands and silts, and some sedimentary rocks. It can also move through fractures and other voids in hard rocks such as granite, although these have little storage capacity. Sediments and rocks that can store and transmit groundwater in useful quantities are called aquifers. An aquifer system is a group of several aquifers that are partially interconnected, such that water can move between them.

The availability of groundwater at any location is governed by the local geology.

The assessment outlines the aquifer characteristics and groundwater resources available for potential abstraction for:

- Lachlan Valley Groundwater Resources;
- The Upper Macquarie; and the
- Orange Basalt Groundwater Resources.

Each is discussed in turn below.

C.9.1 THE LACHLAN VALLEY GROUNDWATER RESOURCES

Groundwater within the Lachlan River Basin is predominantly contained within alluvial aquifers; fractured rock aquifers are present around the margins of the basin but make only a minor contribution to groundwater storage. Groundwater is an option to supplement water supplies in some towns that are located on or close to alluvial aquifers, whereas the fractured rock aquifers do not generally provide sufficient yield for public supples; usually these aquifers are suitable only for domestic and stock watering uses, but there are exceptions, particularly where basalts are present.

The sustainable yield of an aquifer reflects the balance between the natural (or artificial) recharge received by an aquifer, abstractions by pumping, and the natural discharge that may sustain surface water flows or groundwater dependent ecosystems. The sustainable yield is not equal to the recharge– it is that proportion of the recharge that can be utilised without adversely impacting other systems. Because separating acceptable impact from adverse impact requires a subjective judgement, definition of sustainable yield is also subjective.

C.9.2 LACHLAN VALLEY TOWNS

A comprehensive list of the towns located within the Lachlan Valley is shown in Table C-9.

Table C-9: Lachlan Valley towns

TOWN	WATER SUPPLY SCHEME NAME	WATER UTILITY	TYPE OF SUPPLY	HYDROGEOLOGICAL SETTING
Blayney	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Millthorpe	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Carcoar	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Lyndhurst	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Mandurama	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Garland	BLAYNEY01	Garland	Surface Water	Belubula alluvium
Boorowa	BOOROWA01	Boorowa	Surface Water	Hard rock (Lachlan Fold Belt)
Canowindra	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Woodstock	CENTRALTW01	Central Tablelands	Surface Water	Belubula alluvium
Condobolin	LACHLAN01	Condobolin	Surface Water	Upper Lachlan alluvial aquifer
Bendick Murrell	COWRA01	Cowra	Surface Water	Hard rock (Lachlan Fold Belt)
Brundah	COWRA01	Cowra	Surface Water	Hard rock (Lachlan Fold Belt)
Cowra	COWRA01	Cowra	Surface Water	Upper Lachlan alluvial aquifer
Greenethorpe	COWRA01	Cowra	Surface Water	Hard rock (Lachlan Fold Belt)
Koorawatha	COWRA01	Cowra	Surface Water	Hard rock (Lachlan Fold Belt)
Mogongong	COWRA01	Cowra	Surface Water	Hard rock (Lachlan Fold Belt)
Wattamondara	COWRA01	Cowra	Surface Water	Hard rock (Lachlan Fold Belt)
Crookwell	ULACHLAN01	Crookwell	Surface Water	Hard rock (Lachlan Fold Belt)
Cargo	CENTRALTW01	Central Tablelands	Surface Water	Hard rock (Lachlan Fold Belt)
Cudal	CENTRALTW01	Central Tablelands	Surface Water	Hard rock (Lachlan Fold Belt)
Manildra	CENTRALTW01	Central Tablelands	Surface Water	Hard rock (Lachlan Fold Belt)
Forbes	FORBES01	Forbes	Combined	Upper Lachlan alluvial aquifer
Albert	LACHLAN03	Tottenham	Surface Water	Upper Lachlan alluvial aquifer
Tottenham	LACHLAN03	Tottenham	Surface Water	Upper Lachlan alluvial aquifer
Bogan Gate	PARKES02	Trundle	Surface Water	Upper Lachlan alluvial aquifer
Gunningbland	PARKES02	Trundle	Surface Water	Upper Lachlan alluvial aquifer
Trundle	PARKES02	Trundle	Surface Water	Upper Lachlan alluvial aquifer
Tullamore	PARKES02	Trundle	Surface Water	Upper Lachlan alluvial aquifer
Eugowra	CENTRALTW01	Central Tablelands	Surface Water	Upper Lachlan alluvial aquifer
Gooloogong	CENTRALTW01	Central Tablelands	Surface Water	Upper Lachlan alluvial aquifer
Lake Cargelligo	LACHLAN02	Lake Cargelligo	Surface Water	Lower Lachlan alluvial aquifer
Murrin Bridge	LACHLAN02	Lake Cargelligo	Surface Water	Lower Lachlan alluvial aquifer
Tullibigeal	LACHLAN04	Tullibigeal	Surface Water	Lower Lachlan alluvial aquifer

TOWN	WATER SUPPLY SCHEME NAME	WATER UTILITY	TYPE OF SUPPLY	HYDROGEOLOGICAL SETTING
Parkes	PARKES01	Parkes	Combined	Upper Lachlan alluvial aquifer
Cookamidgera	PARKES01	Parkes	Combined	Upper Lachlan alluvial aquifer
Alectown	PARKES01	Parkes	Combined	Upper Lachlan alluvial aquifer
Peak Hill	PARKES01	Parkes	Combined	Upper Lachlan alluvial aquifer

Although Cookamidgera, Alectown and Peak Hill are not strictly within the Lachlan Valley, these three towns have been included in the Lachlan Valley towns list because of the connection to Parkes.

Not all the towns have access to viable groundwater supplies.

C.9.3 REGIONAL HYDROGEOLOGY

The Lachlan River Basin is a broad east–west trending structure located in central western New South Wales. It covers an area of about 84,700 square kilometres (km2), and is approximately 500 kilometres long and 150 kilometres wide. The basin is bordered by the Macquarie River Basin to the west and the Murrumbidgee Basin to the south. The Great Dividing Range bounds its eastern (up-catchment) side.

Within the Lachlan River Basin, aquifer characteristics change with the progression from the upstream (recharge) areas to the downstream regions.

The location of the alluvial aquifers is shown on Figure C-19. The alluvial aquifers within the valley have been divided into three units: the Belubula alluvium (Groundwater Management Unit N21), the Upper Lachlan alluvial aquifer (N11- including both the mainstream system and the Bland Creek system) and the Lower Lachlan alluvial aquifer (N12).

Figure C - 19: Location of Lachlan Valley Alluvial Aquifers

Alluvial aquifers account for 98 per cent of the groundwater resource. The total volume of groundwater in storage has been estimated to be 291,000 gigalitres (GL), with approximately 40 per cent of this being regarded as low salinity – that is, with conductivities less than 1500 microsiemens per centimetre (µS/cm). Upstream of Condobolin, the storage of low salinity groundwater was estimated at 15,000 GL. However, not all this water is available for extraction – in fact, taking into account practical and environmental constraints, only a small proportion – perhaps 10 per cent – of the total storage is available.

UPPER LACHLAN RIVER BASIN

Alluvial sediments within the Upper Lachlan River Basin are divided into two formations, the (deeper) Lachlan Formation and the (shallower) Cowra Formation, on the basis of their age and lithology (Figure C-20).

The most productive aquifers occur in the deeper formation (Lachlan), and are associated with the basal section's relatively thick, well-sorted gravel and sand horizons Yields of up to 130 litres per second (L/s) have been recorded in the Forbes area, and yields in other regions may reach 200 L/s. Groundwater yields in the overlying Cowra Formation are lower, with maximum yields up to 40 L/s. In the Bland Creek area, aquifers with high yield potential are restricted to a well-defined palaeochannel at depths between 60 and 100 metres. Yields up to 120 L/s are recorded, but salinity is very variable and sometimes high. Salinity in the Bland Creek system is higher in the west than in the east, and also increases northwards. Downstream (west) of Condobolin, the Upper Lachlan alluvial aquifers decline in productivity, and the groundwater salinity increases substantially.

Within both the Lachlan and Cowra aquifers, lithology, permeability and bore yield vary greatly over short distances, both laterally and vertically. These aquifers are regarded as a stacked sequence of relatively narrow channel and point bar deposits separated by fine grained materials.

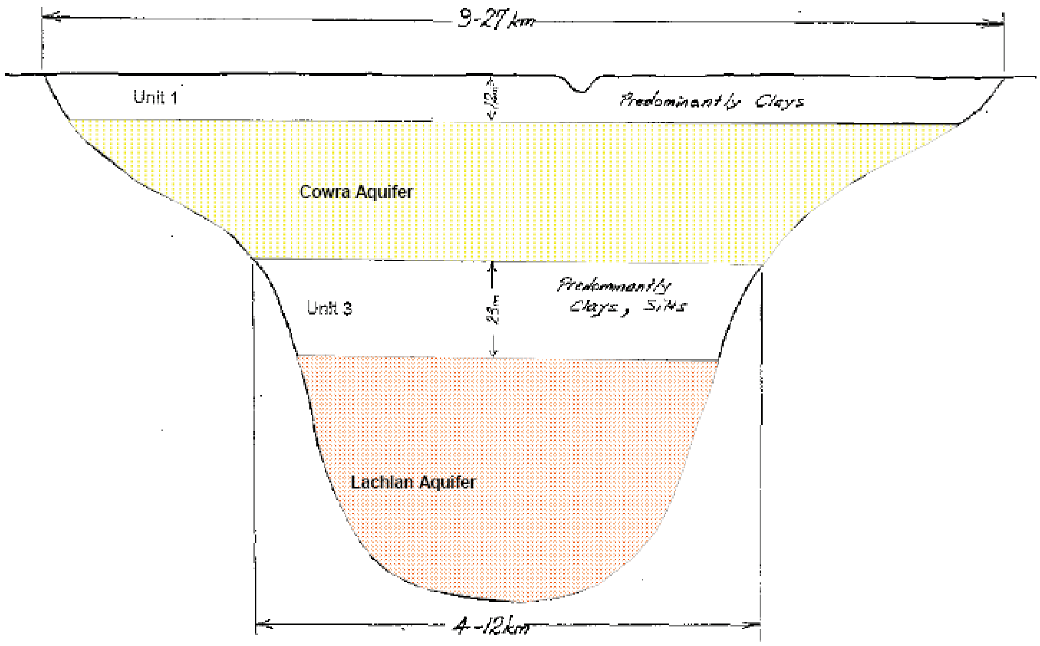


Figure C - 20: Schematic Cross-Section, Lachlan Valley

LOWER LACHLAN RIVER BASIN

West of Lake Cargelligo, the Lower Lachlan aquifer system has developed, similar to that of the Upper Lachlan Valley. The Lower Lachlan system consists of two formations, the (deeper) Pliocene-age Calivil Formation – equivalent of the Lachlan Formation, and the (shallower) Shepparton Formation - equivalent of the Cowra Formation.

Similar to the Upper Lachlan system, the most productive aquifers in the Lower Lachlan River Basin occur in the deeper Pliocene-age Calivil formation. Less extensive and productive, but still useful aquifers are present in the shallower Shepparton Formation.

In the lower Lachlan Valley many bores have been constructed to pump groundwater from the aquifers, for a range of agricultural uses and some other purposes. Between 1993 and 2003 there was a large (tenfold) increase in the volume of water pumped.

The groundwater within the (deeper) Calivil Formation is generally of low salinity, and is suitable for irrigating most crops, as well as for many other uses, such as town water supply, private domestic use and stock watering. Groundwater within the (shallower) Shepparton Formation is more variable in quality, and is sometimes saline. In both deep and shallow aquifers, salinity generally increases to the west.

The Lower Lachlan Groundwater Management Area (012) is one of the major groundwater sources whose management is currently being transferred from the Water Act 1912 to the Water Management Act 2000.

A Water Sharing Plan for the Lower Lachlan Groundwater Source was originally gazetted in 2003, but following objections to its provisions from many water users in the area, it was not commenced.

The Natural Resources Commission (2006) review of the plan focussed on the scientific basis of the estimated average annual recharge for the lower Lachlan groundwater source, which is fundamental to the water-sharing plan. It also considered the basis for the reservation of 20 per cent of the estimated recharge as provision for groundwater dependent ecosystems. The review concluded that there was substantial uncertainty in the recharge estimate, but that it was the best estimate that could be made on the basis of existing data. However, the review recommended that recharge which occurs in areas where the uppermost groundwater source is generally too saline for use (amounting to 20 per cent of total recharge) should be excluded from the overall recharge estimate. The review also concluded that there was no scientific basis for the provision of 20 per cent of total recharge for groundwater dependent ecosystems.

Subsequently, the NSW Department of Water and Energy (DWE) (2007) revised the Water Sharing Plan to incorporate the recommendations of the Natural Resources Commission review, and to ease the transition to the new arrangements for some existing users who were adversely affected by the original plan. In particular this involved recognition of the history of use of individual licence holders, and the issue of supplementary water access licences to entitlement holders whose new entitlement would be less than their history of use. Because the two changes to the recharge assessment that were recommended by the Natural Resources Commission effectively cancelled each other out, there was no change to the sustainable yield provision that forms the basis for the total entitlement.

C.9.4 RESOURCES AVAILABLE FOR INDIVIDUAL TOWNS

This section discusses prospects for groundwater supplies for individual towns. It should be noted that an embargo on new groundwater abstraction licences currently applies to the entire Lachlan Valley, including tributary valleys and hard rock (Lachlan Fold Belt) areas, but that exemptions generally apply for water for public supply purposes.

Prospects are the chance of locating adequate individual bore yield for town supply, ignoring competion, licencing, embargo and allocation issues.

Crookwell

Crookwell is located in the highlands at the eastern (upstream) end of the Lachlan Valley, only just west of the continental divide. The existing volcanic rocks host aquifers that provide baseflow to local creeks and also supplies of potable-quality water to local bores.

In 1986 four test bores were drilled to the west of Crookwell by the NSW Public Works Department (Figure C-21). Subsequent geophysical logging and pump testing of two of these bores (A and C) carried out under the supervision of Coffey & Partners (Coffey) in 1988 showed that:

- Groundwater inflows from discrete fissure zones in weathered and scoriaceous basalts between 18 and 34 metres below the surface, with the main inflows from fissures at 32 to 34 metres depth;
- Yields of 8.2 and 4.9 litres/second (L/s) for the two bores; and
- Calculated aquifer transmissivities of about 60 and 30 m2/d respectively.

On the basis of this testing, Coffey indicated that long term yields of about 10 L/s and 2.5 L/s should be achievable, and recommended that production bores be drilled. Production bores were eventually installed at these sites in 2003, and it is understood that yields have been similar to those predicted by Coffey.

The Tertiary basalts around Crookwell have an outcrop area of about 13.5 km2, so with average recharge of 50 to 85 millimetres per year (mm/yr), the total recharge would be about 700 to 1100 megalitres per year (ML/yr). The existing town bores are well-positioned to exploit this resource, and (at 12.5 L/s) could extract 30 to 50 per cent of the available recharge. Given the number of other bores, mainly stock and domestic bores in the area it is likely that the current abstractions are close to the sustainable yield of the aquifer, so that additional resources would not be available. The location of Crookwell Bores is shown in Figure C-22 (production bores shown in red, exploration bores in black).

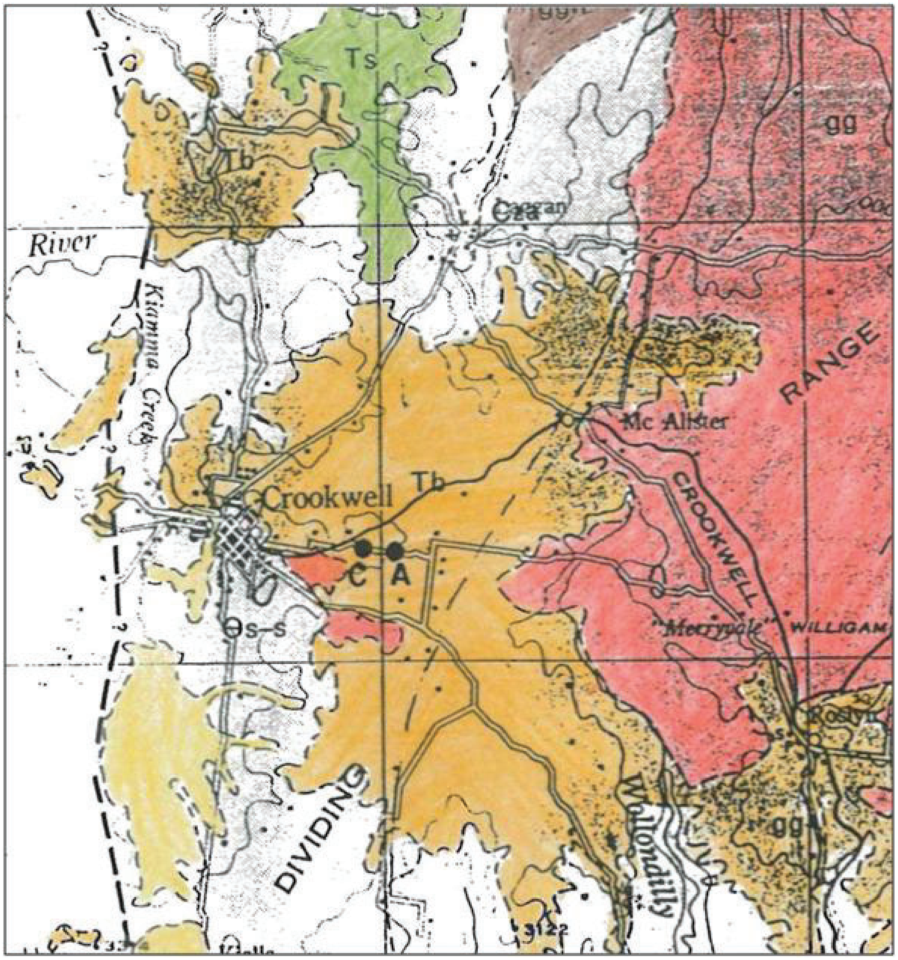


Figure C - 21: Test bores location and geology around Crookwell

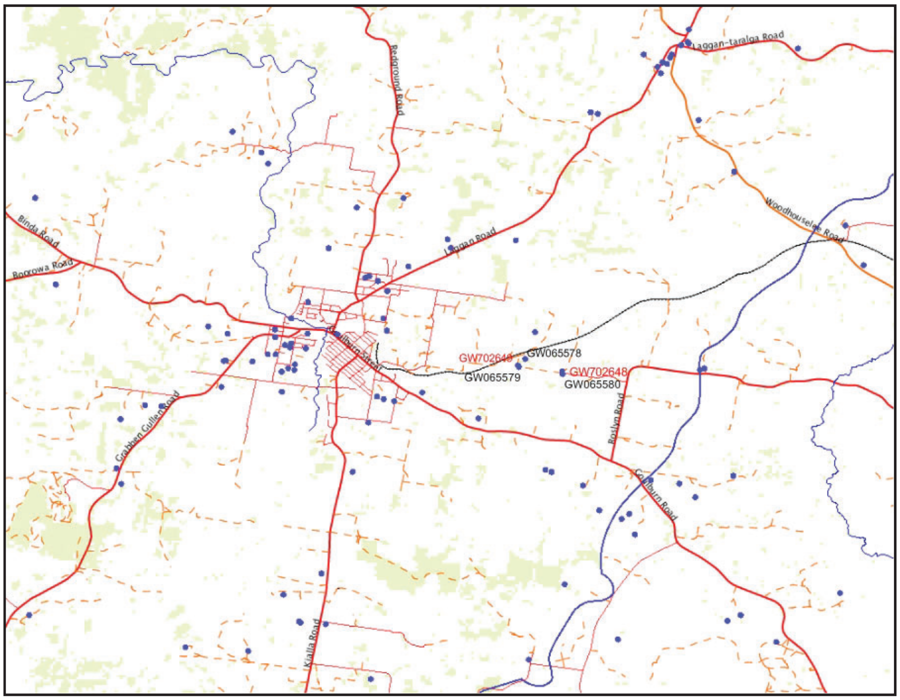


Figure C - 22: Crookwell Bores

Boorowa

Boorowa is underlain by the Silurian-age Douro volcanic sequence – dacite, andesite and tuff, with some minor sedimentary components. There are thin and inpersistent alluvial deposits along Geegulong Creek and the Boorowa River north of the town. The prospects of obtaining adequate supplies of groundwater for town use in this area are poor.

Blayney and other towns on the Belubula

The Belubula Valley alluvium is relatively shallow and is highly connected to the Belubula River, which is a losing stream. The productive aquifer is located well downstream of the major towns, and is a prior channel of the Lachlan River.

CSIRO (2008) indicates that the groundwater in the Belubula Valley is highly over-allocated, with current allocations over 11 times the estimated rainfall recharge. Current (2004/5) abstractions of 5.2 gigalitres per year (GL/yr) are 80 per cent of the allocation of 6.3 GL/yr.

Groundwater can be physically sourced from the alluvial aquifer at many locations in the lower valley, and would be substantially replenished by leakage from the river, which is regulated by Carcoar reservoir. However, the storage level in Carcoar is currently under 8 per cent of capacity and it has not been over 15 per cent in the past three years.

In these circumstances it is inappropriate to recommend groundwater abstraction for town water supply other than as part of a managed recharge / conjunctive use scheme where the river and aquifer are deliberately used together to provide a conduit and short term storage for surface water allocated to town supply.

Cowra

Cowra represents the upstream limit of the Lachlan aquifer, although the shallow Cowra Formation is present in both the Lachlan and Boorowa River valleys upstream of Cowra.

There are reasonable prospects for moderate groundwater yields from the Cowra formation, and sufficient groundwater of good quality to supplement town supplies could be obtained, although a hydrogeological investigation program, careful bore sitting and possibly multiple bores would be required, and the aquifer is fully allocated.

Cargo / Cudal / Manildra

These towns are located away from the main alluvial aquifer, in the upper reaches of Mandagery Creek and its tributaries.

The Lachlan Fold Belt rocks in this area are intensely faulted and folded, and consequently can provide small groundwater supplies. At Cargo a sequence of volcanic and sedimentary rocks are locally overlain by olivine, alluvial sand and gravel. In general in volcanic, the depth interval between 30 and 50 metres provides the highest yields and is unusual to find significant yields below 60 meters.

A review of the records of groundwater borehole drilling in the area held by the Department of Environment, Climate Change and Water (DECCW) indicates that a number of boreholes obtain small stock and domestic supplies to the south-west of Cargo from volcanic and sedimentary rocks. There is also some abstraction from these units around Cargo itself. Generally, recorded yields are in the range 0.1 to 0.2 ML/day. The maximum recorded is approximately 0.3 ML/day, from a borehole just to the north of Cargo.

It is a reasonable assumption that, over the years, most of the more accessible land in this area would have been explored for stock supplies of groundwater. The absence of borehole records for a particular area frequently indicates either inaccessible terrain or that there has been groundwater exploration but that this has proved unsuccessful, and that not even the low yields of groundwater required to justify the installation of a wind pump have been obtained. It is notable that there is a concentration of stock boreholes in a north-west-trending line along Cargo Creek.

Limestones south-west of Cargo do not appear to provide valuable aquifers. On the other hand, the alluvial infill at Cargo can provide both enhanced recharge and enhanced storage for groundwater.

The alignment of Cargo Creek to the south of the site may be structurally controlled, as it parallels a major north-west structural trend and a number of creeks in the area have a similar alignment. Alluvial deposits are developed along Cargo Creek; these may provide some storage for groundwater, even if their groundwater transmission capacity is low. Groundwater stored in the alluvium may be in hydraulic continuity with groundwater in fractures in the underlying volcanic and sedimentary rocks.

It is likely that adequate groundwater could be obtained from the Tertiary basalts located to the north-east of Cargo. However, these basalts appear to be relatively thin and of a limited extend and are located up to 8 kilometres from the town.

Similarly, at Cudal and Manildra it would be wrong to completely discount the prospect of locating small groundwater supplies from fractured rocks, but locating adequate supplies would require careful hydrogeological appraisal, and the outcome would be far from certain.

Eugowra / Canowindra / Gooloogong

Gooloogong is located on the Lachlan River, and here the current river channel and the palaeochannel aquifers are superimposed, so that the town is close to the Cowra and Lachlan aquifers. Canowindra is on the Belubula River just upstream of the confluence with the Lachlan, and Eugowra is on Mandagery Creek.

At Gooloogong the aquifers are narrow, and there are bedrock inliers that split the palaeochannel. Nevertheless, on the basis of experience in areas just downstream, it is possible to locate high-yielding bores here, with careful siting.

Eugowra lies some 7 kilometres north-east of the main Lachlan palaeochannel aquifer, and close to the edge of the Cowra aquifer. Large groundwater supplies are unlikely to be found near Eugowra, but useful supplies may be obtained from the Cowra aquifer close to the town. Small supplies may also be available at Canowindra. There is little doubt that sufficient groundwater to provide reliable supplies for all these towns is available from the Lachlan aquifer near Gooloogong, and will continue to be available. If necessary, demand priority over irrigators could be invoked.

Canowindra lies on the Belubula River, and is close to the main productive section of the Belubula alluvial aquifer which is a prior channel of the Lachlan River.

The existing upper Lachlan groundwater model (which starts at Gooloogong) could readily be extended to cover the palaeochannel between Cowra and Gooloogong.

Forbes

Forbes lies north of the Lachlan River and on the northern edge of the Cowra Formation alluvial deposits. Because the alluvial palaeochannel is not coincident with the current course of the Lachlan River, the town lies about 8 kilometres north-west of the closest part of the Lachlan palaeochannel aquifer, and about 12 kilometres north of the deepest, thickest and probably most productive part of that aquifer.

This section of aquifer 12 kilometres due south of Forbes has not been as heavily developed as the aquifer further east, and this area therefore provides good prospects for additional groundwater supplies. Moreover, this area is sufficiently far from the Parkes borefield to eliminate direct interference between abstractions. This has been demonstrated during previous modelling, and the existing model could be used without modification (other than the update that is currently in progress) to refine site selection and predict borefield performance in this area.

As is discussed in connection with Parkes in the following section, managed aquifer recharge should be an essential consideration in the development of new large groundwater supplies in this area.

Parkes

Parkes obtains its water supplies from two sources, a surface water allocation from the Lachlan River, and a borefield that draws groundwater from the Lachlan and Cowra alluvial aquifers, and is located about 13 kilometres east of Forbes (Figure C-23). The borefield also supplies the Northparkes mine.

In the past, concentrated abstraction from the borefield resulted in the development of an intense cone of depression (drawdown) around the borefield. The main causative factor for drawdown in the vicinity of Parkes Borefield was the expansion in Parkes Borefield abstraction from 1994 to 1995. However, lack of significant recharge events during this period, and irrigation abstractions from the aquifer contributed to the overall decline.

A hydrogeological assessment was carried out in 1998 (C. M. Jewell & Associates Pty Ltd, 1998), a numerical model was completed in 1999, and a revised groundwater model was developed in 2004. Currently, updating that model to incorporate recent groundwater abstraction data is in progress. A number of limiting factors were found to affect the borefield, the most important of these are:

- Non-optimal geometry of the Parkes Borefield position on the outside of a sharp bend in the most transmissive palaeo-channel and the proximity of lateral boundaries;
- A degree of drawdown interference between production bores in the Parkes Borefield due to the less than optimal bore separation; and
- The impediment to infiltration from surface sources imparted by the low hydraulic conductivity sediments overlying the Lachlan Aquifer.

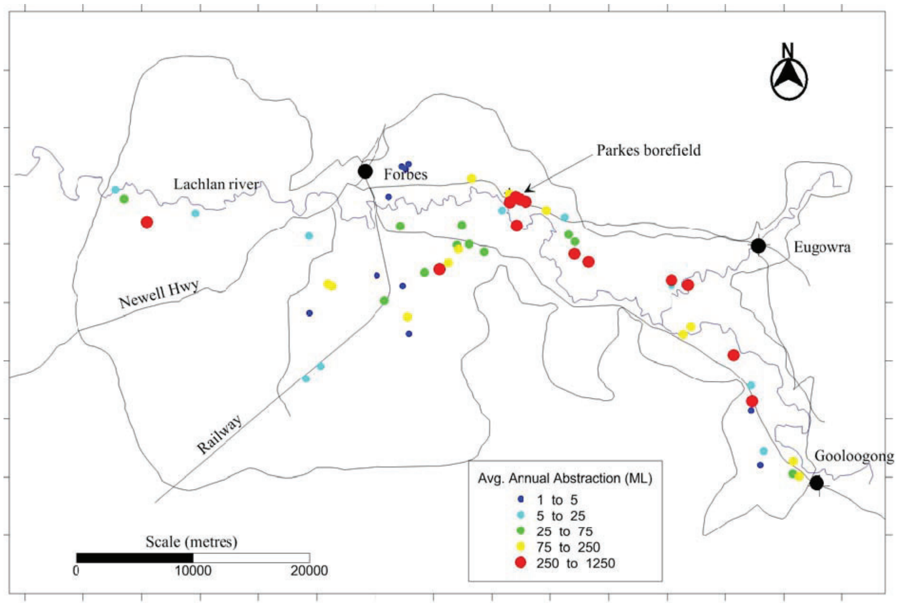


Figure C - 23: Location of Parkes Borefield and other Major Abstractions

Both the hydrogeological assessment and the modelling studies demonstrated that the upper Lachlan Valley aquifers are a leakage-dominated system, with very limited through-flow. This is the case even though vertical hydraulic conductivity is lower than lateral hydraulic conductivity. It reflects the fact that the cross-sectional area over which vertical leakage can occur is very large.

The water balance of the system indicates that leakage from, and outflow to, the Lachlan River are the major recharge and discharge mechanisms for the aquifer system. Rainfall recharge is relatively unimportant, but over-bank floods are significant contributors to recharge.

Because over-bank floods occur rarely, it is difficult to reliably model their contribution to groundwater recharge, but this contribution is vital.

Parkes has implemented a number of measures to manage drawdown at the borefield. These include replacement of inefficient bores, acquisition of additional licences from neighbouring landholders, and greater use of the surface water allocation. Clearly, however, the latter is currently constrained by the limited availability of surface water, a constraint that shows no signs of abatement. Model optimisation of the existing borefield indicates an annual abstraction of 1,200 ML to be sustainable.

Modelling considered a number of options to reduce the impacts of the current borefield configuration. Reference should be made to CMJA (2004) for a full discussion. The most viable options appeared to be:

1. Retention of curtailed Parkes Borefield and construction of new bores south of river

This option retains the existing borefield with an annual abstraction rate of up to 1200 ML, and adds new boreholes located at about 11 kilometres in the south-western portion of the palaeo-channel. A maximum annual abstraction of 2,700 ML from the new boreholes can be obtained without severely depleting water levels in the aquifer. The new borefield could be optimally placed to take advantage of accessible land, power supplies and transmissive parts of the Lachlan Aquifer. This option was considered potentially sustainable and has the following additional advantages:

- The value of the existing Parkes Borefield and associated network is retained.
- The scale and cost of the new bores are less than for complete relocation.
- Some redundancy in pumping plant headworks and pipelines is achieved; this would permit short-term operation of the existing borefield at higher rates in the event of pump failure in the new borefield.

- The following constraints were anticipated.
- Two networks and borefields may complicate engineering and asset management considerations.
- Development to the south of the Lachlan River would present substantial engineering difficulties, and consequent high infrastructure costs.
- Considering the heterogeneity of the aquifer system, and pending further hydrogeological investigation of the area, the viability of the proposed relocation area is not certain.

In the context of the current report, it should be noted that there is potential for conflict with the recommendations made for Forbes.

2. Modification of the existing borefield for use as an Aquifer Storage and Recovery System (ARS)

This option would require modification of the existing boreholes to recharge partially treated river water during the winter months, (or whenever excess flow is available) with re-extraction during the summer months.

Aquifer storage and recovery (ASR) is now an established technology, and there is little doubt that such a system could be technically viable. Demonstration of economic viability will require some further study.

ASR has the following advantages:

- ASR (and borehole artificial recharge) are maturing technologies with an expanding track record in the US and Europe, and in the arid zone in Africa, the Middle East and South Asia.
- It offers a sustainable solution.
- It offers an opportunity to uncouple the dependency of the natural groundwater recharge cycle on rare, unpredictable over-bank flood events.
- At this location – distinctively – ASR will mimic and enhance the natural aquifer recharge mechanism, which modelling has shown to be dominantly from the Lachlan River bed and over-bank flooding.
- It makes maximum use of existing infrastructure, and the value of the existing Parkes Borefield and associated supply network is retained.
- It avoids the need for development on the south side of the Lachlan River.
- Irrigation abstractions from the Lachlan River are low during the winter months; in most years it should be possible to harvest natural flows that are highest during winter. Targeted release from Wyangala Dam would also be feasible when the reservoir contains water.
- ASR can be operated as necessary to maintain pressure in the Lachlan aquifer, with reduced or suspended operation – and thus reduced running costs – if natural flows in the Lachlan and thus natural recharge are high.

ASR has a number of potential constraints, and the policy of DECCW NSW is that artificial recharge schemes will be strictly controlled to protect the intrinsic water quality of the aquifer and maintain aquifer permeability. As indicated above, it is believed that with basic treatment of the Lachlan River water to reduce the suspended solids load (borehole injection does require low-turbidity water), these conditions could be met. ASR is more likely to preserve aquifer structure than is continued over-extraction.

The existing regional and borefield numerical models can readily be adapted to model ASR.

Condobolin

Condobolin lies close to, but just downstream of, the confluence of the Upper Lachlan and Bland Creek systems. Both the Lachlan and Cowra aquifers are available, but salinity in both is significantly higher than further upstream. There is limited groundwater throughflow through the Jemalong gap, and a high proportion of aquifer recharge is derived from river-bed leakage and infiltration from rare flood events. The Bland Creek system makes a significant contribution.

Figure C-24 shows the aquifer thickness and the location of bores in the area immediately upstream of Condobolin.

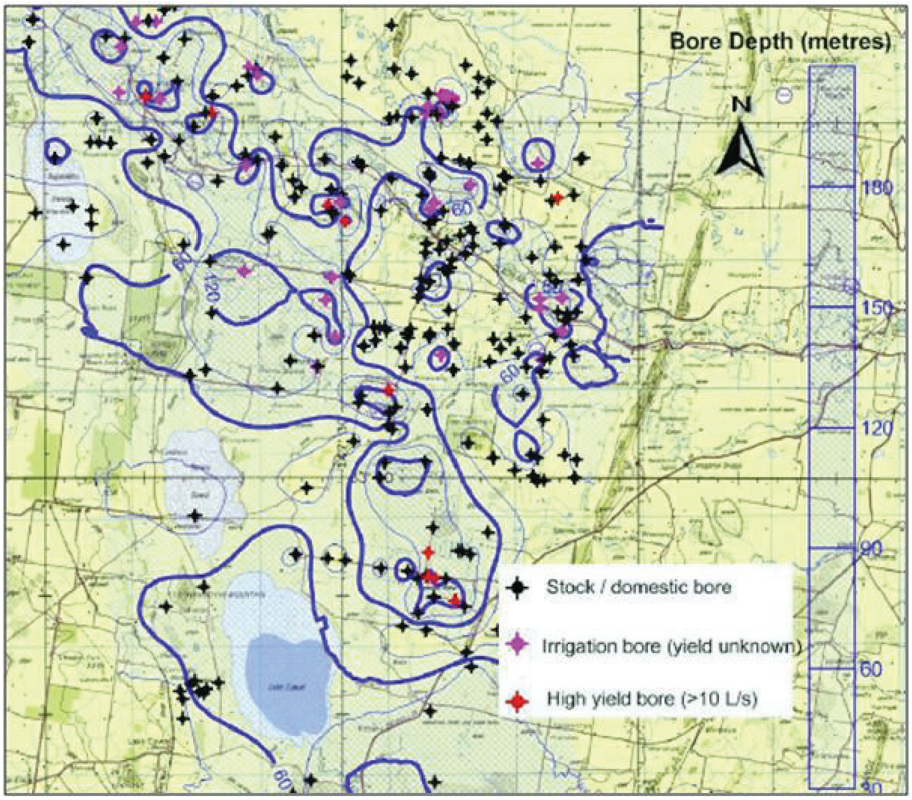


Figure C - 24: Aquifer Thickness and Bore Location, Upstream of Condobolin

The town of Condobolin is supposed to have a current groundwater allocation of 800 ML/yr. This is very small compared with irrigation and mining abstractions.

There are extensive irrigation abstractions in the area between Jemalong Gap and Condobolin; a portion of the allocations in this area have recently been purchased from Twynam Pastoral Company by the Commonwealth Government.

Barrick Gold's Lake Cowal mine is licensed to abstract 3650 ML/year (10 ML/d) from the Bland Creek section Lachlan palaeochannel aquifer, for dewatering and water supply purposes. Drawdown around the abstraction area is reported to be about 35 metres.

In the irrigated areas north of Lake Cowal and south-east of Condobolin, there has historically been a problem of rising groundwater levels and salinisation due to irrigation with surface water. During the late 1980s and early 1990s a groundwater mound developed beneath the Jemalong and Wyldes Plains irrigation area that effectively blocked northward flow from the Bland Creek system. In the mid 1990s additional groundwater abstraction in this area was being actively encouraged as a means of controlling this mound. Since then, low recharge, improvements in irrigation efficiency and restricted availability of surface water for irrigation have all contributed to the decline of this mound. Like the other zones making up GMA 11, this area (Zone 6) is currently under embargo for new groundwater abstraction licences.

There is little doubt that sufficient groundwater to provide reliable supplies for Condobolin is available and will continue to be available. If necessary, demand priority over irrigators could be invoked.

Lake Cargelligo

Lake Cargelligo is located 10 kilometres south of the Lachlan River, and about 560 kilometres west of Sydney. Local rainfall is about 400 mm/yr and evaporation about 1900 mm/yr. Current water demand is 350 to 400 ML/yr, and is met primarily from surface water resources, with some groundwater use. The demand is expected to grow linearly to 500 to 600 ML/yr by 2055.

The Lachlan River system is regulated primarily by Wyangala Dam. Lake Cargelligo is an off-stream storage. Currently Wyangala is at 6 per cent of capacity, while Lake Cargelligo has been at 0 per cent since early April 2009.

The quality of surface water available to the town is poor, and the town would like to source a higher proportion of its demand from groundwater.

Although there are shallow alluvial aquifers (Shepparton / Cowra Formation) containing low salinity groundwater with in a small area immediately around Lake Cargelligo, as shown on Wooley and Williams (1994), the yield of this aquifer is very low, and not adequate for town water supply. As shown on Figure C-25, obtained from the NSW Natural Resource Atlas, the closest part of the Lower Lachlan aquifer with reasonably high yields lies west of Lake Cargelligo.

Figure C-26 shows an enlargement of the eastern part of this map; with registered water bores including the town water supply bore GW039369 shown. The distance from east to west across Figure C-26 is 50 kilometres, so it can be seen that Lake Cargelligo lies about 30 kilometres from the productive part of the aquifer.

This bore obtains a supply of 50 to 60 L/s from a sand aquifer in the Shepparton Formation at a depth of 18 to 28 metres.

Although other production bores at the eastern end of the Lower Lachlan aquifer are completed predominantly in the Shepparton formation, Department of Water and Energy (DWE) observation bores have shown that the Calivil formation is present below the Shepparton in this area, and that this unit has up to 20 metres of clean sand and gravels, indicating an aquifer from which good yields could be obtained.

There is thus little doubt that adequate yields of groundwater to supply the Lake Cargelligo projected demand are available at a distance of 30 to 40 kilometres west of the town. The real issue is the long-term sustainability of this supply.

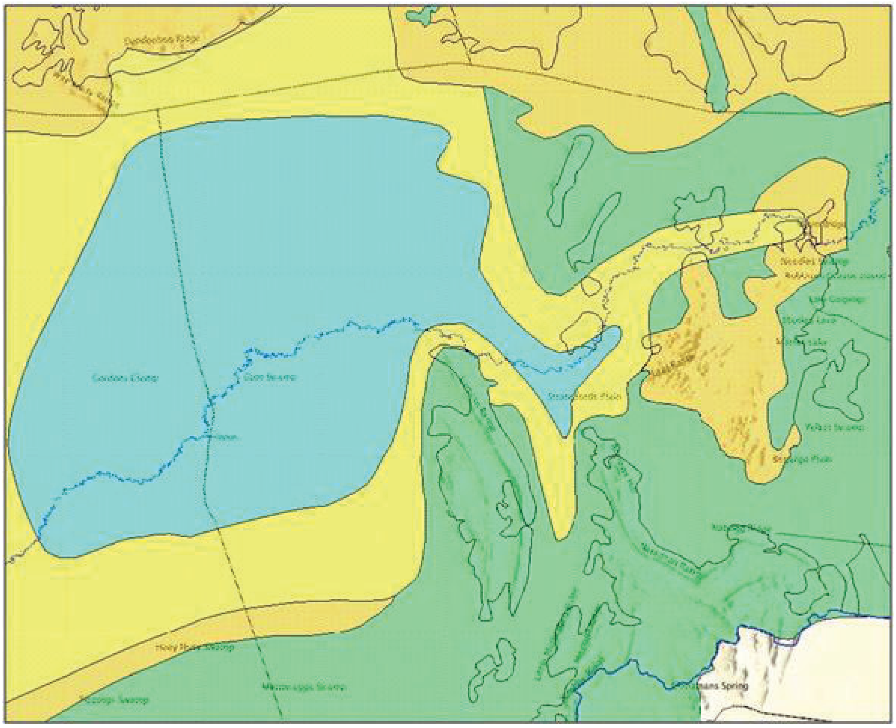


Figure C - 25: Location of Lower Lachlan Aquifer relative to Lake Cargelligo

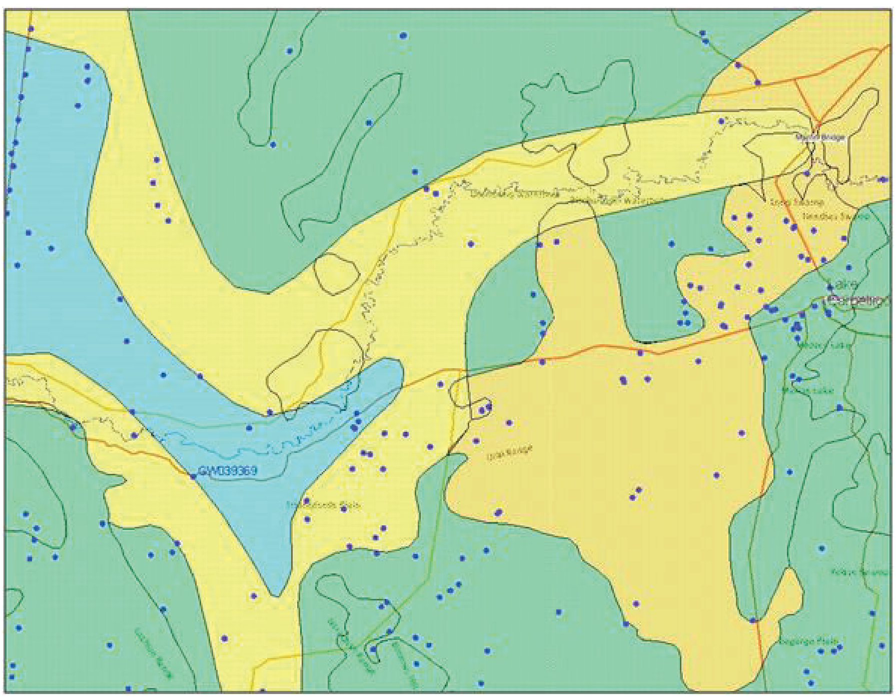


Figure C - 26: Groundwater Bores around Lake Cargelligo

Several attempts have been made to quantify recharge to the Lower Lachlan aquifers. All have had acknowledged flaws and inaccuracies. The most reliable estimate, completed by the predecessors of the DWE in 2001, is 114 GL/year. The Natural Resources Commission review (2006) indicated that this estimate was of low to moderate reliability. CMJA (2004) quantified the maximum uncertainty in this estimate (by summing the component errors) as +/- 26 per cent. Other estimates had uncertainties up to +/-77 per cent.

The DWE recharge estimate used a water balance method to estimate total recharge. The individual recharge components were estimated as shown in Table C-10.

Table C-10: Estimated Individual Recharge Components

COMPONENT	GL/YEAR	PERCENT
Rainfall infiltration	40.1	35
Irrigation leakage and drainage	6.8	6
Infiltration of overbank floods	27.1	24
Seepage from the Lachlan River	40.1	35
Total	**114.1**	**100**

Some key observations on this water balance are:

- Recharge is very strongly linked to surface water flows – infiltration of excess rainfall (rainfall-evaporation) was estimated to account for only 35 per cent of recharge, with the remainder derived from surface flows.
- Seepage from the regulated Lachlan River channel – which under normal (non extreme-drought) conditions should relatively constant from year to year, provides 35 per cent of total recharge. The river is 'uncoupled' from the aquifer, so the seepage rate is not influenced by pumping from the aquifer.
- Infrequent over-bank flood events – with return periods of 27 to 40 years – provide 27 per cent of total recharge.
- The large contribution from overbank flooding to the water balance is particularly problematic, since it is impossible to predict when, or indeed if, such floods will occur in future.

This water balance was based on data for the period since the raising of Wyangala Dam in 1971; this period included two significant flood events, in 1974 and 1990. During the first part of this period, increased flow duration in the Lachlan River as a result of river regulation by dam releases, together with the flood events, resulted in an increase in aquifer storage. More recently, storage has been in decline, with significant falls in groundwater levels – up to 8 metres – recorded in the area west of Hillston.

Trend maps produced by the Bureau of Meteorology (BOM) indicate that average rainfall in the Lachlan catchment has declined by about 3.5 mm per year since 1970, whilst mean annual temperature has increased by about 1°C over this 35-year period.

The most recent climate trend predictions from CSIRO, BOM and international agencies (CSIRO 2007) indicate a continued and accelerating warming trend, with a greater than 50 per cent probability of more than 1°C increase in mean annual temperature in inland south-east Australia over the next 25 years. Rainfall, particularly winter rainfall, is projected to continue to decline, with projections ranging from -2 to -5 per cent relative to the 1990 baseline.

The projected decrease in rainfall and increase in temperature will both negatively affect aquifer recharge, as higher temperatures will be associated with higher evaporation. However, the relationship between recharge and rainfall is indirect, because recharge is more dependent upon the duration of flows in the Lachlan River and the frequency of over-bank flood events (which are directly related to rainfall) than upon residual rainfall infiltration. This makes it particularly difficult to quantify the projected impact upon the water balance of the aquifer.

One clear indicator of the direction of the current water balance is the trend of groundwater levels (or, in the case of the Calivil Aquifer, potentiometric head). Declining levels or head indicate that more water is being pumped from the aquifer than is entering the aquifer by natural recharge processes.

DWE groundwater monitoring bores in the eastern part of the Lower Lachlan Aquifer, near Lake Cargelligo, are shown on Figure C-27.

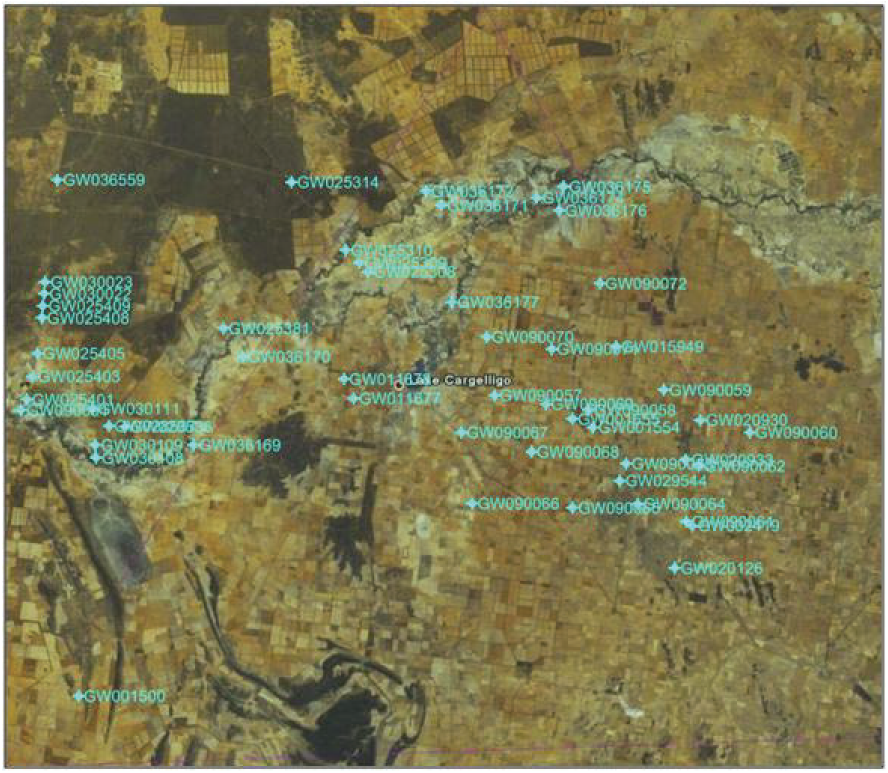
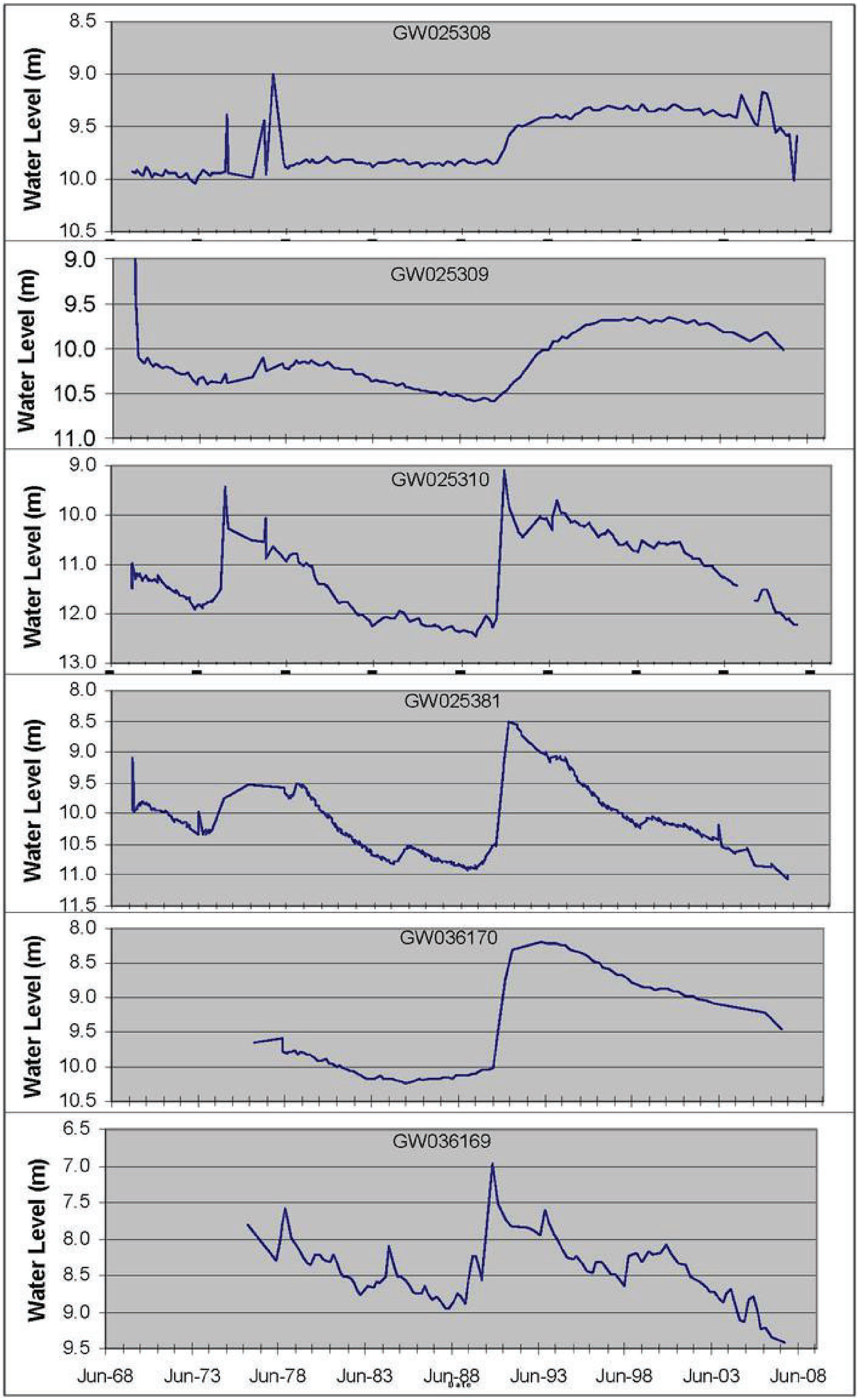


Figure C - 27: Groundwater Monitoring Boreholes

Hydrographs for a selection of these monitoring boreholes are shown on Figure C-28.


GW025308
GW025309
GW025310
GW025381
GW036170
GW036169
Water Level (m)
Jun-68
Jun-73
Jun-78
Jun-83
Jun-88
Jun-93
Jun-98
Jun-03
Jun-08

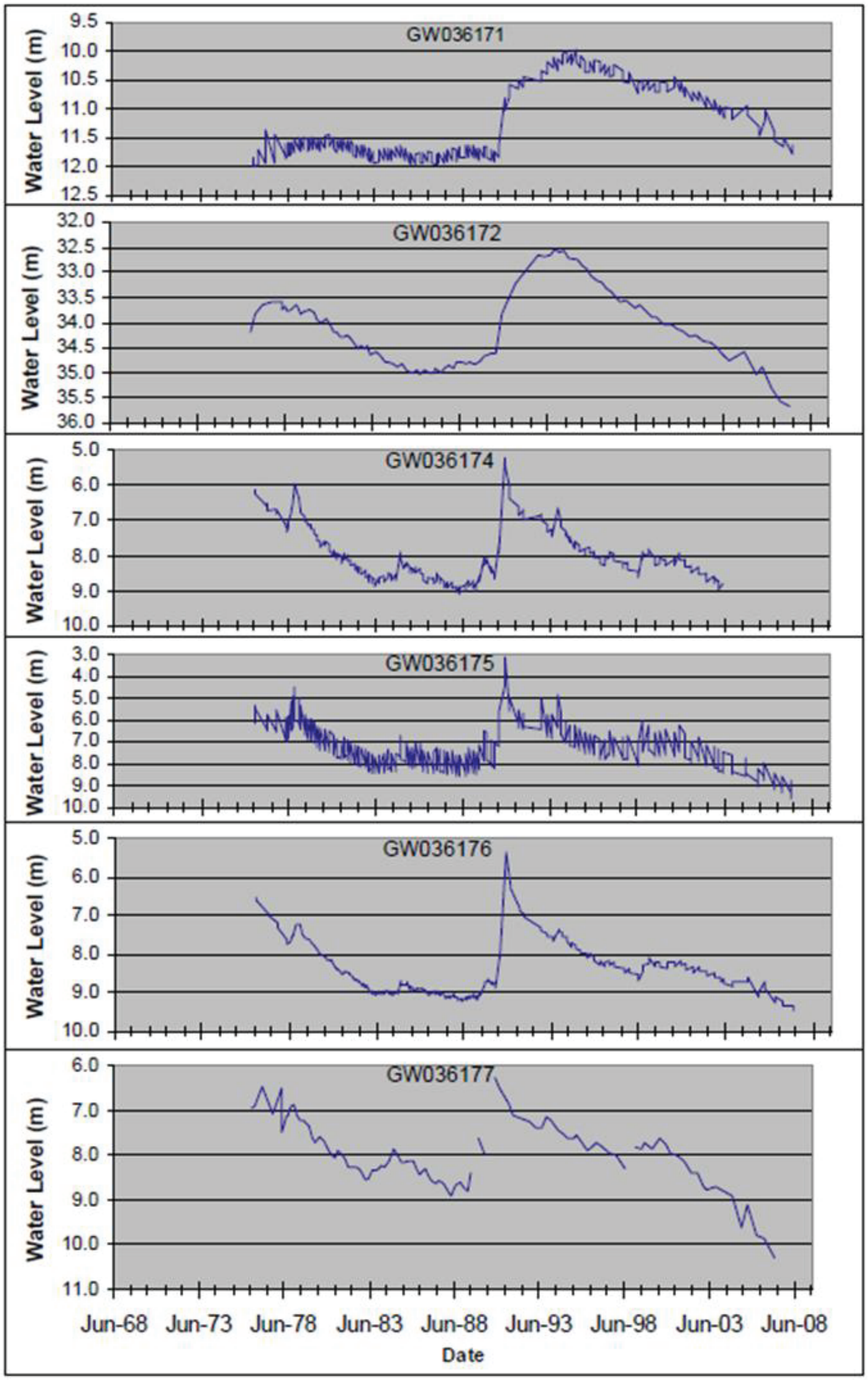


Figure C - 28: Hydrographs for Monitoring Boreholes near Lake Cargelligo

Apart from GW025308 and GW025309, which are located off the main aquifer and appear to have been affected by irrigation return flows, all the hydrographs show a consistent picture of minor recharge episodes superimposed on two main recharge events – in 1974 and 1990, corresponding to the major overbank flooding of the Lachlan River in those years. Generally, groundwater levels have been in decline since 1990, and this decline steepened in the last few years for which data were available. Given the drought that has continued since then, it is likely that groundwater levels have continued to fall. Typically, falls have been of the order of 3 to 4 metres.

The current situation suggests that the level will continue to slowly decline, with a few fluctuations, until there is a major flood. However, it is uncertain how long it will be before the next major flood, or even whether this kind of event will no longer occur. Hence, in the absence of major floods, it is difficult to determine how long the groundwater in storage will last.

Taking GW036169, at the eastern end of the Lower Lachlan Aquifer, as an example, the groundwater level has declined by about four metres in 19 years. The aquifer (Calivil) extends from about 45 to 65 metres depth, and the current potentiometric surface is at about 10 metres depth. That would imply a time-frame of about 175 years before the potentiometric surface fell below the top of the aquifer. Clearly, however, pumping bores create local cones of depression, which can interfere to create compound effects. Large capacity bores may operate with a bore drawdown of 10 to 15 metres, although this is very dependent upon local conditions and individual bore design. It is undesirable to operate a bore with the water level significantly below the top of a confined aquifer.

Thus the sustainable life of the aquifer system without flood recharge or a major reduction in discharge is likely to be considerably less than 175 years, and is probably within a 60-year planning. However, it is likely to be greater than the effective life of individual bores.

Although numerical modelling of a borefield at the eastern end of the aquifer would significantly assist the assessment of sustainability and provide much more rigour than has been possible in this discussion, the real difficulty is that it is unknown whether the average return period of major floods has been significantly extended by climate change, or if these events will simply not occur in the future.

C.9.5 THE UPPER MACQUARIE VALLEY GROUNDWATER RESOURCES

This section deals with groundwater resource availability for the CENTROC towns within the upper Macquarie Valley.

It relates to the towns of Wellington, Geurie and Nanima.

There are broad similarities between the Tertiary/Quaternary alluvial deposits that infill the major valley systems of the Murray-Darling Basin in western New South Wales. The key common characteristics are the presence of two distinct alluvial units – an older, coarser, better-sorted and generally more permeable alluvial deposit whose occurrence is generally restricted to deeper paleochannels cut in the bedrock surface (Calivil/Lachlan/Gunnedah formations) and a younger, generally less permeable but more widespread alluvial deposit that overlies the channel-fills and extends across the present-day valley floors (Shepparton/Cowra/Narrabri formations). The Department of Water and Energy (DWE) has applied the nomenclature originally developed in the Lachlan Valley (Lachlan/Cowra formations), reflecting the closer similarity with the Lachlan Valley, although others have applied the nomenclature used in the Namoi Valley (Gunnedah/Narrabri Formation) to the same systems.

In all these systems the lower part of the younger system (i.e. the lower Cowra formation) tends to consist predominantly of silts and clays, and to act as a leaky confining layer.

From a hydrogeological perspective, a key issue to appreciate is that neither of these systems are uniform, homogeneous isotropic. They are formed by sheets, lenses, strings and bars of clay, silt, sand and gravel, which may have a predominant orientation down-valley but, individually, are not laterally continuous. In other words, they are typical alluvial deposits.

The Upper Macquarie Alluvial Aquifer (Groundwater Management Unit N09) extends from Lake Burrendong to Narromine, and is an important water source for irrigation, stock and domestic purposes and water supply for a number of towns, including the major regional centre of Dubbo.

Immediately downstream of Lake Burrendong, the aquifer is a narrow and relatively thin strip of valley-floor alluvium with low transmissivity; the upstream boundary of the model will be approximately half-way between Lake Burrendong and Wellington.

Downstream of Cumboogle it becomes a substantial aquifer 2 to 4 kilometres wide and 50 to 60 metres deep. Aquifer materials include sands and gravels, and there is also a significant volume of finer grained materials, i.e. silts and clays. The aquifer continues downstream of Dubbo, trending generally west from the junction with the Talbragar paleochannel, to its nominal transition to the Lower Macquarie alluvial aquifer at Narromine.

The deepest and most permeable aquifer units are located in the paleochannels cut by the river and subsequently infilled with alluvium (the Lachlan Formation described in Section 3.1). These paleochannel aquifers do mot generally correspond to the current course of the Macquarie River.

Instantaneous yields for the Dubbo water supply bores range from 40 to 80 litres per second (L/s), or 3 to 7 megalitres per day (ML/d), and irrigation bores yielding up to 10 ML/d are known. These figures indicate the presence of highly permeable aquifer horizons. Similar yields are obtained by some irrigation bores between Dubbo and Narromine, whilst yields for the Narromine town water supply bores are a little lower.

CSIRO (2008) indicates that the current total entitlement for the Upper Macquarie Aquifer is 38.4 gigalitres per year (GL/yr), and that the 2004/05 abstraction was 37 GL. CSIRO estimated that long-term average rainfall recharge to the aquifer is 7.1 GL/yr.

The key water resource issue in the Upper Macquarie Alluvial Aquifer, as in other inland alluvial aquifers in NSW, is thus that rainfall recharge is much less than both the allocated (licensed) abstraction and current abstraction. Recharge to the alluvial aquifer is highly dependent on two other components:

- leakage from the river channel; and
- irrigation return flows derived from pumping from the river.

Thus, surface water and groundwater systems are highly connected.

In the decades since Burrendong Dam was completed in 1967, the flow and stage in the river have been regulated, and were maintained at higher average levels than those that occurred naturally. This resulted in higher rates of leakage from the river channel. Leakage from irrigated fields, also sustained by the regulated river, was a further major source of recharge.

In response, from 1970 through to the mid-1990s, groundwater levels in some parts of the Macquarie aquifers rose substantially. Due to a major increase in groundwater abstraction for irrigation since then, that trend has been reversed, and in many areas water levels are now declining.

Whilst water-sharing plans have been gazetted for the Macquarie and Cudgegong regulated rivers and the Lower Macquarie Alluvial Aquifer, there is no water-sharing plan for the Upper Macquarie Alluvial Aquifer.

With much reduced releases from Burrendong, and consequently much lower irrigation use, recharge to the groundwater system by river leakage and irrigation returns must have fallen, and recharge is now likely to be significantly less than abstraction.

Clearly, the long-term sustainability of groundwater abstraction from the Macquarie alluvium will be highly dependent upon the extent to which surface water flows can, in future, be maintained by release from Lake Burrendong, or the implementation of alternative means to supplement aquifer recharge.

Water Supply Issues

Dubbo and Narromine obtain part or all of their municipal water supply from groundwater.

Dubbo obtains part of its water supply directly from the Macquarie River, a major regulated river, and part from alluvial aquifers that are strongly associated with the same river. That association is both geological – in that the aquifers were originally deposited by the river or its prior streams – and hydrological, because water in the aquifer is substantially replenished by water that leaks from the river, or is pumped from the river and then seeps into the aquifer from irrigation channels and irrigated fields.

Like other inland cities – Parkes in the Lachlan Valley is a close parallel - water resources in Dubbo are stressed because:

- surface water allocations have been cut back due to low levels in river-regulation reservoirs; and
- there is competition for the available groundwater resources from other abstractors (principally irrigators) and groundwater resources have been regionally over-allocated or are locally stressed by a concentration of abstractors.

The challenges facing these cities are to:

- find or reallocate water to meet critical short-term requirements;
- develop more sophisticated strategies to manage the available resources for long-term sustainability;
- balance the need to provide water to meet critical human requirements with the need to minimise damage to industries such as agriculture and mining that sustain the local and regional economy; and
- cope with major uncertainties concerning potential long-term reductions in water availability due to climate change.

Climate Change

CSIRO (2008) indicates that under the best-estimate 2030 climate, there would be an overall 8 per cent reduction in water availability in the Macquarie and a 9 per cent reduction in end-of-system flows. However, when extreme cases are considered, the outcome is very uncertain.

Under the dry extreme for 2030 there would be a 25 per cent reduction in overall water availability and a 28 per cent reduction in end-of-system flows, whilst the wet extreme indicates corresponding increases of 25 per cent and 41 per cent.

Previous Studies and Available Data

The following previous groundwater investigations in the upper Macquarie area are known.

- Mackie-Martin 1986: AQUIFEM-1 Model of the upper Macquarie alluvial aquifer from Cumboogle to the Talbragar confluence.
- O'Neill 1993: Geophysical investigations.
- C. M. Jewell & Associates Pty Ltd: numerous hydrogeological and hydrogeophysical studies focussed on the Macquarie and Talbragar valleys downstream of Dubbo.
- Parsons Brinckerhoff 2004: MODFLOW model of the lower Talbragar/Macquarie aquifers.
- NSW Department of Natural Resources: Lower Macquarie alluvial aquifer groundwater model.
- CSIRO 2008: Water Availability in the Macquarie–Castlereagh – a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yield Project.
- Current Dubbo City Council groundwater model.

Groundwater Prospects

The Macquarie alluvial aquifer between Wellington and Geurie is both narrow and relatively shallow, but provides some prospects for small to medium scale groundwater supply.

In the reach the Macquarie River gains water from the alluvial aquifers.

As indicated in Figure C-29, there are a fair number of existing bores in the area. These provide low to moderate yields of good-quality groundwater, typically from less than 30 metres depth.

It should be possible to meet at least a proportion of the anticipated future demand utilising groundwater from the shallow alluvial aquifer.

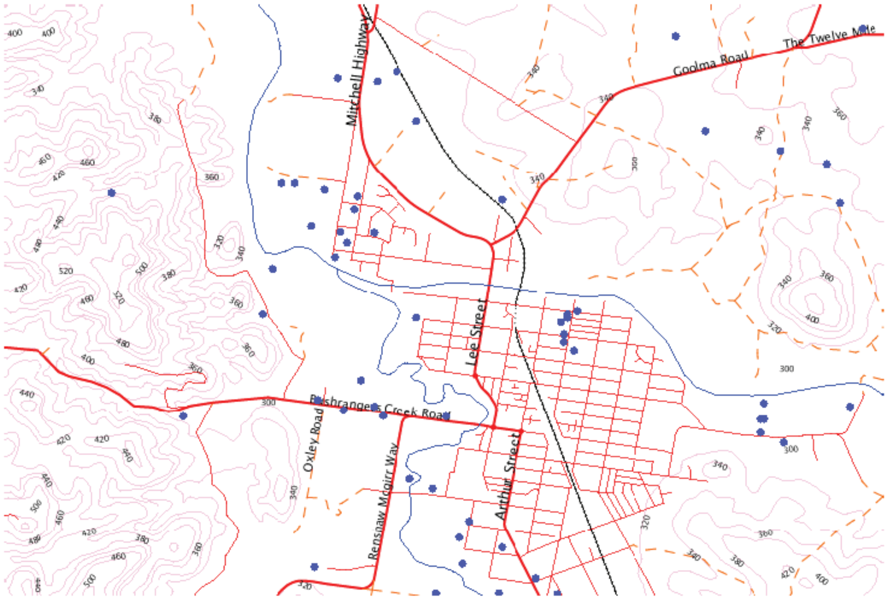


Figure C - 29: Existing Bores in Wellington

C.9.6 ORANGE BASALT GROUNDWATER RESOURCES

This section deals with groundwater resource availability for the CENTROC towns within the Orange Basalt.

The volcanic-rock aquifers (groundwater sources) of the Orange region are often high yielding, but the yield is variable. Their storage depends upon the primary and secondary porosity of the Orange basalts, which are enhanced along fracture and volcanic flow boundaries. There is currently an embargo on new groundwater extraction licences for the Orange basalts, covering all land within Groundwater Management Area 801 (GWMA801). However, boreholes for town or village water supply purposes are exempt.

The distribution and characteristics of groundwater in the Orange region are largely controlled by theregion's geological evolution. This evolution is dominated by the formation of the Lachlan Fold Belt (LFB), which extends within the Murray–Darling Basin from central and south-eastern New South Wales to central and eastern Victoria. The LFB is a composite orogenic belt composed of Early Cambrian to Early Devonian pre-cratonic complexes, and comprises three major lithotectonic assemblages: the greenstone and greenschist facies of Cambrian age; turbidite fan deposits laid down during the Ordovician and Silurian; and finally the complex series of mid Silurian to early Carboniferous plutonic intrusions. Late-stage Tertiary Volcanics, which cover the study area, form part of the extensive series of basaltic and associated extrusive rock types that belong to the larger eastern Australian intraplate volcanic belt, which stretches 4400 kilometres from the Torres Strait, along the eastern highlands of Australia, and into Tasmania.

The Tertiary basalts and trachytes of the Orange Province include the Canobolas Volcanic Complex (CVC). The basalts and trachytes of the CVC cover an extensive area, with outcrops centred on Mount Canobolas and extending to Molong, Orange, Cowra and Blayney. Mount Canobolas is an extinct shield volcano; it last erupted around 11 to 13 million years ago, from around 30 vents within about 30 kilometres of the current summit. It is thought that the main vent continued to erupt for the entire life of the volcano, whilst most of the other vents were only active for short periods.

To the south of Orange, as shown on Figure C-30, the basalts form an extensive series of lava plains resulting from the outpouring of several eruptions from Mount Canobolas during the Tertiary Period (the Orange basalts). The basalts, which radiate outwards from the now dissected volcanic centre, consist mostly of trachyte and alkali rhyolite, with common occurrences of olivine basalt and porphyritic andesine basalt layers throughout the unit. The olivine basalt is more widespread than the trachyte and rhyolite units. Its mineralogy is consistent throughout the district, and it is commonly used as a marker unit for the identification of basalt units in the Orange Province. Scoriaceous and vesicular horizons have also been noted within the volcanic pile, although they are rare.

Beneath the Orange basalts in the study region are Ordovician units, including the Oakdale Formation, which in turn is a member of the Cabonne Group. The Oakdale Formation includes mafic volcanic sandstone, basalt, siltstone, black shale, chert, breccia and conglomerate, and outcrops to the north and south of the Orange basalt.

Geological units in the area are thought to have undergone multiple deformation events and coolinginduced fracturing. Regional jointing and structural patterns would have been adopted into the overlying basalts, contributing to the fractured nature of the unit. Most of the fractures within the basalt would have alignments consistent with those of the major regional structural orientations.

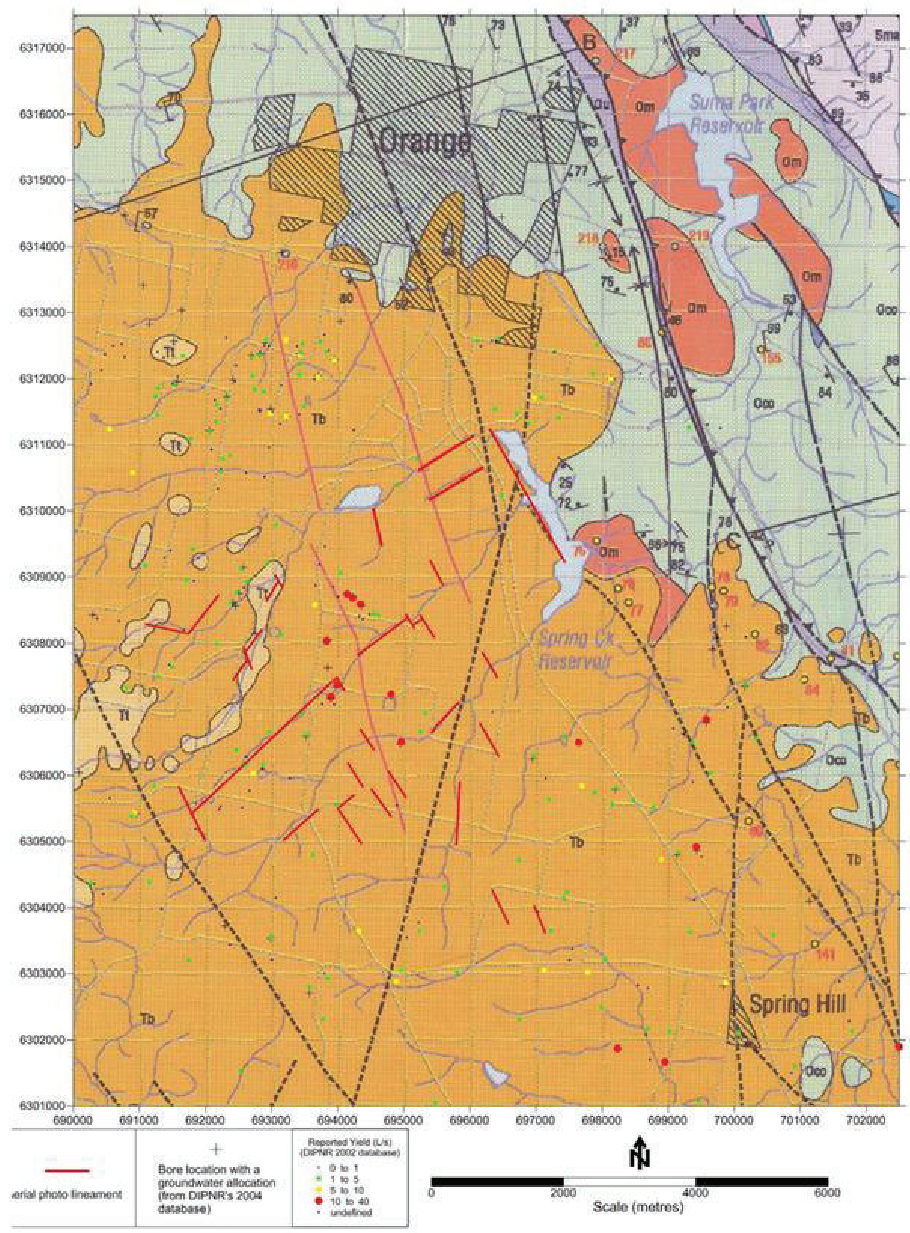


Figure C - 30: Orange

The geological evolution described above has resulted in a groundwater flow pattern that is controlled by the Ordovician palaeodrainage patterns, the Orange basalt flow patterns, and the regional and local fracture and discontinuity orientations.

Groundwater resources are predominantly associated with the numerous basalt units that comprise the Orange basalts, hosted by secondary porosity features such as joints, voids, gravel units and fractures, whilst minor flows associated with weathered horizons and lithological contrasts are thought to contribute to the movement of groundwater within perched horizons, particularly within the weathered profile of the rock mass.

The primary source of groundwater recharge in the area is the infiltration of soil-water (derived from excess precipitation) through the subsoil and unsaturated country rock to the ambient water table. Within the fractured rock aquifer, the water table is not as precisely defined as for granular aquifer materials, and is generally defined as the depth to which interconnecting joints, voids and fractures are water-filled; hence features such as the connectivity of a series of fractures both within and between differing geological units will greatly influence the characteristics of the aquifer.

The interconnected fractures act as an equivalent porous medium in distributing water pressure throughout the fractured rock aquifer. Thus, the depth of saturation measured in a set of fractures will reflect the prevailing water pressure in the vicinity of the measurement, and cannot be assumed for the entire aquifer.

In general, the shallow parts of such aquifers tend to have the highest hydraulic conductivities. The principal exceptions occur where there is lithologically controlled porosity (such as in beds of soft and hard shales), or fracturing caused by deepest structural features such as faults.

Throughout the LFB, the Orange basalts occur as a late-stage capping layer. They are generally favourable areas for boreholes, and are also known for their association with useful springs, both within the unit and at its margins. The smaller size of the basalts and the higher relief renders these boreholes more prone to climatic events, and particularly to prolonged dry periods. They are therefore more susceptible to declining water levels and yields, but also can experience much faster recharge and recovery rates during wet climatic events, usually with a marked impact on local groundwaterdependent ecosystems dependent upon aquifer discharges.

Borehole depths within the basalts vary considerably, from 10 to 140 metres, depending on the area and the topography. Yields obtained from the basalts during favourable climatic regimes are generally higher than those obtained from the granitic and metamorphic terrains within the LFB. Yields up to 30 litres per second (L/s) have been noted in the vicinity of Mount Canobolas, although these boreholes have shown diminishing yields and water tables during long-term pumping.

Groundwater Utilisation

The Orange basalt aquifer is used extensively for irrigation and stock and domestic purposes, and groundwater is also used for municipal water supplies.

The National Land and Water Resources Audit (2000) estimated the sustainable yield of the Orange Basalt at 17,000 megalitres per year (ML/yr). It also estimated the groundwater use at 6400 ML/yr (over an undefined period), and groundwater entitlements at 7684 ML/yr (over a similarly undefined period). The Audit ranked the recharge estimate as Category ‘D’, signifying data that is ‘derived without investigation data’. The figures are estimated ‘from data in nearby catchments, or extrapolated/interpolated from any available data’. The estimated accuracy is ±50 per cent.

The aquifer risk report produced by the NSW Department of Land and Water Conservation (1998) lists GWMA801 as a ‘medium risk’ aquifer. The criteria against which the Orange basalt scored the highest risk ratings are as follows:

- local interference effects (the potential for closely spaced boreholes to impact upon each other);
- land use threats (from urban development, agriculture, and industry);
- system flows (the size of the groundwater system);
- groundwater-dependent ecosystems (the potential for surface ecosystems to be contaminated by deteriorated groundwater quality, and the potential for water losses from over-extraction); and
- licensed entitlements compared with sustainable yield (an indicator of the risk of overextraction of the groundwater).

On 23 May 2003, in an order issued under Section 113A of the Water Act 1912, the NSW Department of Sustainable Natural Resources proclaimed an embargo on further applications for sub-surface water licences in the Orange Basalt Fractured Rock Water Shortage Zone (GWMA 801).

On 19 December 2008, consistent with an agreed national policy, this embargo was replaced with a comprehensive embargo on all new groundwater abstraction licences on a number of GWMAs, including GWMA 801, within the Murray-Darling Basin.

Licences for public water supply are exempt.

Resource Sustainability

Groundwater in the Orange basalt aquifers is not static, but flows radially away from 'recharge centres' and, usually, discharges to the surface drainage system at the edge of the basalt aquifers. The flow rate within individual aquifers depends on their permeability and on the local hydraulic gradient, which is the average difference in pressure per kilometre.

There are also vertical flows within and between aquifers, and, in a similar manner, the direction and quantity of vertical flow depends upon the vertical hydraulic gradient and average vertical permeability.

The natural inflows by which aquifers are replenished are known as recharge. Recharge to the aquifers occurs by infiltration of rainfall and to a lesser extent by seepage of surface water through the beds of stream channels, leakage and deep drainage of irrigation water.

Discharge from the aquifers may occur by pumping, by evapotranspiration, and by natural outflows to creeks/rivers, lakes, springs and swamps.

In the long term, there must be a balance between the recharge to an aquifer system and the discharge from it. In the short term, however, imbalances between recharge and discharge are buffered by the storage capacity of the aquifer. In other words, an excess of discharge over recharge is met by water released from storage in the aquifer, while excess recharge is accommodated in increased aquifer storage. Changes in the volume of water stored are evidenced by changes in aquifer pressure, or the water level measured in boreholes that are open to the aquifer. The relative volume of water stored or released in response to a change in water level is a fundamental property of a particular aquifer, and depends upon the aquifer's effective porosity and elasticity, as well as the extent to which the aquifer is confined by overlying low-permeability layers.

This ability to store water (without evaporation loss) and thus to some extent 'even out' year-to-year fluctuations in recharge – in turn related to fluctuations in rainfall – is one of the great advantages of groundwater over surface water as a source for water supply. Thus, groundwater supplies are intrinsically less volatile and more dependable than surface water supplies.

The period over which aquifer storage can act as a buffer must clearly depend upon the volume of water in storage relative to the average excess pumping rate. Although the volume of groundwater in storage cannot be calculated with accuracy –there are too many variables affecting aquifer thickness, composition and porosity – total storage in an aquifer system such as the Orange Basalts is likely to be equivalent to several years of use. One issue that must be recognised in relation to the Orange Basalts is that because much of the groundwater is transmitted through fracture systems and relatively thin scoriaceous zones and interflow horizons, the effective porosity is low in comparison with granular aquifer systems.

There are also some important caveats. If a long-term imbalance between recharge and discharge develops, then the hydraulic gradient within the aquifer will adjust itself so that discharge is again balanced by recharge. Under natural conditions, this might occur in response to a change in recharge due to a climatic shift. With less recharge, the groundwater level in the recharge areas would decline, resulting in a lower hydraulic gradient between recharge and discharge areas, less driving force for groundwater flow, and ultimately a reduction in groundwater discharge, so that this is again in balance with the reduced recharge. Under pumped discharge conditions, the imbalance could be due to increased pumping, reduced recharge, or both. The most obvious effect would be a decline in groundwater level, leading to reduced bore yields and higher pumping costs. Eventually, bores would begin to run dry.

Recharge Estimates

CMJA is not aware of any previous rigorous attempt to quantify recharge to the Orange Basalts as a whole, and this has not been done as part of this program. In the context of this study it would make more sense to quantify recharge and discharge in the sub-catchments relevant to individual bores. It is intended to carry out this work in the later stages of this study, since it will, in part, be dependent upon bore testing results.

Recharge estimates are generally (and necessarily) based on historical meteorological data, either directly, or through calibration of groundwater models that are themselves based on historical meteorological data. This approach has limitations during a time of changing climate, and it is important to try to understand the potential impacts of these limitations.

Trend maps produced by the Bureau of Meteorology (BOM) indicate that average rainfall in central western NSW catchments has declined by about 3.5 millimetres per year since 1970, whilst mean annual temperature has increased by about 1° C over this 35-year period.

The most recent climate trend predictions from CSIRO, BOM and international agencies (CSIRO 2007) indicate a continued and accelerating warming trend, with a greater than 50 per cent probability of more than 1° C increase in mean annual temperature in inland south-east Australia over the next 25 years. Rainfall, particularly winter rainfall, is projected to continue to decline, with projections ranging from –2 to –5 per cent relative to the 1990 baseline. The projected decrease in rainfall and increase in temperature will both negatively affect aquifer recharge, as higher temperatures will be associated with higher evaporation. It would be sensible to expect average recharge to decline by at least 10 per cent.

Aquifer Management

Apart from the inevitable uncertainty in estimates of the long-term recharge rate, there are other sound technical and environmental reasons for not allowing deep and prolonged drawdown of an aquifer. These include the likelihood that the water level will fall below the pump intake – or even the bottom – of the shallowest bores in the area (often domestic and stock bores), and the risk of loss of baseflow in surface streams.

Other issues that affect granular aquifers - such as reduced pore-pressure allowing consolidation of the aquifer and permanent loss of storage capacity, and the risk that saline groundwater will be drawn into productive aquifers - are less of a concern in the Orange Basalts. For these reasons, DWE, most groundwater professionals and most groundwater users recognise that aquifer management needs to be conservative. Permitted long-term abstraction should not exceed the long-term average recharge rate of the aquifer less any allowance for maintenance of ecosystems. DWE defines this figure as the sustainable yield or long-term average extraction limit. Because of the uncertainty inherent in estimating the recharge rate, the sustainable yield needs to be set conservatively.

Whilst public water supply is given the highest priority in the allocation of water resources, it is still necessary to consider the sustainability of the system as a whole.

Options for Improving Sustainability

Because the Orange Basalt Aquifer is already heavily used, and has been declared a water shortage area, it is likely that use of the aquifer for town water supply would be at the expense of existing (primarily agricultural) users. It may be necessary to reduce the allocations of such users. Whilst this can and would be done in emergency, it is appropriate to look also at groundwater management options and technologies that may enhance the long-term sustainability of the resource, providing more water for all users. One such option is Aquifer Storage and Recovery (ASR).

Exploration Targets

In 2004 CMJA identified a number of groundwater exploration targets for Orange City Council. In 2008 and 2009, a number of these targets have been drilled, with mixed success. Unfortunately, where reasonable yields have been found, there has been strong community opposition to groundwater abstraction. Groundwater assessment in the area is continuing, in conjunction with the stormwater harvesting and management project.

C.9.7 SUMMARY

The key outcomes of the hydrogeological assessment for the Centroc region are summarised in Table C-11.

Table C-11: Groundwater Potential for Towns

TOWN NAME	POPULATION 2006	WATER UTILITY	CURRENT PRIMARY TYPE OF SUPPLY	DSS MODEL	PROSPECTS	POTENTIAL AQUIFER	DEPTH (M)	DISTANCE (KM)	POTENTIAL INDIVIDUAL BORE YIELD (L/S)	LIKELY SUSTAINABLE AQUIFER YIELD (GL/YR)	CURRENT ALLOCATION STATUS	NOTES
Bathurst	28,994	Bathurst	Surface Water	Bathurst	Possible	Macquarie alluvial deposits	20 to 30	<5	1 to 2	1000		Alluvial deposits thin and generally low yielding
Perthville	450	Bathurst	Surface Water	Bathurst	Possible	Macquarie alluvial deposits	20 to 30	<8	1 to 2	1000		
Blayney	2,743	Central Tablelands	Surface Water	Blayney-Caroar	Possible	Belubula alluvial aquifer	5 to 50	>30	20	6000	grossly overallocated (>300%)	The productive part of the Belubula aquifer is located well downstream from these towns.
Millthorpe	726	Central Tablelands	Surface Water	Blayney-Caroar	Possible	Orange basalt	20 to 50	<5	10	17	approximately 50%	
Carcoar	216	Central Tablelands	Surface Water	Blayney-Caroar	Possible	Belubula alluvial aquifer	5 to 50	>18	20	6	grossly overallocated (>300%)	
Lyndhurst	257	Central Tablelands	Surface Water	Blayney-Caroar	Possible	Belubula alluvial aquifer	5 to 50	>15	20	6	grossly overallocated (>300%)	
Mandurama	149	Central Tablelands	Surface Water	Blayney-Caroar	Possible	Belubula alluvial aquifer	5 to 50	>16	20	6	grossly overallocated (>300%)	
Garland	65	Garland	Surface Water	Blayney-Caroar	Possible	Belubula alluvial aquifer	5 to 50	>18	20	6	grossly overallocated (>300%)	
Boorowa	1,071	Boorowa	Surface Water	Boorowa	Poor	Lachlan fold belt fractured rocks	up to 60	<10	<1	N/A	N/A	Located on productive part of the Belubula aquifer
Canowindra	1,500	Central Tablelands	Surface Water	Canowindra	Good	Belubula alluvial aquifer	5 to 50	<2	20	6	grossly overallocated (>300%)	
Woodstock	263	Central Tablelands	Surface Water	Canowindra	Good	Belubula alluvial aquifer	5 to 50	>18	20	6	grossly overallocated (>300%)	
Condobolin	2,849	Condobolin	Surface Water	Condobolin	Good	Upper Lachlan alluvial aquifers	50 to 120	<5	50	200	fully allocated	
Bendick Murrell	45	Cowra	Surface Water	Cowra-Koorawatha	Poor	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Brundah	0	Cowra	Surface Water	Cowra-Koorawatha	Poor	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Cowra	8,432	Cowra	Surface Water	Cowra-Koorawatha	Good	Upper Lachlan alluvial aquifers	20 to 50	<5	10 to 20	200	fully allocated	
Greenethorpe	30	Cowra	Surface Water	Cowra-Koorawatha	Poor	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Koorawatha	258	Cowra	Surface Water	Cowra-Koorawatha	Poor	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Mogongong	0	Cowra	Surface Water	Cowra-Koorawatha	Poor	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Wattamondara	30	Cowra	Surface Water	Cowra-Koorawatha	Poor	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Crookwell	1,993	Crookwell	Combined	Crookwell	Good	Tertiary basalts	20 to 40	<5	2 to 10	0.3 to 0.5	fully allocated	
Cargo	280	Central Tablelands	Surface Water	Cudal/Cargo/ Manildra	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Cudal	389	Central Tablelands	Surface Water	Cudal/Cargo/ Manildra	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Manildra	503	Central Tablelands	Surface Water	Cudal/Cargo/ Manildra	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Cumnock	288	Cumnock	Surface Water	Cumnock-Yeoval	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Yeoval	292	Yeoval	Surface Water	Cumnock-Yeoval	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Forbes	6,954	Forbes	Surface Water	Forbes	Good	Upper Lachlan alluvial aquifers	50 to 120	<5	100	200	fully allocated	
Albert	60	Tottenham	Surface Water	Forbes	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	Experience has been that adequate groundwater supplies are very hard to locate south of the Bogan River. The Lachlan fold belt rocks are generally tight, with little groundwater. Small supplies have been obtained from alluvial deposits. Prospects from Mesozoic sandstones north of the Bogan are better.
Tottenham	343	Tottenham	Surface Water	Forbes	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Bogan Gate	125	Trundle	Surface Water	Forbes	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Gunningbland	40	Trundle	Surface Water	Forbes	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Trundle	379	Trundle	Surface Water	Forbes	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Tullamore	211	Trundle	Surface Water	Forbes	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Eugowra	535	Central Tablelands	Surface Water	Gooloogong-Eugowra	Good	Upper Lachlan alluvial aquifers	50 to 120	10	50	200	fully allocated	
Gooloogong	169	Central Tablelands	Surface Water	Gooloogong-Eugowra	Good	Upper Lachlan alluvial aquifers	50 to 120	<5	50	200	fully allocated	
Grenfell	1,993	Central Tablelands	Surface Water	Grenfell	Poor	Lachlan fold belt fractured rocks	<60	N/A	<0.5	N/A	N/A	
Lake Cargelligo	1,148	Lake Cargelligo	Surface Water	Lake Cargelligo	Good	Lower Lachlan alluvial aquifers	30	30	60	80	over allocated	Main lower Lachlan aquifer 30 km west
Murrin Bridge	102	Lake Cargelligo	Surface Water	Lake Cargelligo	Good	Lower Lachlan alluvial aquifers	30	<5	5	80	over allocated	Reasonable prospects for small local supply
Tullibigeal	132	Tullibigeal	Surface Water	Lake Cargelligo	Good	Lower Lachlan alluvial aquifers	30	50	60	80	over allocated	No prospect of local supply - need to go to main aquifer
Lithgow	11,298	Lithgow (Farmers Ck)	Surface Water	Lithgow	Poor	Berry Formation / Illawarra CM	N/A	N/A	N/A	N/A	N/A	Generally saline
Molong	1,569	Molong	Surface Water	Molong	Poor	Lachlan fold belt fractured rocks	<60	N/A	<2	N/A	N/A	
		Molong	Surface Water	Molong	Possible	Molong Creek alluvium	<60	<1	5	0.1	N/A	Potential for useful supplies from alluvial deposits

TOWN NAME	POPULATION 2006	WATER UTILITY	CURRENT PRIMARY TYPE OF SUPPLY	DSS MODEL	PROSPECTS	POTENTIAL AQUIFER	DEPTH (M)	DISTANCE (KM)	POTENTIAL INDIVIDUAL BORE YIELD (L/S)	LIKELY SUSTAINABLE AQUIFER YIELD (GL/YR)	CURRENT ALLOCATION STATUS	NOTES
Galong	122	Harden	Surface Water	Murrumburrah (Harden)	Possible	Young Granite	20	<2	<1 to 5	15.5	over-allocated (116%)	
Murrumburrah (Harden)	1,997	Harden	Surface Water	Murrumburrah (Harden)	Possible	Young Granite	20	<2	<1 to 5	15.5	over-allocated (116%)	Located away from known aquifer zone
Jugiong	120	Jugiong	Surface Water	Murrumburrah (Harden)	Good	Murrumbidgee alluvium	30	<2	20	10	35%	
		Jugiong	Surface Water	Murrumburrah (Harden)	Possible	Young Granite	20	<2	<1 to 5	15.5	over-allocated (116%)	
Wombat	130	Jugiong	Surface Water	Murrumburrah (Harden)	Possible	Young Granite	20	<2	<1 to 5	15.5	over-allocated (116%)	
Oberon	2,474	Oberon	Surface Water	Oberon	Possible	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	Some prospect of small local supply based on CMJA study
Clifton Grove	621	Orange	Surface Water	Orange	Possible	Lachlan fold belt fractured rocks	<60	N/A	<1	N/A	N/A	
Orange	31,544	Orange	Surface Water	Orange	Possible	Orange basalt	20 to 50	<5	10	17	approximately 50%	
Cookamidgera	30	Parkes	Combined	Parkes + Peak Hill	Good	Upper Lachlan alluvial aquifers	50 to 120	30	100	200	fully allocated	
Parkes	9,826	Parkes	Combined	Parkes + Peak Hill	Good	Upper Lachlan alluvial aquifers	50 to 120	30	100	200	fully allocated	
Alectown	25	Parkes	Combined	Parkes + Peak Hill	Good	Upper Lachlan alluvial aquifers	50 to 120	30	100	200	fully allocated	
Peak Hill	945	Parkes	Combined	Parkes + Peak Hill	Good	Upper Lachlan alluvial aquifers	50 to 120	30	100	200	fully allocated	
Geurie	465	Geurie	Surface Water	Wellington-Geurie	Possible	Upper Macquarie alluvial aquifer	10 to 30	<10	5 to 30	30	over-allocated (150%)	
Nanima	80	Nanima	Surface Water	Wellington-Geurie	Possible	Upper Macquarie alluvial aquifer	10 to 30	<6	5 to 30	30	over-allocated (150%)	
Wellington	4,660	Wellington	Surface Water	Wellington-Geurie	Possible	Upper Macquarie alluvial aquifer	10 to 30	<2	5 to 30	30	over-allocated (150%)	
Young	7,140	Young	Surface Water	Young	Possible	Young granite	20	<2	<1 to 5	15.5	over-allocated (116%)	Located within known aquifer zone

Notes:

Prospects: the chance of locating adequate individual bore yield for town supply, ignoring competition, licencing, embargo and allocation issues.

Sustainable yield: portion of the long term average annual recharge which can be extracted each year without causing unacceptable impacts on the environment or other groundwater users

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