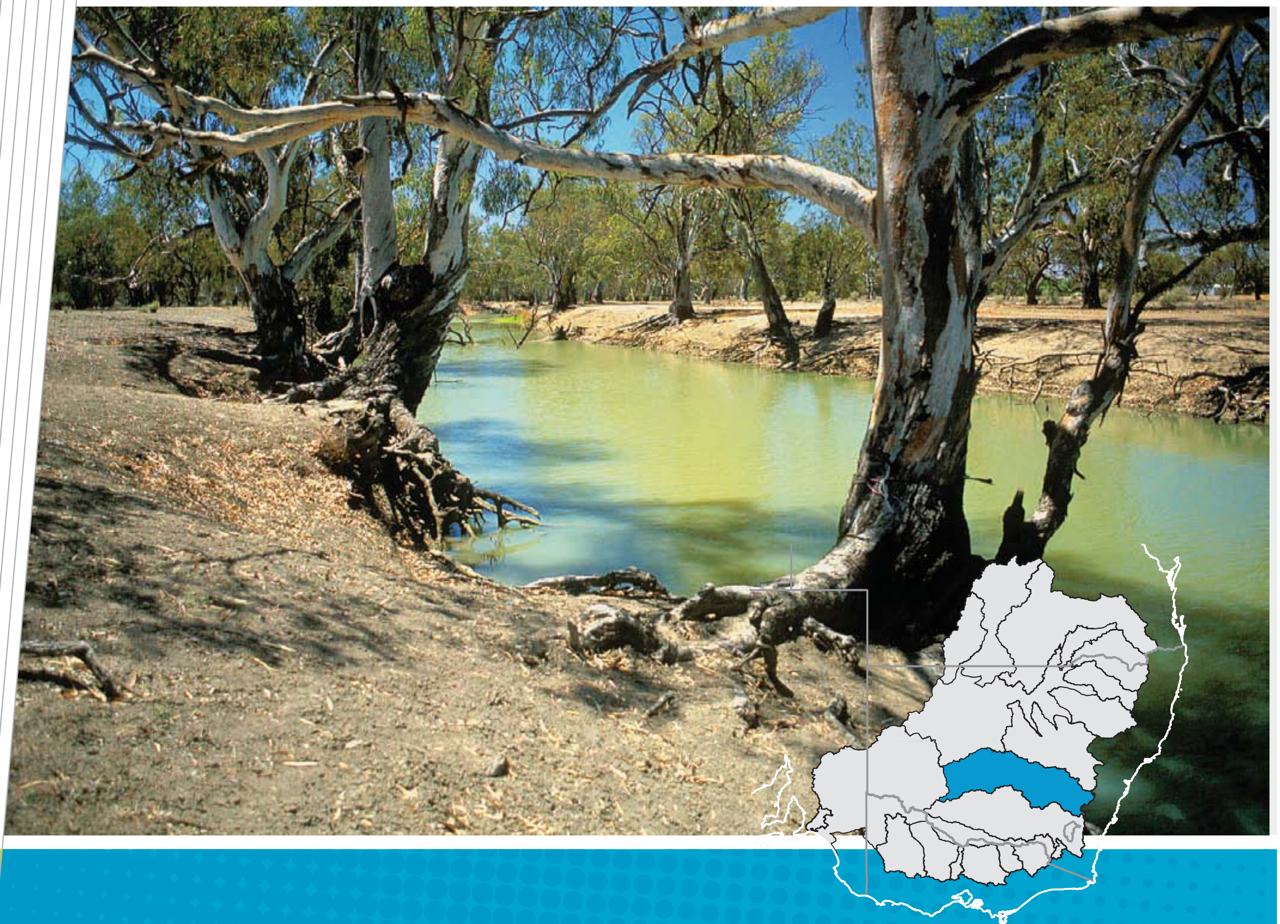

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Water Availability in the Lachlan

A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project

March 2008

Murray-Darling Basin Sustainable Yields Project acknowledgments

The Murray-Darling Basin Sustainable Yields project is being undertaken by CSIRO under the Australian Government's Raising National Water Standards Program, administered by the National Water Commission. Important aspects of the work were undertaken by Sinclair Knight Merz; Resource & Environmental Management Pty Ltd; Department of Water and Energy (New South Wales); Department of Natural Resources and Water (Queensland); Murray-Darling Basin Commission; Department of Water, Land and Biodiversity Conservation (South Australia); Bureau of Rural Sciences; Salient Solutions Australia Pty Ltd; eWater Cooperative Research Centre; University of Melbourne; Webb, McKeown and Associates Pty Ltd; and several individual sub-contractors.

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Photo on cover Lachlan River, Hillston, NSW, CSIRO Land and Water.

Director's Foreword

Following the November 2006 Summit on the Southern Murray-Darling Basin, the then Prime Minister and Murray-Darling Basin state Premiers commissioned CSIRO to report on sustainable yields of surface and groundwater systems within the Murray-Darling Basin. This report from the CSIRO Murray-Darling Basin Sustainable Yields Project details the assessments for one of 18 regions that encompass the Basin.

The CSIRO Murray-Darling Basin Sustainable Yields Project is providing critical information on current and likely future water availability. This information will help governments, industry and communities consider the environmental, social and economic aspects of the sustainable use and management of the precious water assets of the Murray-Darling Basin.

The project is the first rigorous attempt worldwide to estimate the impacts of catchment development, changing groundwater extraction, climate variability and anticipated climate change, on water resources at a basin-scale, explicitly considering the connectivity of surface and groundwater systems. To do this, we are undertaking the most comprehensive hydrologic modelling ever attempted for the entire Basin, using rainfall-runoff models, groundwater recharge models, river system models and groundwater models, and considering all upstream-downstream and surface-subsurface connections. We are complementing this work with detailed surface water accounting across the Basin – never before has surface water accounting been done in such detail in Australia, over such a large area, and integrating so many different data sources.

To deliver on the project CSIRO is drawing on the scientific leadership and technical expertise of national and state government agencies in Queensland, New South Wales, Victoria, the Australian Capital Territory and South Australia, as well as the Murray-Darling Basin Commission and Australia's leading industry consultants. The project is dependent on the cooperative participation of over 15 government and private sector organisations contributing over 100 individuals. The project has established a comprehensive but efficient process of internal and external quality assurance on all the work performed and all the results delivered, including advice from senior academic, industry and government experts.

The project is led by the Water for a Healthy Country Flagship, a CSIRO-led research initiative which was set up to deliver the science required for sustainable management of water resources in Australia. The Flagship goal is to achieve a tenfold increase in the social, economic and environmental benefits from water by 2025. By building the capacity and capability required to deliver on this ambitious goal, the Flagship is ideally positioned to accept the challenge presented by this complex integrative project.

CSIRO has given the Murray-Darling Basin Sustainable Yields Project its highest priority. It is in that context that I am very pleased and proud to commend this report to the Australian Government.

Dr Tom Hatton

Director, Water for a Healthy Country

National Research Flagships

CSIRO

Executive Summary

Background

The CSIRO Murray-Darling Basin Sustainable Yields Project is providing governments with a robust estimate of water availability for the entire Murray-Darling Basin (MDB) on an individual catchment and aquifer basis, taking into account climate change and other risks. This report describes the assessment undertaken for the Lachlan region. While key aspects of the assessment and modelling methods used in the project are contained in this report, fuller methodological descriptions will be provided in a series of project technical reports.

The Lachlan region is in central western NSW and covers 8 percent of the total area of the MDB. The region is based around the virtually terminal Lachlan River. The population is around 90,000 or 4.7 percent of the MDB total, concentrated in the major centres of Cowra, Young, Parkes, Forbes, West Wyalong and Condobolin. The dominant land use is dryland pasture used for sheep and beef cattle grazing. There were 47,900 ha of irrigated cropping within the region in 2000 dominated by cereal, pasture and hay, with small areas of cotton, orchards, viticulture and horticulture. Less than 20 percent of the region retains native vegetation. The region includes the nationally significant Booligal Wetlands and the Great Cumbung Swamp on the lower reaches of the Lachlan River. The region uses 3.5 percent of the surface water diverted for irrigation in the MDB and 14.1 percent of the MDB groundwater use. Wyangala Dam on the Lachlan River upstream of Cowra is the major water storage. Approximately two-thirds of irrigation water used is sourced from surface water diversions. Groundwater is extracted from alluvial aquifers in the western portion of the region to irrigate cotton crops and for stock and domestic use.

Key Messages

The key messages relating to climate, surface water resources, groundwater and the environment are presented below for scenarios of current and possible future conditions. The scenarios assessed are defined in Chapter 1.

Historical climate and current development (Scenario A)

The average annual rainfall for the entire Lachlan region is 461 mm and modelled average annual runoff is 23 mm. Rainfall is fairly uniform throughout the year but runoff is highest in the winter months. The region is about 8 percent of the MDB and contributes about 6.5 percent of the total MDB runoff.

Current average surface water availability is 1139 GL/year and on average about 321 GL/year (or 28 percent) of this water is used. This is a moderately high level of development and includes surface water diversions (292 GL/year) and eventual streamflow leakage to groundwater induced by current groundwater use. Flows in the Lachlan River are highly regulated (Wyangala Dam regulates 68 percent of all inflows) and general security water in the system is highly utilised (71 percent of the allocated general security water used). Groundwater extraction from the Upper and Lower Lachlan alluvia is expected to eventually increase streamflow losses from the Lachlan River by about 50 percent over and above the natural streamflow loss to groundwater. Most of this additional loss will occur in the Upper Lachlan (while most of the natural loss occurs in the Lower Lachlan).

Total groundwater extraction in the Lachlan region in 2004/05 is estimated to have been 236 GL. This represents 14.1 percent of groundwater use in the Murray-Darling Basin (MDB), excluding use from the confined aquifers of the Great Artesian Basin. This level of groundwater use represents 45 percent of total water use in the region on average, and 90 percent of total water use in years of minimum surface water diversion. Most of the extraction (84 percent) was from the Upper Lachlan Alluvium (31 percent) and Lower Lachlan Alluvium (53 percent) groundwater management units (GMUs). For the Lower Lachlan Alluvium GMU 2004/05 extraction exceeded the long-term average extraction limit (LTAEL) due to supplementary licences with entitlements that decrease to zero by 2018. The reduction in entitlements to the LTAEL level is funded by the New South Wales and Australian governments under the ‘Achieving Sustainable Groundwater Entitlements’ program. Recently, the interim LTAEL was changed from 96 GL/year to 108 GL/year.

Groundwater extraction exceeds rainfall recharge several-fold in the Belubula Valley GMU. This is a very high level of development. However, the aquifer receives considerable recharge from streamflow due to the close connection between the surface water and groundwater in this area. A single water sharing plan is being considered for the Belubula Valley GMU and its associated streamflow which will ensure fuller accounting for all sources of water and comparison of extraction with total recharge from all sources.

Groundwater modelling for the Lower Lachlan Alluvium GMU indicates that extraction cannot be maintained at the former interim LTAEL (96 GL/year plus basic rights for the modelled area). Average extraction (94 GL/year for the modelled area) is about 71 percent of the 'effective recharge' (recharge without lateral inflow) and exceeds effective recharge 56 percent of the time. This is a high level of development which will reduce groundwater levels by up to 10 m in some parts of the lower aquifer requiring responses from both groundwater users and groundwater managers in order to reduce extraction in areas of falling watertables. As the area of lowered watertable grows, additional recharge is likely to be induced from the Lachlan River, but the timeframe for this to occur is likely to be extremely long. The long-term (over 200 years) impact of extraction at the former interim LTAEL is expected to be about a 3 GL/year reduction on streamflow in the Lachlan River. This 3 GL/year is in addition to the 'natural' 42 GL/year streamflow loss to the GMU from the lower Lachlan River. The ultimate impact is likely to be much greater than this, but due to the large extent and thus slow response of the aquifer, it will take a long time for these greater impacts to occur.

Groundwater modelling for the Upper Lachlan Alluvium GMU indicates that the LTAEL (61 GL/year for the modelled area) is about 117 percent of the current total groundwater recharge. Extraction exceeds recharge 92 percent of the time. This is a very high level of development which will reduce groundwater levels by up to 20 m in some parts of the lower aquifer requiring responses from both groundwater users and groundwater managers in order to reduce extraction in areas of falling watertables. As the area of lowered watertable grows, additional recharge is likely to be induced from the Lachlan River, but the timeframe for this to occur is likely to be extremely long. Dynamic equilibrium with stable groundwater levels would be attained at an extraction rate of about 50 GL/year. The long-term (several decades) impact of groundwater extraction on flows in the upper Lachlan River is about 17 GL/year. This 17 GL/year is in addition to the 'natural' 8 GL/year streamflow loss to the GMU from the upper Lachlan River.

As a result of water resource development the average period between winter–spring floods entering the Booligal wetlands has increased from 6.2 to 8.3 years (34 percent). The maximum period between these events has increased from 18.7 to 22.2 years (9 percent). These changes are consistent with observed substantial reductions in the frequency and size of waterbird breeding events. As a result of water resource development there has been a substantial increase in the average period between winter–spring flood events in the Great Cumbung Swamp from 1.2 to 2.5 years (102 percent). The maximum period between these events has increase from 6.6 years to 16 years (143 percent). These changes are consistent with observed deterioration in the condition of vegetation in the swamp.

Recent climate and current development (Scenario B)

The average annual rainfall and runoff over the ten-year period 1997 to 2006 are 8 percent and 24 percent lower respectively than the long-term averages, but statistically, they are not significantly different due to high inter-annual variability. A scenario based on the last ten years was therefore not modelled for the region.

Future climate and current development (Scenario C)

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Lachlan region is more likely to decrease than increase. Two-thirds of the modelling results show a decrease in runoff and one-third of the results show an increase in runoff. The best estimate (median) is a 10 percent reduction in mean annual runoff by ~2030 relative to ~1990. The extreme estimates, which come from the high global warming scenario, range from a 34 percent reduction to a 17 percent increase in mean annual runoff. By comparison, the range from the low global warming scenario is a 12 percent reduction to a 4 percent increase in mean annual runoff.

Under the best estimate 2030 climate there would be an 11 percent reduction in water availability, a 13 percent reduction in end-of-system flows and an 8 percent reduction in diversions overall. Diversion impacts would differ between water products. General security water use would decrease by 2 percent in the Belubula system and 9 percent in the Lachlan system. Other high security use would increase by 5 and 7 percent in the Belubula and Lachlan systems respectively due to increases in demand driven by climate change. High security town water supplies would not be impacted in either system.

The Lachlan River Environmental Contingency Allowance (ECA) would be reduced by 12 percent. The climate extremes for 2030 indicate that under the wet extreme climate there would be increases of 6 percent in water availability, 9 percent in end-of-system flows and 4 percent in total diversions. Under the dry extreme climate there would be decreases of 30 percent in water availability, 35 percent in end-of-system flows and 22 percent in total diversions. Furthermore, under the dry extreme 2030 climate high security town water supplies would not be met (a 2 percent reduction in supply would occur), but there would be a 20 and 18 percent increases in use by other high security users in the Belubula and Lachlan systems respectively; there would be a 53 percent reduction in the ECA.

Under the best estimate 2030 climate there would be little change in rainfall recharge to either the Upper or the Lachlan Alluvium GMUs. However, under the wet extreme 2030 climate in the Lower Lachlan there would be a 22 percent increase in rainfall recharge and under the dry extreme 2030 climate there would be a 34 percent reduction in rainfall recharge; net river losses would be largely unaffected. Under the best estimate 2030 climate in the Upper Lachlan there would be a 17 percent increase in rainfall recharge and under the dry extreme 2030 climate there would be a 28 percent reduction in rainfall recharge; once again net river losses would be unaffected.

Under the best estimate 2030 climate the average period between winter–spring inflows to the Booligal Wetlands would increase by a further 24 percent. This would be likely to reduce the frequency of waterbird breeding events in these wetlands. Under the dry extreme 2030 climate the average period between winter–spring inflows would increase by 87 percent (to once in over 15 years on average). The maximum period between the events would increase by 47 percent (or by an additional ten years). These changes would be very likely to have major ecological consequences including much longer periods between waterbird breeding events and adverse effects on the status of the Lignum vegetation used as breeding habitat by some waterbirds. The wet extreme 2030 climate would cause a 21 percent decrease in the average period and a 16 percent decrease in the maximum period between winter–spring inflow events.

Under the best estimate 2030 climate the average period between winter–spring flood events to the Great Cumbung Swamp would increase by a further 24 percent and the maximum period between events would increase by a further 16 percent. These increases would be likely to further adversely affect the vegetation of the swamp and its use by waterbirds. Under the dry 2030 climate extreme the average period between winter–spring floods events would increase by 131 percent and the maximum period would increase by 39 percent. These changes are very likely to have substantial adverse consequences for the condition and composition of current vegetation. The wet extreme 2030 climate would cause an 11 percent decrease in the average period between events but would not affect the maximum period between events.

Future climate and future development (Scenario D)

Groundwater extraction outside of the Upper and Lower Lachlan Alluvium GMUs is expected to increase more than three-fold by 2030, with nearly all of the increase occurring in the Lachlan Fold Belt GMU. This would mean total groundwater extraction for the region would be 440 GL/year – an increase of 86 percent over 2004/05 extraction levels. Predicted future groundwater extraction would (under the best estimate 2030 climate) represent 63 percent of total water use on average and 95 percent of total water use in years of minimum surface water diversion. For the Upper Lachlan Alluvium GMU groundwater extraction is projected to be 121 GL/year in the modelled area by 2030. This level of extraction cannot be maintained by the existing distribution of bores. The maximum level of extraction that could be maintained from the existing bores is about 67 GL/year. The total eventual impacts of future groundwater extraction across the region will be an estimated additional 30 GL/year reduction in streamflow. Of this impact, streamflow leakage and the larger individual inflow reductions were included in the river modelling.

The projected growth in commercial forestry plantations in the Lachlan region is negligible. Farm dam storage capacity over the Lachlan region is projected to increase by 36,000 ML (an increase of 14 percent of current farm dam storage capacity) by 2030. This increase in farm dams would reduce mean annual runoff by less than 2 percent, which is relatively small compared to the best estimate climate change impact on runoff (10 percent). The best estimate of the combined impact of climate change and farm dam development is a 12 percent reduction in mean annual runoff. Extreme estimates range from a 35 percent reduction to a 15 percent increase.

Projected future development (additional groundwater extraction and farm dams) would reduce river inflows (under the best estimate future climate) by 2 percent or 28 GL/year, of which about two thirds would be due to farm dams and one third due to future groundwater extraction. There would also be an additional 6 GL/year increase in streamflow leakage to groundwater in alluvial reaches due to projected increases in groundwater extraction (under the best estimate 2030 climate). Diversions would reduce by an additional 2 percent to be 10 percent lower than current. The impact on average end-of-system flows would be a total reduction (development and climate impacts) of 15 percent. Development would exacerbate the impact on high security town water supplies: supplies would be affected under both the best estimate and the dry extreme 2030 climate. Development would also reduce the ECA by a further 4 percent in addition to the climate change impacts. The relative level of use would be 32 percent – this is a high level of development and is 4 percent higher than the current level.

Projected future catchment and groundwater development would have no additional effect on the frequency of floods reaching the Booligal Wetlands and only small additional increases in the average period between winter–spring flood events for the Great Cumbung Swamp.

Uncertainty

The runoff estimates for the eastern parts of the Lachlan region, where runoff is highest, are relatively good because there are many gauged catchments there from which to estimate the model parameter values. The largest source of uncertainty for future climate results are the climate change projections (global warming level) and the modelled implications of global warming on regional rainfall. The results from 15 global climate models were used but there are large differences amongst these models in terms of regional rainfall predictions. There are also considerable uncertainties associated with the future projections of farm dams and commercial forestry plantations. Future developments could differ considerably from these projections if governments were to impose different policy controls.

Assessment of river model uncertainty was limited to the Upper Lachlan. Overall the quality of the model appears good and suitable for the purposes of this project. The uncertainty around groundwater exchanges appears small in the Upper Lachlan. The greatest uncertainty is associated with climate projections. This uncertainty is amplified by the construction and testing of the model over a relatively narrow climate range. Projected changes due to development are small and of similar magnitude to the internal uncertainty in the river model.

The groundwater models for the Lower and Upper Lachlan have been assessed as thorough, and thus both are adequate for providing information on water availability in the context of this project. However, neither model reached dynamic equilibrium during scenario runs. The model results have a low to moderate level of uncertainty due to the nature of model calibration – the calibrations could be improved. The models are however, unsuitable as water allocation tools since local aquifer use rules are not currently implemented and the redistribution of groundwater extraction that would take place as pumping bores dry out is not currently incorporated in a realistic manner. Notwithstanding the level of uncertainty surrounding the model, the level of analysis for the Lower Lachlan and Upper Lachlan Alluvium GMUs is commensurate with the priority ranking of these GMU for the project objectives.

There is considerable uncertainty in the future projections of groundwater development outside of the two modelled GMUs, but the estimates do show the importance of development in these areas. In particular, there is a large uncertainty introduced by the inability to estimate recharge to the Belubula Valley GMU aquifer from streamflow. The groundwater projections would generally represent the upper limit of groundwater development as developments can be constrained by pumping rules, groundwater quality and land suitability. However, the outcome of this analysis is considered conservative due to the use of current entitlements for current stream impacts, ignoring subcatchments where impact on streamflow is less than 2 GL/year and the use of connectivity estimates based effectively on conservative 'best guesses'.

The environmental assessments of this project only consider a subset of the important assets for this region and are based on limited hydrology parameters with no direct quantitative relationships for environmental responses. Considerably more detailed investigation is required to provide the necessary information for informed management of the environmental assets of the region.

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1 Introduction

1.1 Background

Australia is the driest inhabited continent on Earth, and in many parts of the country – including the Murray-Darling Basin – water for rural and urban use is comparatively scarce. Into the future, climate change and other risks (including catchment development) are likely to exacerbate this situation and hence improved water resource data, understanding and planning and management are of high priority for Australian communities, industries and governments.

On 7 November, 2006, the then Prime Minister of Australia met with the First Ministers of Victoria, New South Wales, South Australia and Queensland at a water summit focussed primarily on the future of the Murray-Darling Basin (MDB). As an outcome of the Summit on the Southern Murray-Darling Basin, a joint communiqué called for "CSIRO to report progressively by the end of 2007 on sustainable yields of surface and groundwater systems within the MDB, including an examination of assumptions about sustainable yield in light of changes in climate and other issues".

The subsequent Terms of Reference for what became the Murray-Darling Basin Sustainable Yields Project specifically asked CSIRO to:

- estimate current and likely future water availability in each catchment and aquifer in the MDB considering:
    - climate change and other risks
    - surface–groundwater interactions
- compare the estimated current and future water availability to that required to meet the current levels of extractive use.

The Murray-Darling Basin Sustainable Yields Project is reporting progressively on each of 18 contiguous regions that comprise the entire MDB. These regions are primarily the drainage basins of the Murray and the Darling rivers – Australia's longest inland rivers, and their tributaries. The Darling flows southwards from southern Queensland into New South Wales west of the Great Dividing Range into the Murray River in southern New South Wales. At the South Australian border the Murray turns southwesterly eventually winding to the mouth below the Lower Lakes and the Coorong. The regions for which the project assessments are being undertaken and reported are the Paroo, Warrego, Condamine-Balonne, Moonie, Border Rivers, Gwydir, Namoi, Macquarie-Castlereagh, Barwon-Darling, Lachlan, Murrumbidgee, Murray, Ovens, Goulburn-Broken, Campaspe, Loddon-Avoca, Wimmera and Eastern Mount Lofty Ranges (see Figure 1-1).

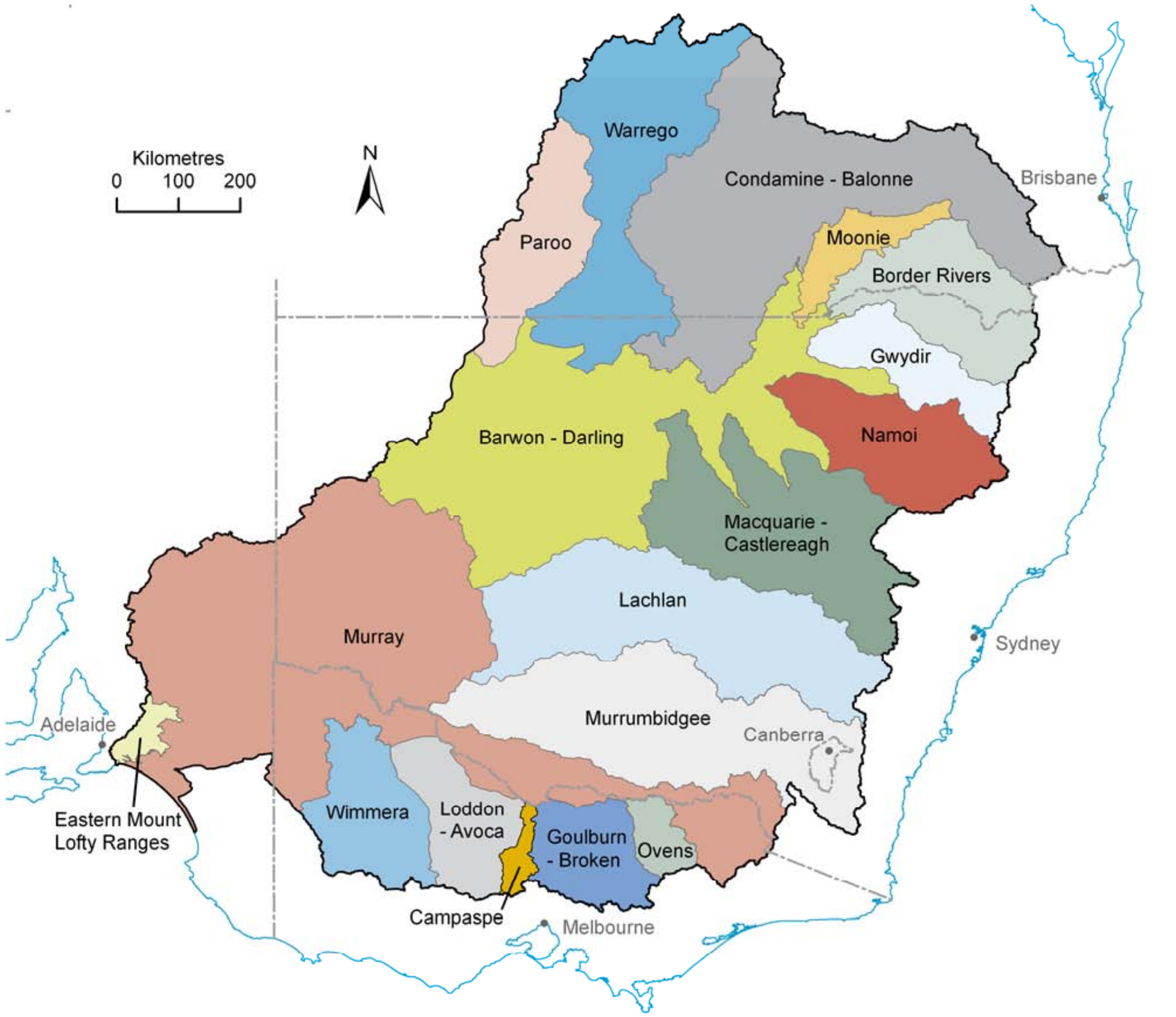

Figure 1-1. Region by region map of the Murray-Darling Basin

The Murray-Darling Basin Sustainable Yields Project will be the most comprehensive MDB-wide assessment of water availability undertaken to-date. For the first time:

- daily rainfall-runoff modelling has been undertaken at high spatial resolution for a range of climate change and development scenarios in a consistent manner for the entire MDB
- the hydrologic subcatchments required for detailed modelling have been precisely defined across the entire MDB
- the hydrologic implications for water users and the environment by 2030 of the latest Intergovernmental Panel on Climate Change climate projections, the likely increases in farm dams and commercial forestry plantations and the expected increases in groundwater extraction have been assessed in detail (using all existing river system and groundwater models as well new models developed within the project)
- river system modelling has included full consideration of the downstream implications of upstream changes between multiple models and between different States, and quantification of the volumes of surface–groundwater exchange
- detailed analyses of monthly water balances for the last ten to twenty years have been undertaken using available streamflow and diversion data together with additional modelling including estimates of wetland evapotranspiration and irrigation water use based on remote sensing imagery (to provide an independent cross-check on the performance of river system models).

The successful completion of these outcomes, among many others, relies heavily on a focussed collaborative and team-oriented approach between CSIRO, State government natural resource management agencies, the Murray-Darling Basin Commission, the Bureau of Rural Sciences, and leading consulting firms – each bringing their specialist knowledge and expertise on the MDB to the project.

1.2 Project methodological framework

The methodological framework for the project is shown in the diagram below (Figure 1-2). This also indicates in which chapters of this report the different aspects of the project assessments and results are presented.

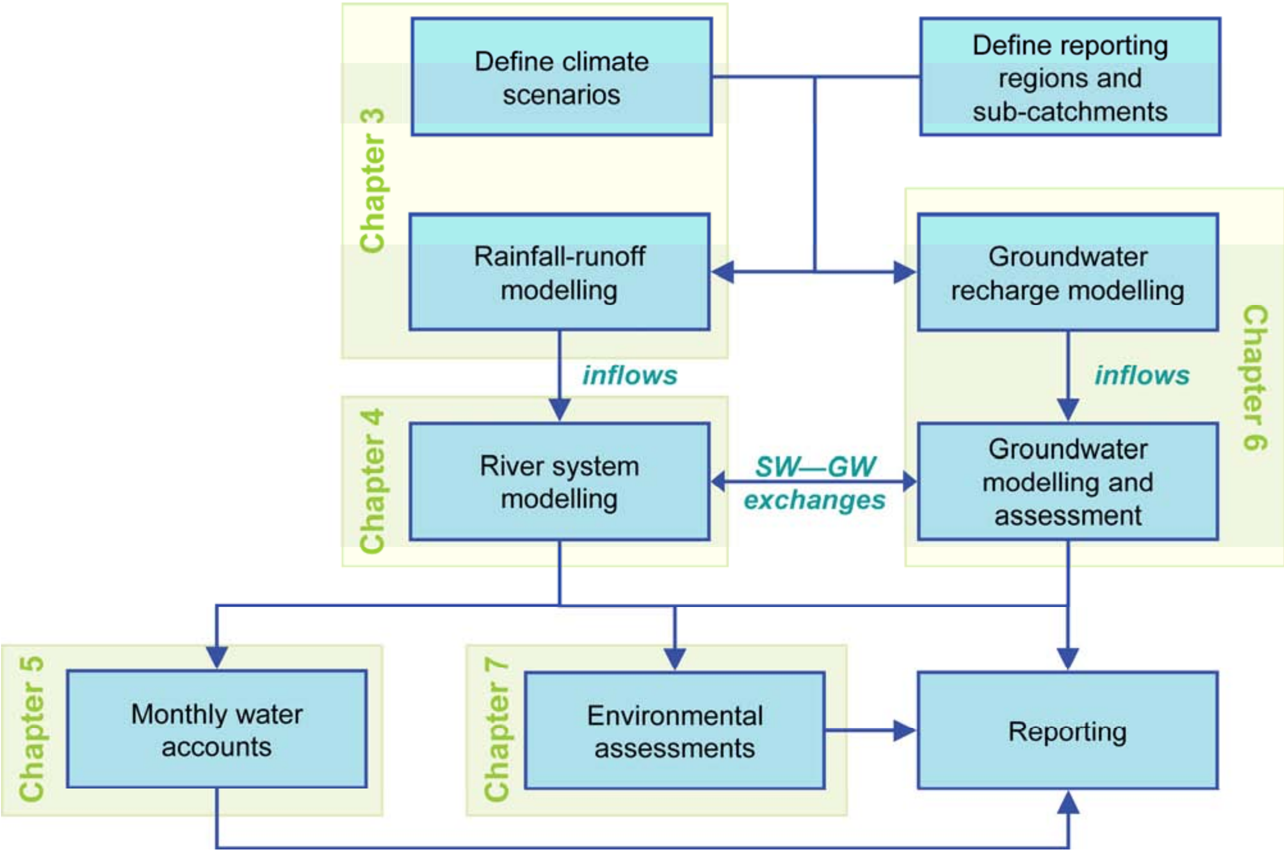

Figure 1-2. Methodological framework for the Murray-Darling Basin Sustainable Yields Project

The first steps in the sequence of the project are definition of the reporting regions and their composite subcatchments, and definition of the climate and development scenarios to be assessed (including generation of the time series of climate data that describe these scenarios). The second steps are rainfall-runoff modelling and rainfall-recharge modelling for which the inputs are the climate data for the different scenarios. Catchment development scenarios for farm dams and commercial forestry plantations are modifiers of the modelled runoff time series.

Next, the runoff implications are propagated through river system models and the recharge implications propagated through groundwater models – for the major groundwater resources – or considered in simpler assessments for minor groundwater resources. The connectivity of surface and groundwater is assessed and the actual volumes of surface–groundwater exchange under current and likely future groundwater extraction are quantified. Uncertainty levels of the river system models are then assessed based on monthly water accounting.

The results of scenario outputs from the river system model are used to make limited hydrological assessments of ecological relevance to key environmental assets. Finally, the implications of the scenarios for water availability and water use under current water sharing arrangements are assessed, synthesised and reported.

1.3 Climate and development scenarios

The project is assessing the following four scenarios of historical and future climate and current and future development, all of which are defined by daily time series of climate variables based on different scalings of the historical 1895 to 2006 climate sequence:

- historical climate and current development
- recent climate and current development
- future climate and current development
- future climate and future development.

These scenarios are described in some detail below with full details provided in Chiew et al. (2008a).

1.3.1 Historical climate and current development

Historical climate and current development – referred to as 'Scenario A' – is the baseline against which other climate and development scenarios are compared.

The historical daily rainfall time series data that are used are taken from the SILO Data Drill of the Queensland Department of Natural Resources and Water database which provides data for a 0.05^{o} x 0.05^{o} (5 km x 5 km) grid across the continent (Jeffrey et al., 2001; and www.nrm.qld.gov.au/silo). Areal potential evapotranspiration (PET) data are calculated from the SILO climate surface using Morton's wet environment evapotranspiration algorithms (www.bom.gov.au/climate/averages; and Chiew and Leahy, 2003).

Current development for the rainfall-runoff modelling is the average of 1975 to 2005 land use and small farm dam conditions. Current development for the river system modelling is the dams, weirs and licence entitlements in the latest State agency models, updated to 2005 levels of large farm dams. Current development for groundwater models is 2004 to 2005 levels of licence entitlements. Surface–groundwater exchanges in the river and groundwater models represent an equilibrium condition for the above levels of surface and groundwater development.

1.3.2 Recent climate and current development

Recent climate and current development – referred to as 'Scenario B' – is used for assessing future water availability should the climate in the future prove to be similar to that of the last ten years. Climate data for 1997 to 2006 is used to generate stochastic replicates of 112-year daily climate sequences. The replicate which best produces a mean annual runoff value closest to the mean annual runoff for the period 1997 to 2006 is selected to define this scenario.

Scenario B is only analysed and reported upon where the mean annual runoff for the last ten years is statistically significantly different to the long-term average.

1.3.3 Future climate and current development

Future climate and current development – referred to as 'Scenario C' – is used to assess the range of likely climate conditions around the year 2030. Three global warming scenarios are analysed in 15 global climate models (GCM) to provide a spectrum of 45 climate variants for the 2030. The scenario variants are derived from the latest modelling for the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007).

Two types of uncertainties in climate change projections are therefore taken into account: uncertainty in global warming mainly due to projections of greenhouse gas emissions and global climate sensitivity to the projections; and uncertainty in GCM modelling of climate over the MDB. Results from each GCM are analysed separately to estimate the change per degree global warming in rainfall and other climate variables required to calculate PET. The change per degree of global warming is then scaled by a high, medium and low global warming by 2030 relative to 1990 to obtain the changes in the climate variables for the high, medium and low global warming scenarios. The future climate and current development Scenario C considerations are therefore for 112-year rainfall and PET series for a greenhouse enhanced climate around 2030 relative to 1990 and not for a forecast climate at 2030.

The method used to obtain the future climate and current development Scenario C climate series also takes into account different changes in each of the four seasons as well as changes in the daily rainfall distribution. The consideration of changes in the daily rainfall distribution is important because many GCMs indicate that extreme rainfall in an enhanced greenhouse climate is likely to be more intense, even in some regions where projections indicate a decrease in mean seasonal or annual rainfall. As the high rainfall events generate large runoff, the use of traditional methods that assumes the entire rainfall distribution to change in the same way will lead to an underestimation of mean annual runoff in regions where there is an increase, and an overestimation of the decrease in mean annual runoff where there is a decrease (Chiew, 2006).

All 45 future climate and current development Scenario C variants are used in rainfall-runoff modelling; however, three variants – a 'dry', a 'mid' (best estimate – median) and a 'wet' variant – are presented in more detail and are used in river and groundwater modelling.

1.3.4 Future climate and future development

Future climate and future development – referred to as 'Scenario D' – considers the 'dry, 'mid' and 'wet' climate variants from the future climate and current development Scenario C together with likely expansions in farm dams and commercial forestry plantations and the changes in groundwater extractions anticipated under existing groundwater plans.

Farm dams here refer only to dams with their own water supply catchment, not those that store water diverted from a nearby river, as the latter require licences and are usually already included within existing river system models. A 2030 farm dam development scenario for the MDB has been developed by considering current distribution and policy controls and trends in farm dam expansion. The increase in farm dams in each subcatchment is estimated using simple regression models that consider current farm dam distribution, trends in farm dam (Agrecon, 2005) or population growth (Australian Bureau of Statistics, 2004; and Victorian Department of Sustainability and Enviroment (DSE), 2004) and current policy controls (Queensland Government, 2000; New South Wales Government, 2000; Victoria Government, 1989; South Australia Government, 2004). Data on the current extent of farm dams is taken from the 2007 Geosciences Australia 'Man-made Hydrology' GIS coverage and from the 2006 VicMap 1:25,000 topographic GIS coverage. The former covers the eastern region of Queensland MDB and the northeastern and southern regions of the New South Wales MDB. The latter data covers the entire Victorian MDB.

A 2030 scenario for commercial forestry plantations for the MDB has been developed using regional projections from the Bureau of Rural Sciences which takes into account trends, policies and industry feedbacks. The increase in commercial forestry plantations is then distributed to areas adjacent to existing plantations (which are not natural forest land use) with the highest biomass productivity estimated from the PROMOD model (Battaglia and Sands, 1997).

Growth in groundwater extractions has been considered in the context of existing groundwater planning and sharing arrangements and in consultation with State agencies. For groundwater the following issues have been considered:

- growth in groundwater extraction rates up to full allocation
- improvements in water use efficiency due to on-farm changes and lining of channels
- water buy-backs.

1.4 Rainfall-runoff modelling

The adopted approach provides a consistent way of modelling historical runoff across the MDB and assessing the potential impacts of climate change and development on future runoff.

The lumped conceptual daily rainfall-runoff model, SIMHYD, with a Muskingum routing method (Chiew et al., 2002; Tan et al., 2005), is used to estimate daily runoff at 0.05^{o} grids (~ 5 km x 5 km) across the entire MDB for the four scenarios.

The model is calibrated against 1975 to 2006 streamflow data from about 200 unregulated catchments of 50 km^2 to 2000 km^2 across the MDB (calibration catchments). Although unregulated, streamflow in these catchments for the calibration period may reflect low levels of water diversion and the effects of historical land use change. The calibration period is a compromise between a shorter period that would better represent current development and a longer period that would better account for climatic variability. In the model calibration, the six parameters in SIMHYD are optimised to maximise an objective function that incorporates the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) of monthly runoff and daily flow duration curve, together with a constraint to ensure that the total modelled runoff over the calibration period is within 5 percent of the total recorded runoff. The resulting optimised model parameters are therefore identical for all cells within a calibration catchment.

The runoff for non-calibration catchments is modelled using optimised parameter values from the geographically closest calibration catchment, provided there is a calibration catchment point within 250 km. Once again the parameter values for each grid cell within a non-calibration catchment are identical. For catchments more than 250 km from a calibration catchment default point the parameter values are used. The default parameter values are taken from the entire MDB modelling run (identical parameters across the entire MDB are chosen to ensure a realistic runoff gradient across the drier parts of the MDB) which best matched observed flows at calibration points. The places these 'default' values are used are therefore all areas of very low runoff.

As the parameter values come from calibration against streamflow from 50 km^2 to 2000 km^2 catchments, the runoff defined here is different, and can be much higher, than streamflow recorded over very large catchments where there can be significant transmission losses (particularly in the western and northwestern parts of the MDB). Almost all of the catchments available for model calibration are in the higher runoff areas in the eastern and southern parts of the MDB. Runoff estimates are therefore generally good in the eastern and southern parts of the MDB and are comparatively poor elsewhere.

The same model parameter values are used for all the simulations. The future climate Scenario C simulations therefore do not take into account the effect on forest water use of global warming and enhanced atmospheric CO_2 concentrations. There are compensating positive and negative global warming impacts on forest water use, and it is difficult to estimate the net effect because of the complex climate-biosphere-atmosphere interactions and feedbacks. This is discussed in Marcar et al. (2006) and in Chiew et al. (2008b).

Bushfire frequency is also likely to increase under the future climate Scenario C. In local areas where bushfires occur, runoff would reduce significantly as forests regrow. However, the impact on runoff averaged over an entire reporting region is unlikely to be significant (see Chiew et al., 2008b).

For the Scenario D (future climate and future development scenario) the impact of additional farm dams on runoff is modelled using the CHEAT model (Nathan et al., 2005) which takes into account rainfall, evaporation, demands, inflows and spills. The impact of additional plantations on runoff is modelled using the FCFC model (Forest Cover Flow Change), Brown et al. (2006) and www.toolkit.net.au/fcfc.

The rainfall-runoff model SIMHYD is used because it is simple and has relatively few parameters and, for the purpose of this project, provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire MDB and for assessing the potential impacts of climate change and development on future runoff. It is possible that, in data-rich areas, specific calibration of SIMHYD or more complex rainfall-runoff models based on expert judgement and local knowledge as carried out by some state agencies would lead to better model calibration for the specific modelling objectives of the area. Chiew et al. (2008b) provide a more detailed description of the rainfall-runoff modelling, including details of model calibration, cross-verification and regionalisation with both the SIMHYD and Sacramento rainfall-runoff models and simulation of climate change and development impacts on runoff.

1.5 River system modelling

The project is using river system models that encapsulate descriptions of current infrastructure, water demands, and water management and sharing rules to assess the implications of the changes in inflows described above on the reliability of water supply to users. Given the time constraints of the project and the need to link the assessments to State water planning processes, it is necessary to use the river system models currently used by State agencies, the Murray-Darling Basin Commission and Snowy Hydro Ltd. The main models in use are IQQM, REALM, MSM-Bigmod, WaterCress and a model of the Snowy Mountains Hydro-electric Scheme.

The modelled runoff series from SIMHYD are not used directly as subcatchment inflows in these river system models because this would violate the calibrations of the river system models already undertaken by State agencies to different runoff series. Instead, the relative differences between the daily flow duration curves of the historical climate Scenario A and the remaining scenarios (scenarios B, C and D respectively) are used to modify the existing inflows series in the river system models (separately for each season). The scenarios B, C and D inflow series for the river system modelling therefore have the same daily sequences – but different amounts – as the Scenario A river system modelling series.

Table 1-1. River system models in the Murray-Darling Basin

Model	Description	Rivers modelled
IQQM	Integrated Quantity-Quality Model: hydrologic modelling tool developed by the NSW Government for use in planning and evaluating water resource management policies.	Paroo, Warrego, Condamine-Balonne (Upper, Mid, Lower), Nebine, Moonie, Border Rivers, Gwydir, Peel, Namoi, Castlereagh, Macquarie, Marthaguy, Bogan, Lachlan, Murrumbidgee, Barwon-Darling
REALM	Resource Allocation Model: water supply system simulation tool package for modelling water supply systems configured as a network of nodes and carriers representing reservoirs, demand centres, waterways, pipes, etc.	Ovens (Upper, Lower), Goulburn, Wimmera, Avoca, ACT water supply.
MSM-BigMod	Murray Simulation Model and the daily forecasting model BigMod: purpose-built by the Murray-Darling Basin Commission to manage the Murray River system. MSM is a monthly model that includes the complex Murray accounting rules. The outputs from MSM form the inputs to BigMod, which is the daily routing engine that simulates the movement of water.	Murray
WaterCress	Water Community Resource Evaluation and Simulation System: PC-based water management platform incorporating generic and specific hydrological models and functionalities for use in assessing water resources and designing and evaluating water management systems.	Eastern Mt Lofty Ranges (six separate catchments)
SMHS	Snowy Mountains Hydro-electric Scheme model: purpose built by Snowy Hydro Ltd to guide the planning and operation of the SMHS.	Snowy Mountains Hydro-electric Scheme

A few areas of the MDB have not previously been modelled and hence some new IQQM or REALM models have been implemented. In some cases ancillary models are used to estimate aspects of water demands of use in the river system model. An example is the PRIDE model used to estimate irrigation for Victorian REALM models.

River systems that do not receive inflows or transfers from upstream or adjacent river systems are modelled independently. This is the case for most of the river systems in the MDB and for these rivers the modelling steps are:

- model configuration
- model warm-up to set initial values for all storages in the model, including public and private dams and tanks, river reaches and soil moisture in irrigation areas
- using scenario climate and inflow time series, run the river model for all climate and development scenarios

- where relevant, extract initial estimates of surface–groundwater exchanges and provide this to the groundwater model
- where relevant, use revised estimates of surface–groundwater exchanges from groundwater models and re-run the river model for all scenarios.

For river systems that receive inflows or transfers from upstream or adjacent river systems, model inputs for each scenario were taken from the upstream models. In a few cases several iterations were required between upstream and downstream models because of the complexities of the water management arrangements. An example is the connections between the Murray, Murrumbidgee and Goulburn regions and the Snowy Mountains Hydro-electric Scheme.

For all scenarios, the river models are run for the 111-year period 1 July 1895 to 30 June 2006. This period therefore ignores the first and last six months of the 112-year period considered in the climate analyses and the rainfall-runoff modelling.

1.5.1 Surface–groundwater interactions

The project explicitly considers and quantifies the water exchanges between rivers and groundwater systems. The approaches used are described below.

The river models used by State agencies have typically been calibrated by State agencies to achieve mass balance within calibration reaches over relatively short time periods. When the models are run for extended periods the relationships derived during calibration are assumed to hold for the full modelling period. In many cases, however, the calibration period is a period of changing groundwater extraction and a period of changing impact of this extraction on the river system. That is, the calibration period is often one of changing hydrologic relationships, a period where the river and groundwater systems have not fully adjusted to the current level of groundwater development. To provide a consistent equilibrium basis for scenario comparisons it is necessary to determine the equilibrium conditions of surface and groundwater systems considering their interactions and the considerable lag times involved in reaching equilibrium.

Figure 1-3 shows an indicative timeline of groundwater use, impact on river, and how this has typically been treated in river model calibration, and what the actual equilibrium impact on the river would be. By running the groundwater models until a ‘dynamic equilibrium’ is reached, a reasonable estimate of the ultimate impact on the river of current groundwater use is obtained. A similar approach is used to determine the ultimate impact of future groundwater use.

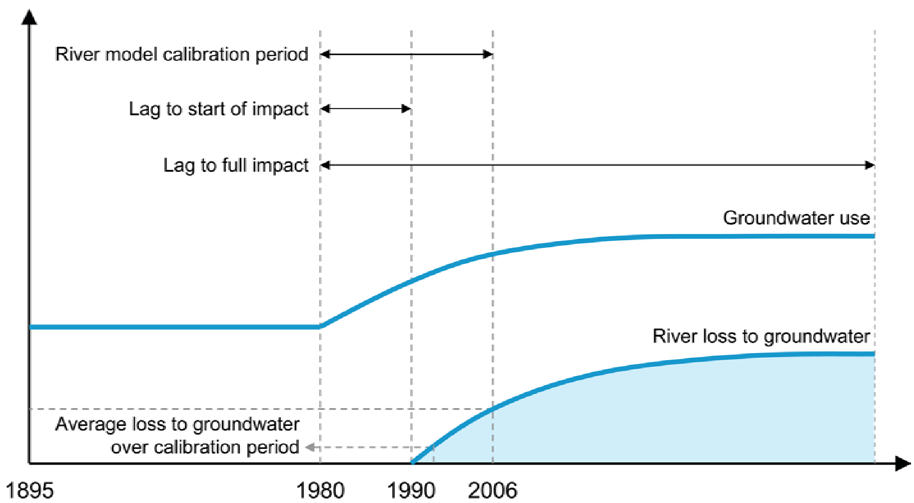

Figure 1-3. Timeline of groundwater use and resultant impact on river

For some groundwater management units – particularly fractured rock aquifers – there is significant groundwater extraction but no model available for assessment. In these cases there is the potential for considerable impacts on streamflow. At equilibrium, the volume of water extracted must equal the inflows to the aquifer from diffuse recharge, lateral flows and flows from overlying rivers. The fraction that comes from the overlying rivers is determined using a 'connectivity factor' that is estimated from the difference in levels between the groundwater adjacent to the river and the river itself, the conductance between the groundwater pump and the river, and the hydrogeological setting. Given the errors inherent in this method, significant impacts are deemed to be those about 2 GL/year for a subcatchment, which given typical connectivity factors translates to groundwater extraction rates of around 4 GL/year for a subcatchment.

1.6 Monthly water accounts

Monthly water accounts provide an independent set of the different water balance components by river reach and by month. The water accounting differs from the river modelling in a number of key aspects:

- the period of accounting extends to 2006 where possible, which is typically more recent than the calibration and evaluation periods of the river models assessed. This means that a comparison can produce new insights about the performance and assumptions in the river model, as for example associated with recent water resources development or the recent drought in parts of the MDB
- the accounting is specifically intended to estimate, as best as possible, historical water balance patterns, and used observed rather than modelled data wherever possible (including recorded diversions, dam releases and other operations). This reduces the uncertainty associated with error propagation and assumptions in the river model that were not necessarily intended to reproduce historical patterns (e.g. differences in actual historical and potential future degree of entitlement use)
- the accounting uses independent, additional observations and estimates on water balance components not used before such as actual water use estimates derived from remote sensing observations. This can help to constrain the water balance with greater certainty.

The water accounting methodology invokes models and indirect estimates of water balance components where direct measurements are not available. These water accounts are not an absolute point of truth. They provide an estimate of the degree to which the river water balance is understood and gauged, and a comparison between river model and water account water balances provides one of several lines of evidence to inform our (inevitably partially subjective) assessment of model uncertainty and its implications for the confidence in findings. The methods for water accounting are based on existing methods and those used by Kirby et al. (2006) and Van Dijk et al. (2008) and are described in detail in Kirby et al. (2008).

1.6.1 Wetland and irrigation water use

An important component of the accounting is an estimate of actual water use based on remote sensing observations. Spatial time series of monthly net water use from irrigation areas, rivers and wetlands are estimated using interpolated station observations of rainfall and climate combined with remote sensing observations of surface wetness, greenness and temperature. Net water use of surface water resources is calculated as the difference between monthly rainfall and monthly actual evapotranspiration (AET).

AET estimates are based on a combination of two methods. The first method uses surface temperature remotely sensed by the AVHRR series of satellite instruments for the period 1990 to 2006 and combines this with spatially interpolated climate variables to estimate AET from the surface energy balance (McVicar and Jupp, 2002). The second method loosely follows the FAO56 'crop factor' approach and scales interpolated potential evaporation (PET) estimates using observations of surface greenness and wetness by the MODIS satellite instrument (Van Dijk et al., 2008). The two methods are constrained using direct on-ground AET measurements at seven study sites and catchment streamflow observations from more than 200 catchments across Australia. Both methods provide AET estimates at 1 km resolution.

The spatial estimates of net water use are aggregated for each reach and separately for all areas classified as either irrigation area or floodplains and wetlands. The following digital data sources were used:

- land use grids for 2000/01 and 2001/02 from the Bureau of Rural Sciences (adl.brs.gov.au/mapserv/landuse/)
- NSW wetlands maps from the NSW Department of Environment and Conservation (NSW DEC)
- hydrography maps, including various types of water bodies and periodically inundated areas, from Geoscience Australia (GA maps; Topo250K Series 3)
- long-term rainfall and AET grids derived as outlined above
- LANDSAT satellite imagery for the years 1998 to 2004.

The reach-by-reach estimates of net water use from irrigation areas and from floodplains and wetlands are subject to the following limitations:

- partial validation of the estimates suggested an average accuracy in AET estimation within 15 percent, but probably decreasing with the area over which estimates are averaged. Uncertainty in spatial estimates originates from the interpolated climate and rainfall data as well as from the satellite observations and the method applied
- errors in classification of irrigation and floodplain/wetland areas may have added an unknown uncertainty to the overall estimates, particularly where subcatchment definition is uncertain or wetland and irrigation areas are difficult to discern
- estimated net water use cannot be assumed to have been derived from surface water in all cases as vegetation may also have access to groundwater use, either directly or through groundwater pumping
- estimated net water use can be considered as an estimate of water demand that apparently is met over the long-term. Storage processes, both in irrigation storages and wetlands, need to be simulated to translate these estimates in monthly (net) losses from the river main stem.

Therefore, the AET and net water use estimates are used internally to conceptual water balance models of wetland and irrigation water use that include a simulated storage as considered appropriate based on ancillary information.

1.6.2 Calculation and attribution of apparent ungauged gains and losses

In a river reach, ungauged gains or losses are the difference between the sum of gauged main stem and tributary inflows, and the sum of main stem and distributary outflows and diversions. This would be equal to measured main stem outflows and water accounting could occur with absolute certainty. The net sum of all gauged gains and losses provides an estimate of ungauged apparent gains and losses. There may be differences between apparent and real gains and losses for the following reasons:

- apparent ungauged gains and losses will also include any error in discharge data that may originate from errors in stage gauging or from the rating curves associated to convert stage height to discharge
- ungauged gains and losses can be compensating and so appear smaller than in reality. This is more likely to occur at longer time scales. For this reason water accounting was done on a monthly time scale
- changes in water storage in the river reach, connected reservoirs, or wetlands can lead to apparent gains and losses that become more important as the time scale of analysis decreases. A monthly time scale has been chosen to reduce storage change effects, but they can still occur.

The monthly pattern of apparent ungauged gains and losses are evaluated for each reach in an attempt to attribute them to real components of water gain or loss. The following techniques are used in sequence:

- analysis of normal (parametric) and ranked (non-parametric) correlation between apparent ungauged gains and losses on one hand, and gauged and estimated water balance components on the other hand. Estimated components included SIMHYD estimates of monthly local inflows and remote sensing-based estimates of wetland and irrigation net water use
- visual data exploration: assessment of temporal correlations in apparent ungauged gains and losses to assess trends or storage effects, and comparison of apparent ungauged gains and losses and a comparison with a time series of estimated water balance components.

Based on the above information, apparent gains and losses are attributed to the most likely process, and an appropriate method was chosen to estimate the ungauged gain or loss using gauged or estimated data.

The water accounting model includes the following components:

- a conceptual floodplain and wetland running a water balance model that estimates net gains and losses as a function of remote sensing-based estimates of net water use and main stem discharge observations
- a conceptual irrigation area running a water balance model that estimates (net) total diversions as a function of any recorded diversions, remote sensing-based estimates of irrigated area and net crop water use, and estimates of direct evaporation from storages and channels
- a routing model that allows for the effect of temporary water storage in the river system and its associated water bodies and direct open water evaporation
- a local runoff model that transforms SIMHYD estimates of local runoff to match ungauged gains.

These model components are will be described in greater detail in Kirby et al. (2008) and are only used where the data or ancillary information suggests their relevance. Each component has a small number of unconstrained or partially constrained parameters that need to be estimated. A combination of direct estimation as well as step-wise or simultaneous automated optimisation is used, with the goal to attribute the largest possible fraction of apparent ungauged gains and losses. Any large residual losses and gains suggest error in the model or its input data.

1.7 Groundwater modelling

Groundwater assessment, including groundwater recharge modelling, is undertaken to assess the implications of the climate and development scenarios on groundwater management units (GMUs) across the MDB. A range of methods are used appropriate to the size and importance of different GMUs. There are over 100 GMUs in the MDB, and the choice of methods was based on an objective classification of the GMUs as high, medium or low priority.

Rainfall-recharge modelling is undertaken for all GMUs. For dryland areas, daily recharge was assessed using a model that considered plant physiology, water use and soil physics to determine vertical water flow in the unsaturated zone of the soil profile at a single location. This model is run at multiple locations across the MDB in considering the range of soil types and land uses to determine scaling factors for different soil and land use conditions. These scaling factors are used to scale recharge for given changes in rainfall for all GMUs according to local soil types and land uses.

For many of the higher priority GMUs, recharge is largely from irrigation seepage. In New South Wales this recharge has been embedded in the groundwater models as a percentage of the applied water. For irrigation recharge, information was collated for different crop types, irrigation systems and soil types, and has been used for the scenario modelling.

For high priority GMUs numerical groundwater models are being used. In most cases these already exist but often require improvement. In some cases new models are being developed. Although the groundwater models have seen less effort invested in their calibration than the existing river models, the project has invested considerable effort in model calibration and various cross-checks to increase the level of confidence in the groundwater modelling.

For each groundwater model, each scenario is run using river heights as provided from the appropriate river system model. For recent and future climate scenarios, adjusted recharge values are also used, and for future development the 2030 groundwater extractions levels are used. The models are run for two consecutive 111-year periods (to match the 111-year period used for the river modelling). The average surface-groundwater flux values for the second 111-year period are passed back to the river models as the equilibrium flux. The model outputs are used to assess indicators of groundwater use and reliability.

For lower priority GMUs no models are available and the assessments are limited to simple estimates of recharge, estimates of current and future extraction, allocation based on State data, and estimates of the current and future impacts of extraction on streamflow where important.

1.8 Environmental assessment

Environmental assessments on a region by region basis consider the environmental assets already identified by State governments or the Australian Government that are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001) or the updated on-line database of the directory. From this directory, environmental assets are selected for which there exists sufficient publicly available information on hydrological indicators (such as commence-to-fill levels) which relate to ecological responses such as bird breeding events.

Information sources include published research papers and reports, accessible unpublished technical reports, or advice from experts currently conducting research on specific environmental assets. In all cases the source of the information on the hydrological indicators used in each assessment is cited. The selection of the assets for assessment and hydrologic indicators was undertaken in consultation with State governments and the Australian Government through direct discussions and through reviews by the formal internal governance and guidance structures of the project.

The Directory of Important Wetlands in Australia (Environment Australia, 2001) lists over 200 wetlands in the MDB. Information on hydrological indicators of ecological response adequate for assessing scenario changes only exists for around one-tenth of these. More comprehensive environmental assessments are beyond the terms of reference for the project. The Australian Department of Environment and Water Resources has separately commissioned a compilation of all available information on the water requirements of wetlands in the MDB that are listed in the Directory of Important Wetlands in Australia.

For regions where the above selection criteria identify no environmental assets, the river channel itself is considered as an asset and ecologically-relevant hydrologic assessments are reported for the channel. The locations for which these assessments are provided are guided by prior studies. In the Victorian regions for example, detailed environmental flow studies have been undertaken which have identified environmental assets at multiple river locations with associated hydrological indicators. In these cases a reduced set of locations and indicators has been selected in direct consultation with the Victorian Department of Sustainability and Environment. In regions where less information is available, hydrological indicators may be limited to those that report on the water sharing targets that are identified in water planning policy or legislation.

Because the environmental assessments are a relatively small component of the project, a minimal set of hydrological indicators are used in assessments. In most cases this minimum set includes change in the average period between events and change in the maximum period between events as defined by the indicator.

A quality assurance process is applied to the results for the indicators obtained from the river system models which includes checking the consistency of the results with other river system model results, comparing the results to other published data and with the asset descriptions, and ensuring that the river system model is providing realistic estimates of the flows required to evaluate the particular indicators.

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2 Overview of the region

The Lachlan region is in central western New South Wales and covers 8 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the virtually terminal Lachlan River. The population is around 90,000 or 4.7 percent of the MDB total, concentrated in the major centres of Cowra, Young, Parkes, Forbes, West Wyalong and Condobolin. The dominant land use is dryland pasture used for sheep and beef cattle grazing. There were 47,900 ha of irrigated cropping within the region in 2000. Enterprises included cotton, pasture, hay and cereal grain production. Small volumes of grapes and other horticultural products are produced in the upper and lower Lachlan valley. Slightly less than 20 percent of the region is covered with native vegetation. The region includes the nationally significant Booligal Wetlands and Great Cumbung Swamp located on the lower reaches of the Lachlan River.

The region uses 3.5 percent of the surface water diverted for irrigation and 14.1 percent of the groundwater used in the MDB (one of the highest levels of groundwater extraction within the MDB). Wyangala Dam located on the Lachlan River upstream of Cowra is the major water storage in the region. Approximately two-thirds of the irrigation water used is sourced from surface water diversions. Groundwater is extracted from alluvial aquifers in the western portion of the region to irrigate cotton crops, and for stock and domestic purposes.

The following sections summarise the region’s biophysical features including rainfall, topography, land use and the environmental assets of significance. It outlines the institutional arrangements for the region’s natural resources and presents key features of the surface and groundwater resources of the region including historical water use.

2.1 The region

The Lachlan region is located within central western New South Wales and covers 85,532 km^2 or 8 percent of the MDB. It is bounded to the east by the Great Dividing Range, to the north by the Macquarie-Castlereagh region, to the north-west by the Barwon-Darling region and to the south by the Murrumbidgee region. The region terminates to the west at the gauging station on the Lachlan River at Oxley where it joins the Murray region some 46 km above the Lachlan’s junction with the Murrumbidgee River. The region’s topography varies from tablelands in the east, through the central slopes to western plains where the Lachlan River terminates in the extensive wetlands of the Great Cumbung Swamp. Major water resources in the Lachlan region include the Lachlan River and its tributaries, alluvial aquifers, wetlands and water storages. Both public and private infrastructure is associated with these water storages, including the Wyangala Dam in the headwaters of the Lachlan River and on-farm water storages.

The mean annual rainfall for the region is 461 mm varying from around 1000 mm in the east to 200 mm in the west. Rainfall varies considerably between years and is generally higher in the summer months in the north, tending to winter dominant rainfall in the south. The region’s average annual rainfall was relatively consistent over the 40 years to 1995 at a level higher than the preceding 60 years. The mean annual rainfall over the ten-year period 1997 to 2006 of 425 mm is around 8 percent lower, but not statistically significantly different, than the long-term (1895 to 2006) mean values.

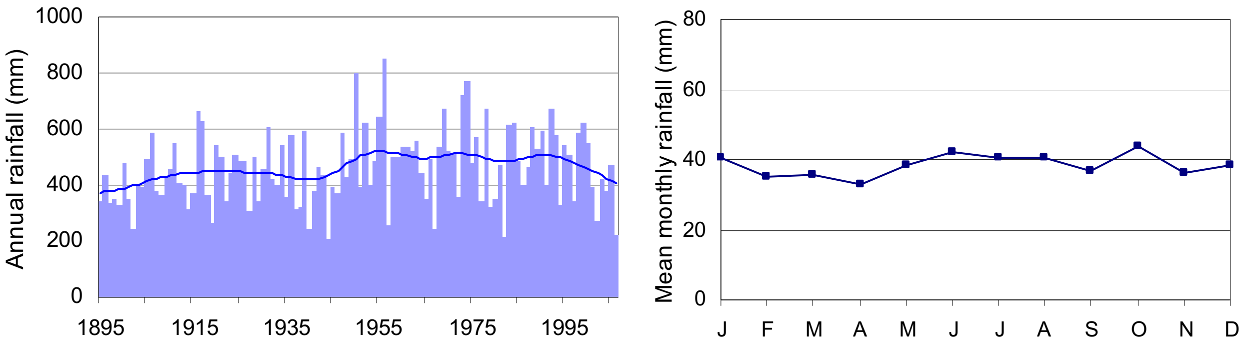

Figure 2-1. 1895 to 2006 annual and monthly rainfall averaged over the region. The curve on the annual graph shows the low frequency variability.

The Lachlan region contributes about 6.5 percent of the total runoff in the MDB. The mean annual modelled runoff over the region for the 112-year period is 23 mm and is highest in the winter months. The mean annual modelled runoff over the ten-year period 1997 to 2006 was 24 percent lower, but not statistically significantly different, than the long-term (1895 to 2006) mean values.

The regional population is approximately 90,000 or 4.7 percent of the MDB's total population. The larger towns in the region are Cowra, Young, Parkes, Forbes, West Wyalong and Condobolin. The dominant land use is dryland pasture used for broadacre grazing. Dryland cropping is a major enterprise and almost 20 percent of the region is covered with native vegetation. There are 47,900 ha of irrigated cropping within the region with the major enterprises being pastures and hay and cereal grain production. Cherries and other stone fruits are grown in the upper (unregulated) parts of the catchment around Young. Grapes are grown near Cowra and crops such as cotton and summer crops, including lucerne, are irrigated along the broad floodplains of the lower valley (NSW IC, 2007). The area of irrigated cropping varies depending on water availability and averaged 85,000 ha between 1988/89 and 1998/99 with almost 100,000 ha grown in 1996/97 (NSW Agriculture, 2003). The land use map (Figure 2-2) and land use area (Table 2-1) are based on the '2000 land use of the MDB grid', derived from 2001 Bureau of Rural Sciences AgCensus data. Irrigation estimates are based on crop areas recorded as irrigated in the census.

Table 2-1. Summary of land use in the year 2000 within the Lachlan region

Land use	Area		
	percent		ha
Dryland crops	15.5%		1,328,600
Dryland pasture	62.6%		5,349,800
Irrigated crops	0.6%		47,900
Cereals		*25.3%*	*12,100*
Cotton		*5.2%*	*2,500*
Horticulture		*3.3%*	*1,600*
Orchards		*6.7%*	*3,200*
Pasture and hay		*55.3%*	*26,500*
Vine fruits		*4.2%*	*2,000*
Native vegetation	19.6%		1,676,900
Plantation forests	0.8%		64,200
Urban	0.1%		12,400
Water	0.8%		71,700
Total	**100.0%**		**8,551,500**

Source: BRS, 2000.

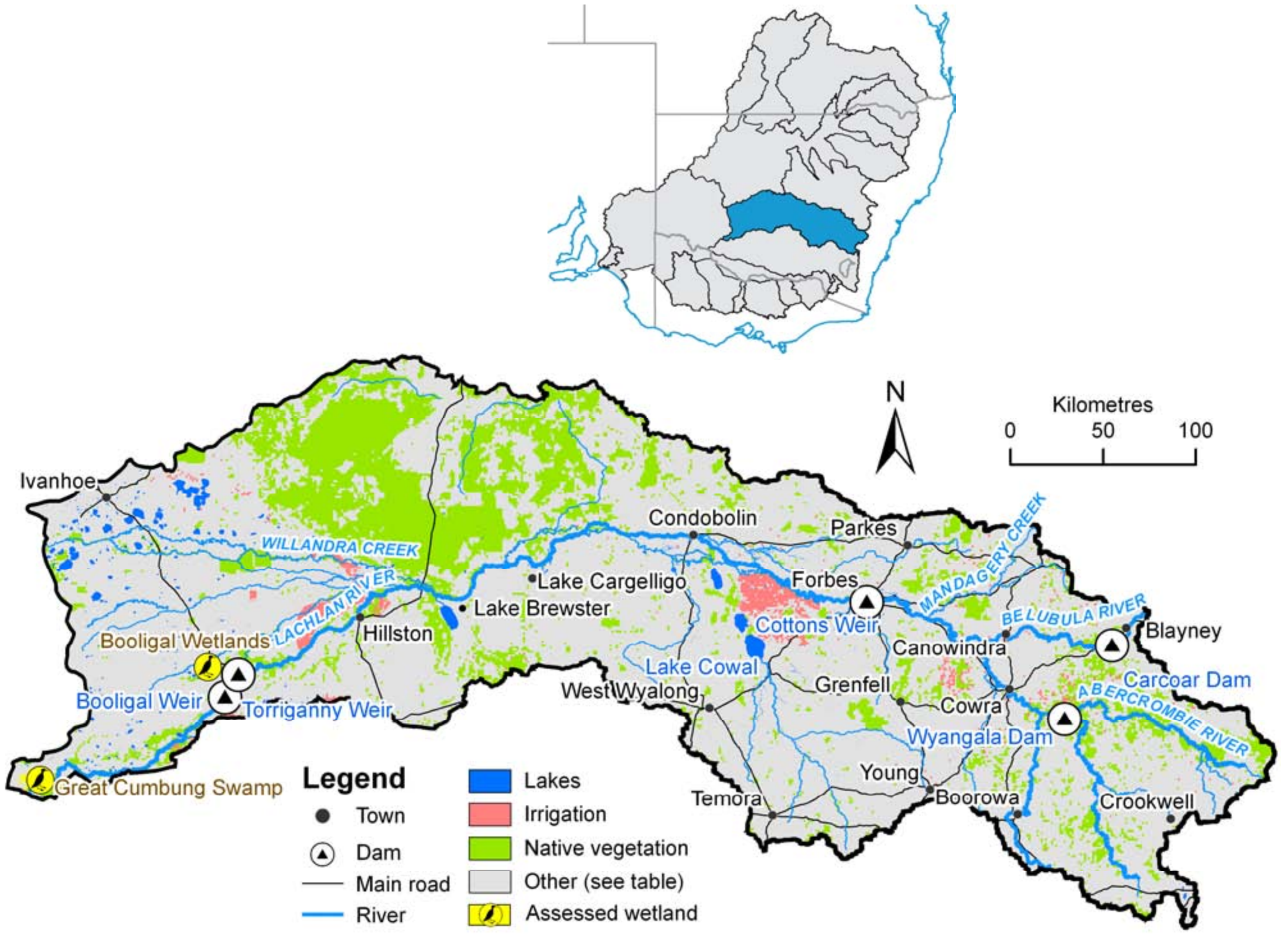

Figure 2-2. Map of dominant land uses of the Lachlan region with inset showing the region's location within the Murray-Darling Basin. Due to the lack of space only major towns and dams are shown. The assets shown are only those assessed in the study (see Chapter 7) and that fall within the region. A full list of key assets associated with the region is in Table 2-2.

The Lachlan Catchment Action Plan provides a strategy for managing natural resources in the region. It was prepared under the Catchment Management Authorities (CMA) Act 2003 and was approved in January 2007 for a term of ten years. The plan focuses on four main natural resource management issues including: biodiversity and native vegetation; land management; water and aquatic ecosystems; and people and community. It specifies catchment and management targets for each of these areas that will contribute to the implementation of state-wide targets for natural resource management. The Lachlan Catchment Action Plan will guide investment towards managing priority natural resource issues within the Lachlan catchment, ensuring the best outcomes for the environment and the community (LCMA, 2007).

The water theme within the Lachlan Catchment Action Plan covers groundwater and river ecosystems. The strategic objective is 'Water resources that meet community and environmental needs for quality and quantity'. The CMA seeks to address pressures on water quality (physical and chemical), on water use (surface and groundwater) and on the habitats found instream, in wetlands and on floodplains. Carp were identified by the community as a contributor to all of these pressures. This theme also deals with operational influences such as instream structures (weirs), flow regimes and flooding. Social values stated by the Lachlan community, such as Aboriginal and European cultural values and aesthetics, have also been recognised in developing the targets (LCMA, 2007).

2.2 Environmental description

Climate, soils and geology vary significantly throughout the region, creating ecosystems classified as sub-alpine in the east to semi-arid rangeland in the west of the catchment. The region can be broken up into three zones – the upper, mid- and lower catchment.

The upper catchment is characterised by elevated undulating country of the western slopes of the Great Dividing Range. Lucerne is grown on the small alluvial flats.

The mid-catchment is characterised by undulating landscape and fertile alluvial floodplains adjacent to the watercourses and includes the section of river between Wyangala Dam and Lake Brewster. Large areas of lucerne and pasture are irrigated on the fertile alluvial floodplains and smaller areas of winter cereals and pastures are irrigated on the poorer red soils. The Jemalong Irrigation Ltd area of operations is located within this section of the region.

The lower catchment includes the area west of Lake Brewster and includes the broad alluvial floodplain. A range of winter crops are grown on the poor red soils and more recently areas of citrus, cotton, vines and vegetables have been grown near Hillston (NSW Agriculture, 2003).

The region's geology is complex. The soils range from very robust, durable soils to very fragile soils and naturally acidic and sodic soils. This variability in soil types creates significant management issues for erosion control, nutrient management and salinity management (LCMB, 2003). A land and water management plan has been developed to address, in part, salinity within the Jemalong Irrigation Ltd area of operations. The salinity levels of the Lachlan River are predicted to increase from 560 EC units in 1998 to 1460 EC units by 2100 (MDBC, 1999).

Native vegetation in the Lachlan region was substantially altered by the development of land for timber, agriculture, mining and housing and by the introduction of weeds and pest species. The Lachlan River and its main tributaries have become regulated due to the demand for a more reliable water supply for these land uses (LCMB, 2003).

The Lachlan region contains several important and large wetlands. The wetlands within the region that have national importance are detailed in Table 2-2. There are no wetlands classified as Ramsar sites of international significance within the region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people. The Booligal Wetlands and the Great Cumbung Swamp are amongst the most notable sites.

The Booligal Wetlands cover approximately 5000 ha on the lower Lachlan River near the township of Booligal. The wetlands are low-gradient braided channels situated on the Muggabah-Merrimajeel Creek, a distributary creek system which leaves the Lachlan River. The wetlands include the Booligal Swamp, and Little Gum Swamp, and are also associated with Lake Merrimajeel and Murrumbidgil swamps which are downstream on the same creek system. Flood flows into the system are infrequent and the area drains rapidly once floods in the river recede (Environment Australia, 2001).

The wetlands are well known for providing habitat for a large number and species of waterbirds when the area is flooded. Breeding colonies of 80,000 pairs have been recorded, including Straw-necked (*Threskiornis spinicollis)*, White (*T. mollucca*) and Glossy Ibis (*Plegadis falcinellus*). This area is considered to be one of the top five breeding sites for these species in Australia. Freckled Duck (*Stictonetta naevosa*) and Blue-billed Duck (*Oxyura australis*) are state vulnerable species and have been recorded at this site. Little Gum Swamp is notable for providing breeding habitat for several species of egret. Lignum (*Muehlenbeckia florulenta*) is the primary vegetation of the Booligal Swamp area, with River Red Gum (*Eucalyptus camaldulensis*) being the dominant over-storey at Little Gum Swamp (Magrath, 1992).

The Great Cumbung Swamp is around 16,000 ha located at the terminus of the Lachlan River and is adjacent to the Murrumbidgee River and the Lowbidgee Wetlands (described within the project report for the Murrumbidgee region (CSIRO, 2008)). The swamp is dependent on flood flows in the Lachlan River (Environment Australia, 2001). The core area of approximately 4000 ha of the swamp is dominated by Common Reed (*Phragmites australis*). Cumbungi (*Typha orientalis*) occurs along the more frequently flooded stream lines. River red gum (*Eucalyptus camaldulensis*) and Black Box (E. *argiflorens*) woodland cover large areas of the swamp. Numerous species of waterbird are found at the swamp particularly after flooding, including Freckled Duck (*Stictonetta naevosa*) and Blue-billed Duck (*Oxyura australis*).

Table 2-2. Ramsar wetlands and wetlands of national significance located within the Lachlan region

Site code	Directory of Important Wetlands in Australia name	Area[(1)]	Ramsar sites
		ha	
NSW040	Lake Cowal/Wilbertroy Wetlands	20,500	N
NSW043	Booligal Wetlands	5,000	N
NSW044	Cuba Dam	1,680	N
NSW045	Great Cumbung Swamp	16,000	N
NSW047	Lachlan Swamp (Part of mid-Lachlan Wetlands)	6,600	N
NSW048	Lake Brewster	6,140	N
NSW049	Lake Merrimajeel/Murrumbidgil Swamp	300	N
NSW051	Merrowie Creek (Cuba Dam to Chillichil Swamp)	2,500	N

[(1)]Wetland areas have been extracted from the Australian Wetlands Database and are assumed to be correct as provided from state and territory agencies.

Source: Environment Australia, 2001.

2.3 Surface water resources

2.3.1 Rivers and storages

The Lachlan River flows in a westerly direction from its headwaters in the foothills of the Great Dividing Range near Gunning between Yass and Goulburn and terminates in the Great Cumbung Swamp near Oxley in southwestern New South Wales. Wyangala Dam, located upstream of Cowra at the confluence of the Lachlan and Abercrombie rivers, is the major water storage within the region and has a storage capacity of 1218 GL. The major tributary streams of the Lachlan River include the Abercrombie, Boorowa, Belubula and Crookwell rivers, and Mandagery and Willandra creeks. Small instream storages include Carcoar Dam (36 GL) located on the Belubula River upstream of Canowindra and numerous smaller weirs along the length of the Lachlan River including Brewster Weir (5.5 GL), as well as Nanami, Cottons, Jemalong, Booberoi, Lake Cargelligo, Willandra, Gonowlia, Hillston, Whealbah, Torriganny and Booligal weirs. Offstream storages include Lake Cargelligo (36 GL) and Lake Brewster (153 GL) near Hillston (State Water, 2005). The estimated total volume of hillside dams with their own catchment is reported as 261 GL (Chapter 3). The Lachlan river model does not include any private on-farm storages for irrigation (Chapter 4).

2.3.2 Surface water management institutional arrangements

The Water Management Act 2000 in New South Wales requires the implementation of ten-year plans defining water sharing arrangements between the environment and water users and amongst water user groups. The plans aim to protect rivers and aquifers and their dependent ecosystems, and to provide water users with clarity and certainty regarding water access rights.

Water access is based on a long-term average annual extraction limit. The basic rights (native title rights, domestic and stock rights) and access licences for domestic and stock use and local water utilities are volumetric and are granted highest access priority. High and general security access licences are based on shares of the water available, with high security having priority over general security. Most general security access licences are expressed as a relative unit share of the available water rather than as an annual volume. Licensing continues under the Water Act 1912 in areas where water sharing plans have not yet been gazetted.

The water sharing arrangements for this region are contained in the Water Sharing Plan (WSP) for the Lachlan Regulated River Water Source 2003 (DIPNR, 2004a) and WSP for the Mandagery Creek Water Source (DIPNR, 2004b). The Lachlan Regulated River WSP applies to the section of the Lachlan River downstream of Wyangala Dam to the Great Cumbung Swamp. The plan also covers the upstream, regulated portion of Willandra Creek. The Mandagery Creek water source is one of the major tributaries of the Lachlan River. It is an unregulated stream that drains Mt Canobolas in the east, the Curumbenya Range in the north and the Harvey and Croker Ranges to the north-west.

Other streams in the Lachlan region not covered by these plans are currently subject to the macro water sharing planning process. This includes several distributary streams on the lower Lachlan River that receive water from the Lachlan Regulated River WSP area.

Macro water plans are being prepared for unregulated rivers and groundwater in New South Wales and will include up to 28 surface water plans and 5 groundwater plans. Macro water plans are WSPs which apply to a number of water sources across catchments or to different types of aquifers. These plans will generally apply to catchments where there is less intensive water use and which account for most of the remaining 20 percent of water use not already managed by existing WSPs. Macro WSPs contain a standard set of rules extended across catchments with similar attributes and values (social, economic and environmental) and reflect the priorities of environment, basic landholder rights, town water and licensed domestic and stock use and other extractive uses (including irrigation). Implementation is expected to occur from 2009 (DWE, 2007).

The water sharing arrangements for the Lachlan region are detailed in Table 2-3.

Table 2-3. Summary of surface water sharing arrangements

Water products	Priority of access	Lachlan Regulated River Water Sharing Plan	Mandagery Creek Water Source
		Allocated entitlement	
		ML/y	
Basic rights			
Stock and domestic rights		None	6.3 ML/day
Native title		None	0
Extraction shares			
Total licensed (long-term) extraction limit		305,000	Not specified
Local water utilities	high	15,539	
High security access	high	26,472 unit shares	
General security access	medium	592,847 unit shares	7,748
Conveyance	high	17,911	
Domestic and stock	high	13,100	
Environmental provisions			***
Total environmental share		907,000*	
Environmental allocation	high	350,000 unit shares**	

Source: DIPNR (2004a and 2004b).

* By limiting long-term average annual extractions to an estimated 305,000 ML/y this plan ensures that approximately 75 percent of the long-term average annual flow in this water source (estimated to be 1,212,000 ML/y) will be preserved and will contribute to the maintenance of basic ecosystem health.

** An allowance for replenishment flows to be provided for the environment and unregulated river access licences if required, of up to 12,000 ML/y to Willandra Creek; 9,000 ML/y to Marrowie Creek; 9,000 ML/y to Torriganny/ Muggabah/ Merrimajeel Creeks; and 12,500 ML/y to Booberoi Creek.

*** The environmental flow provision for Mandagery Creek Water Source is the total daily flow minus the total daily extraction limit and stock and domestic rights. The total daily extraction limit varies with the daily flow level.

2.3.3 Water products and use

There is extensive irrigation in the mid to lower areas of the Lachlan region. A range of crops are grown including grapes, horticulture, pasture, lucerne, cotton and cereals. Major irrigation development dates from the construction of the Jemalong scheme in 1934 and the completion of Wyangala Dam in 1937. The dam was enlarged to a capacity of 1220 GL in 1971.

The Jemalong Irrigation District, located between Forbes and Condobolin, covers 93,000 ha. Its boundaries are the Lachlan River to the north, Lake Cowal to the south and narrow hilly ranges to the east and west.

The district is primarily a mixed farming area, with an annual rainfall of 432 mm. Irrigated enterprises include prime lamb and cattle production, irrigated and dryland summer and winter cropping, lucerne and lucerne seed production. Between 12,000 and 20,000 ha are irrigated annually from a current total irrigable area of approximately 41,500 ha.

Surface water diversions within the region have declined substantially from around 300 to 400 GL/year prior to 2002/03 to less than 100 GL/year over the past six years due to low runoff and hence low annual water allocations (Figure 2-3). General security water licence holders have only had annual allocations in two years since 2001/02: in 2002/03 (3 percent); and 2005/06 (19 percent). High security licence holders received annual water allocations of between 30 and 100 percent of entitlement each year since 2001/02 (DNR, 2007).

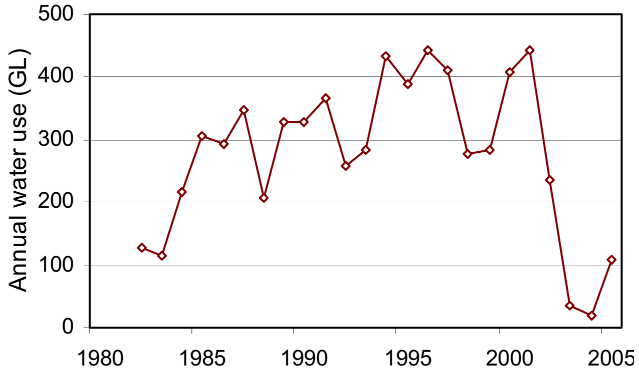

Figure 2-3. Historical surface water diversions

Note: The data in different years are not always comparable because the areas defined in each catchment changed, as did the definitions of water uses. Even where data sets should refer to the same records, data from state and Murray-Darling Basin Commission databases often vary. Sources: MDBC, 2007a.

2.4 Groundwater

2.4.1 Groundwater management units – the hydrogeology and connectivity

The primary source of groundwater resources in the Lachlan region are the Lower and Upper Lachlan alluvial aquifers.

In the western parts the basal aquifer in the sequence is the Renmark Group. It comprises alluvial sands and gravels and black clay and peat. The Renmark Group is hydraulically connected to the overlying Calivil Formation and is highly productive in areas where groundwater salinity is sufficiently low for irrigation.

The Calivil Formation is deposited within a Late Miocene and Pliocene drainage system. It is composed of coarse alluvial channel sands and gravels. The Calivil Formation is the watertable aquifer for much of the western area and the overlying Shepparton Formation is above the watertable in many areas.

The Shepparton Formation is composed of river and lake deposits of variegated clay and lenses of yellow and brown shoestring sands. It is deposited in the western portion of the region and displays low yields and generally high salinities.

In the middle section of the region the valley is in-filled by the basal Lachlan Formation which in turn is overlain by the Cowra Formation. The Lachlan Formation hosts the major groundwater resource and is composed of alluvial sands and gravels. The Cowra Formation is composed of alluvial channel sands and floodplain clays and displays generally low yields. The Lachlan Formation is used to source water for towns including Parkes.

There is a lower level of groundwater development outside of the Lower and Upper Lachlan Alluvium aquifers. Recharge to the fractured rock systems within the highland areas of the catchment flows through the fractures to discharge into adjacent streams and valley floors. Alluvium is deposited within the highland valleys and the rivers in these valleys tend to be gaining in nature.

The region can be divided into two broad hydrogeological areas: the hilly country to the east and the broad flat alluvial plain to the west.

The Central West Highlands cover approximately half of the Lachlan region and outcropping highland rocks surround the Upper Lachlan Catchment. The following hydrogeological description is sourced from the Murray Darling-Basin Commission Groundwater Status Report (URS, 2006).

In the highland reaches of the catchment the hydrogeology is dominated by fractured rock aquifers in a range of different geologies including granites, volcanics, basalts and consolidated sediments. Generally the permeability of these systems is low but can be locally high where secondary porosity has developed via intense fracturing of hard rocks or dissolution in limestone belts.

The major source of recharge is seasonal via rainfall. Recharge to the fractured rocks occurs on hilltops and slopes, particularly where there is a thin soil cover. Discharge typically occurs in localised areas at the break-of-slope, at changes in lithology, along structural geological controls, at changes in soil texture and at low positions in the landscape.

Streams receive discharge as baseflow and washoff. Groundwater salinity levels in the fractured rocks are variable but generally low in the east and higher in the west.

Basaltic flows, sills, dykes, laccoliths and plugs within the catchment also contain groundwater. These typically occur in the more highly elevated areas of the catchment, or as low-profile sheet flows and sills. There is significant development of groundwater within the Orange Basalt.

Horizontal and vertical water movement occurs readily through fractures in the rock. These systems respond rapidly to changes in the water balance and receive a high degree of recharge that flushes the systems of salt. Therefore groundwater salinity is typically low. Discharge occurs at stratigraphic and structural boundaries and where streams have locally incised the basalts to receive low-salinity groundwater as baseflow.

Weathered and unweathered granite bodies occur within the catchment and express gently undulating hills and valleys with minor granitic outcrops to tors and other larger granitic outcrops. Groundwater flows through fractures and through pores in the weathered granites. Recharge is largely via seasonal rainfall and occurs mostly on hilltops and slopes where weathered sequences are thin or non-existent. Discharge occurs in localised areas at the break-of-slope, at lateral changes in soil texture and in the bases of some valleys. Streams receive discharge as baseflow and runoff. These systems have highly variable salinity and respond to changes in the water balance rapidly. Weathered zones may contain lower salinity groundwater. There is significant development of groundwater within the Young Granites.

In the highland valleys there are accumulations of alluvial sediment consisting of sands and gravels deposited along the valley floors and terraced floodplains. Recharge is seasonal and episodic in nature and depends on the nature of the soils and weathered rock above the watertable and on the frequency and intensity of floods. Discharge occurs typically along drainage lines and in localised areas at changes in soil texture, at the break-of-slope and at the bases of terraces.

Unconsolidated alluvial sediment deposited in the larger highland valleys of the major rivers experiences groundwater flows perpendicular to the river. The precise direction of this flow is dependent on the local geological conditions as the alluvium tends to contain layers of sands and gravels as well as possible clay layers. This can result in a varying connection with the stream as it passes through the alluvium, being gaining in one place, losing in another and disconnected in others. Groundwater salinity increases towards the more remote parts of the aquifer.

The Lachlan River and the Cowra Formations are highly connected in the middle sections of the valley, between Cowra and Hillston. All streams run across the top of the Shepparton Formation in the western parts of the region on the alluvial plain. The rivers at the eastern margin of the plain are in direct hydraulic contact with the watertable. The watertable further towards the west falls well below the streams and an unsaturated zone develops resulting in constant leakage from streams to the underlying aquifer. Recharge to the groundwater system on the alluvial plain is primarily from leakage from the stream channel under normal flows, leakage from overbank flooding, and infiltration from rainfall. The watertable in the far western parts of the region is shallow and diffuse groundwater discharge is possible. There are no coordinated surface drainage systems in this area and most groundwater would be lost to the atmosphere via evapotranspiration.

Groundwater levels in the fractured rock aquifers of the Lachlan region show a broad correlation with long-term climate. Rising water level trends of the mid-1990s have been replaced by falling trends during the current extended drought. Within the Renmark Group groundwater levels have shown three distinct trends. Levels are rising in bores that are close to the Lachlan River but removed from areas of groundwater extraction.

These rising levels are thought to correlate with increased river leakage due to river regulation. Falling levels are associated with the major areas of groundwater extraction. Steady water levels are associated with areas in the western parts of the western plain.

The Calivil Formation displays similar water level trends to those in the Renmark Group. Generally, water levels have risen except in areas where groundwater use is high. In these areas the rising trend of the 1980s and 1990s has been reversed, probably due to pumping. Water levels in the Cowra Formation have fallen significantly displaying declines of up to 6 m over ten years. These declines have demonstrated the impact that pumping in the deeper Lachlan Formation has had on the groundwater levels of the Cowra Formation.

The Lachlan region is subdivided into six Groundwater Management Units (GMUs) for management purposes, excluding the minor parts of the Lower Murrumbidgee Alluvium (N02) that overlap into the Lachlan region.

These GMUs cover the entire region and are based on an appreciation of the hydrogeological setting of the groundwater resource in each case. The Lachlan region GMUs are shown in Figure 2-4.

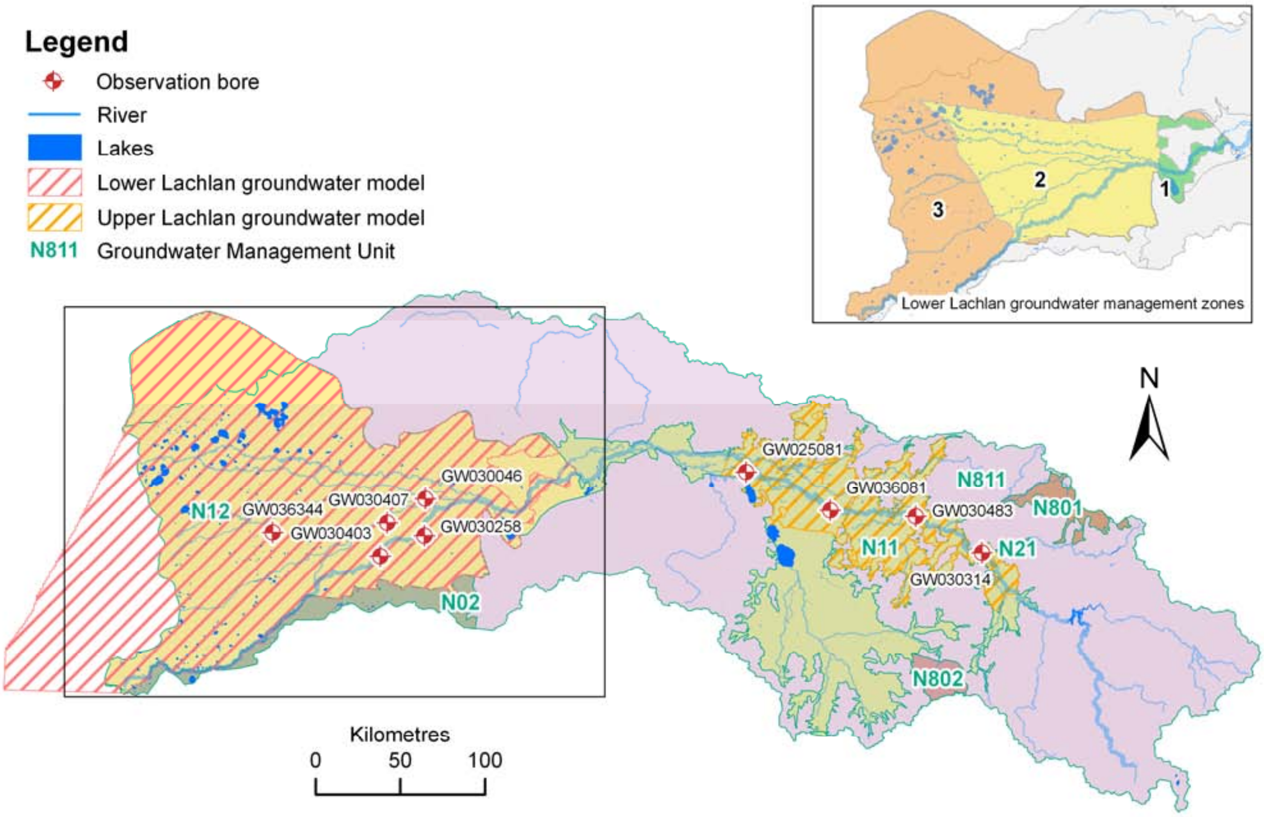

Figure 2-4. Map of groundwater management units within the Lachlan region with inset showing Lower Lachlan groundwater management zones (Chapter 6)

The Lachlan region includes two GMUs that partially overlap four other GMUs. The Lower Lachlan Alluvium GMU and the Upper Lachlan Alluvium GMU are categorised as very high priority and are subject to detailed analysis using numerical groundwater modelling techniques (Chapter 6). The Belubula Valley Alluvium is categorised as low priority. There are three other low-priority GMUs that extend into adjacent regions. These GMUs are ranked according to the degree of development and the stress on the groundwater resource, the complexity of hydrogeological assessments available for the individual areas, and the degree of connectivity between the groundwater and surface water resources.

Current groundwater extraction, entitlement and recharge is itemised for each GMU in the Lachlan region (Table 2-4). All data in the table is sourced from a summary of Macro Groundwater Sharing Plans provided by New South Wales Department of Water and Energy (DWE) unless otherwise indicated.

Table 2-4. Categorisation of groundwater management units, including annual extraction, entitlement and recharge details

Code	GMU	Priority	Assessment	Total entitlement	Current extraction* (2004/05)	Long-term average extraction limit***	Maximum likely extraction without plan revision
				GL/y			
N12	Lower Lachlan Alluvium	high	thorough	108**	125.7	108 (plus basic landholder rights)**	108 (plus basic landholder rights)**
N11	Upper Lachlan Alluvium	very high	thorough	191.99	72.73	91.55	191.99
N21	Belubula Valley Alluvium	high	simple	6.29	5.18	0.22	6.29
N801	Orange Basalt	low	simple	6.23	3.89	12.9	6.45
N802	Young Granite	low	simple	7.75	6.19	7.55	7.75
N811	Lachlan Fold Belt	low	simple	33.46	22.28	476.75	119.19

* Current groundwater extraction for Macro Groundwater Sharing Plan areas is based on metered and estimated data provided by DWE. Data quality is variable depending on the location of bores and the frequency of meter reading.

** Source: DWE, 2008.

*** For Macro Groundwater Sharing Plan areas, these limits are draft, as plans for these areas are not yet gazetted.

2.4.2 Water management institutional arrangements

The Water Management Act 2000 in New South Wales requires the implementation of ten-year plans defining water sharing arrangements between the environment and groundwater users and amongst water user groups, in a similar way to that required for surface water diversions. WSPs have been prepared for the more highly developed GMUs to protect rivers and aquifers and their dependent ecosystems, and to provide water users with clarity and certainty regarding water access rights. Where current extraction levels exceed the long-term extraction limit a supplementary access volume has been determined. This access volume will decrease to zero within ten tears of commencement of the WSP. Outside of areas covered by WSPs, groundwater extraction is controlled by Macro Water Sharing Plans (Macro WSPs) which provide a groundwater extraction limit and environmental provisions. Groundwater extraction records for the Macro WSP regions are generally poor. The Macro WSPs will commence in 2009.

The WSP for the Lower Lachlan Groundwater Source was gazetted in February, 2008 (DWE, 2008). The plan applies to all water contained in the Lower Lachlan unconsolidated alluvial aquifers and sets a long term extraction limit of 108 GL/year. The extraction limit allows for access licences up to 105.654 GL/year plus town water supply and basic rights. The WSP is expected to reduce extraction to the long-term average extraction limit (LTAEL) by 2018 via the use of supplementary licences. The WSP also estimates recharge to be 108 GL/year.

The Upper Lachlan GMU is under embargo on new entitlement (except for Basic Rights) and there is no limit on usage. The LTAEL used in this report was provided by DWE for this project only as a possible long term limit in the absence of any plan.

The ‘Achieving Sustainable Groundwater Entitlements’ structural adjustment program, funded jointly by the New South Wales and the Australian governments under the National Water Initiative, is supporting the reduction in entitlements to equal the LTAEL.

An environmental provision exists equal to the long-term average storage component of the groundwater resource. This will be reviewed within five years of the plan coming into effect. A domestic and stock entitlement of 0.024 GL/year per bore has been calculated. The plan recognises that this may increase over the life of the plan.

Groundwater extraction in other parts of the region is controlled by Groundwater Macro WSPs. The groundwater sharing arrangements are detailed in Table 2-5.

Table 2-5 Summary of groundwater management plans

Description	Lower Lachlan Alluvium	Remaining GMUs
Name of plan	Water Sharing Plan for the Lower Lachlan Groundwater Source 2003	Groundwater Macro Water Plans
Year of plan	2008	*
Environmental provisions		
Planned share	The long-term average storage component of this groundwater source minus the supplementary water access component	30–50% of rainfall recharge
Adaptive provisions	Water may be committed in this water source for environmental purposes by an adaptive environmental water condition	none
Basic rights		
Domestic and stock rights	4 GL/y	28.15 GL/y
Access licences		
Native title	0 GL/y	none
Urban	2.32 GL/y	11.12 GL/y
Planned share	105.65 GL/y	206.44 GL/y
Supplementary provisions	Supplementary component of 21.25 GL/y reduced to zero GL/y by 2018	none
Available water determination	An available water determination will be made at the start of each water year based on a share of the resource	none

* The Macro WSPs are planned to commence in 2009.

2.4.3 Water products and use

Total current (2004/05) groundwater extraction within the Lachlan region accounts for 14.1 percent (236 GL/year) of the total groundwater extraction in the MDB. There are 8573 groundwater users. The majority of the extractions are for stock and domestic use. Groundwater is extracted from alluvial deposits and fractured granites and basalts. There is a large number of bores in the Lower and Upper Lachlan Alluvium. Other groundwater development areas include the Young Granites and the Orange Basalt GMUs. Pumping bores are distributed relatively widely outside of these areas and are constructed in consolidated and fractured rock aquifers with poorer water quality and yields.

Significant groundwater development in the Lower Lachlan Alluvium GMU began in the late 1970s. Records indicate that groundwater extraction increased rapidly in the late 1990s after the mid-1990s drought. Current (2004/05) extraction is 122.47 GL/year (MDBC, 2007b). Groundwater extraction in the Upper Lachlan in 2004/05 is reported as 65 GL/year and is used to supply irrigation, stock, domestic and town water supplies.

The Lower Lachlan Alluvium GMU is the most developed GMU in the Lachlan region and has been subject to investigation and management over a long period. The Upper Lachlan Alluvium GMU is also well developed. Historical annual groundwater extraction is shown in Figure 2-5. Very little information exists for the region's other four GMUs. The major use of groundwater in low priority areas is for stock and domestic supplies.

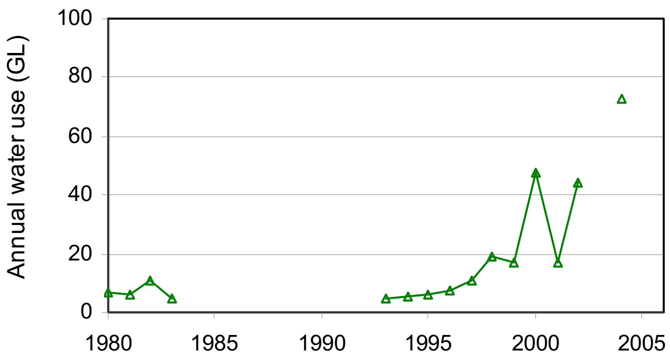

Figure 2-5. Historical groundwater extractions within the Upper Lachlan Alluvium

2.5 References

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3 Rainfall-runoff modelling

This chapter includes information on the climate and rainfall-runoff modelling for the Lachlan region. It has four sections:

- a summary
- an overview of the regional modelling approach
- a presentation and description of results
- a discussion of key findings.

3.1 Summary

3.1.1 Issues and observations

- The methods used for climate scenario and rainfall-runoff modelling across the Murray-Darling Basin (MDB) are described in Chapter 1. There are no significant differences in the methods used to model the Lachlan region.

3.1.2 Key messages

- The mean annual rainfall and modelled runoff averaged over the Lachlan region are 461 mm and 23 mm respectively. Rainfall is fairly uniform throughout the year and runoff is highest in the winter months. The Lachlan region covers about 8 percent of the MDB and contributes about 6.5 percent of the total runoff in the MDB.
- The mean annual rainfall and runoff over the ten-year period 1997 to 2006 are 8 percent and 24 percent lower respectively than the long-term (1895 to 2006) means values. However, because of the inter-annual variability and the ten-year period used being relatively short as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the long-term (1895 to 1996) mean values, even at a significance level of $\alpha = 0.2$.
- Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Lachlan region is more likely to decrease than increase. Two-thirds of the modelling results show a decrease in runoff and one-third of the results show an increase in runoff. The best (median) estimate is a 10 percent reduction in mean annual runoff by 2030. The extreme estimates, which come from the high global warming scenario, range from a 34 percent reduction to a 17 percent increase in mean annual runoff. By comparison, the range from the low global warming scenario is a 12 percent reduction to a 4 percent increase in mean annual runoff.
- The projected growth in commercial forestry plantations in the Lachlan region is negligible. The total farm dam storage volume over the entire Lachlan region is projected to increase by 36,000 ML (an increase of 14 percent of current farm dam storage volume) by ~2030. This projected increase in farm dams will reduce mean annual runoff by less than 2 percent, which is relatively small compared to the best estimate climate change impact on runoff (10 percent). The best estimate of the combined impact of climate change and farm dam development is a 12 percent reduction in mean annual runoff. Extreme estimates range from 35 percent reduction to a 15 percent increase.

3.1.3 Uncertainty

- Scenario A – historical climate and current development
  The runoff estimates for the eastern parts of the Lachlan region, where runoff is highest, are relatively good because there are many gauged catchments there from which to estimate the model parameter values. Rainfall-runoff model verification analyses for the MDB indicate that the mean annual runoff estimated for individual ungauged catchments using optimised parameter values from a nearby catchment have an error of less than 20 percent in more than half the catchments and less than 50 percent in almost all the catchments (with similar amounts of underestimations and overestimations).
- Scenario C – future climate and current development
  The biggest uncertainty in Scenario C modelling is in the global warming projections and the modelled implications of global warming on local rainfall. The uncertainty in the rainfall-runoff modelling of climate change impact on runoff is small compared to the climate change projections. This project takes into account the current uncertainty in climate change projections explicitly by considering results from 15 global climate models and three global warming scenarios based on the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007). The results are then presented as a median estimate of climate change impact on runoff and as the range of the extreme estimates.
- Scenario D – future climate and future development
  After the Scenario C climate change projections, the biggest uncertainty in Scenario D modelling is in the projections of future increases in commercial forestry plantations and farm dam development and the impact of these developments on runoff. The impact of commercial forestry plantations on runoff is not modelled because the Bureau of Rural Sciences projections indicate negligible growth in commercial forestry in the Lachlan region. The increase in farm dams is estimated by considering trends in historical farm dam growth and current policy controls in New South Wales and there is uncertainty both as to how landholders will respond to these policies and how governments may set their future policies.

3.2 Modelling approach

3.2.1 Rainfall-runoff modelling – general approach

The general rainfall-runoff modelling approach is described more fully in Chapter 1 and in detail in Chiew et al. (2008). A brief summary is given below.

The lumped conceptual daily rainfall-runoff model, SIMHYD, is used with a Muskingum routing method to estimate daily runoff at 0.05^{o} grids (~ 5 km x 5 km) across the entire MDB for the four scenarios. The rainfall-runoff model is calibrated against 1975 to 2006 streamflow from about 180 small and medium size unregulated catchments (50 to 2000 km^2). The six parameters of SIMHYD are optimised in the model calibration to maximise an objective function that incorporates the Nash-Sutcliffe efficiency of monthly runoff and daily flow duration curve. The optimisation includes a volumetric constraint to ensure that the total modelled runoff over the calibration period is within 5 percent of the total recorded runoff. The runoff for a 0.05^{o} grid cell in an ungauged subcatchment is modelled using optimised parameter values for a calibration catchment closest to that subcatchment.

The rainfall-runoff model SIMHYD is used because it is simple and has relatively few parameters. For the purpose of this project it provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire MDB and for assessing the potential impacts of climate change and development on future runoff. In data-rich areas, specific calibration of SIMHYD or more complex rainfall-runoff models based on expert judgement and local knowledge as carried out by some state agencies, would lead to better model calibration for the specific modelling objectives of the area.

3.2.2 Rainfall-runoff modelling for the Lachlan region

The rainfall-runoff modelling is carried out to estimate runoff in 0.05^{o} grid cells in 17 subcatchments as defined for the river system modelling in Chapter 4 for the Lachlan region (Figure 3-1). Optimised parameter values from seven calibration catchments are used. Six of these calibration catchments are in the Lachlan region. The other calibration catchment is in the Macquarie-Castlereagh region just north of the Lachlan region. All the calibration catchments are in the high runoff areas in the eastern parts of the region.

Scenario B modelling is not carried out for the Lachlan region because the mean annual rainfall and modelled runoff for the ten-year 1997 to 2006 period are not significantly different (at statistical significance level of α = 0.2 with the Student-t and Rank-Sum tests) from the long-term (1895 to 1996) means values (Section 3.3.1).

The impact of commercial forestry on runoff is not modelled because the Bureau of Rural Sciences projections that take into account industry information indicate negligible growth in commercial plantation forestry in the Lachlan region.

The increase in farm dams in each subcatchment is estimated as the lower of the available harvestable right volume based on current policies and the projected additional storage volume based on extrapolation of historical farm dam growth rate. This resulted in an estimate of 36,000 ML increase in farm dam storage volume by ~2030 over the entire Lachlan region. The projected increases in farm dam storage volume by ~2030 for each subcatchment are given in Appendix A.

The farm dam projection is dependent on three factors: current farm dam storage volume; growth rate of farm dams; and maximum harvestable right in New South Wales Water Management Act 2000 (New South Wales Government, 2000). The current farm dam storage volume is estimated from satellite imagery captured between 2004 and 2006 (Geosciences Australia, 2007). The farm dam growth rate is estimated using data from Agrecon (2005) for 1999 to 2004. This indicates a growth rate of 0.6 percent per year in this region. The maximum harvestable right volume is estimated by multiplying the area of each land parcel by the harvestable right dam capacity per unit area multiplier for that property (New South Wales Department of Natural Resources, supplied 7 March 2007) and then aggregating the values for all of the individual properties across the reporting region. The maximum harvestable right across rural land in the Lachlan region is about 322,000 ML. The estimate of current farm dam storage volume over the entire Lachlan region is about 260,000 ML, with these farm dams utilising about 127,000 ML of the harvestable right. There are farm dams capturing more than the maximum harvestable right volume that was later defined by the Water Management Act. The available harvestable right is therefore about 195,000 ML. The projection of 36,000 ML increase in farm dam storage volume over the entire Lachlan region by ~2030 is therefore an increase of about 14 percent of current farm dam storage volume and about 19 percent of the remaining available harvestable right.

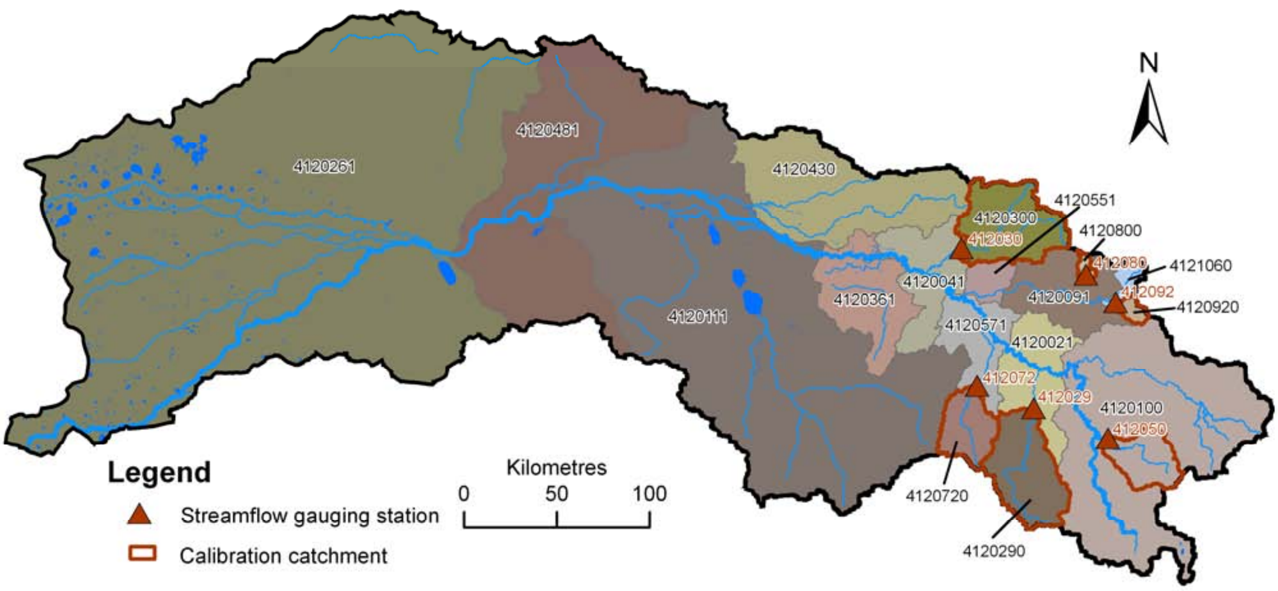

Figure 3-1. Map of the modelling subcatchments and calibration catchments

3.2.3 Model calibration

Figure 3-2 compares the modelled and observed monthly runoff and the modelled and observed daily flow duration curves for the 7 calibration catchments. The results indicate that the SIMHYD calibration can reproduce reasonably the observed monthly runoff series (Nash-Sutcliffe E values generally greater than 0.7) and the daily flow duration characteristic (Nash-Sutcliffe E values generally greater than 0.8). The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration to optimise Nash-Sutcliffe E means that more importance is placed on the simulation of high runoff, and therefore SIMHYD modelling of the medium and high runoff are considerably better than the simulation of low runoff. Nevertheless, an optimisation to reduce overall error variance will result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow duration curves. The disagreement between the modelled and observed daily runoff characteristics is discernable for runoff that is exceeded less than 0.1 or 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis.

The runoff estimates for the eastern parts of the Lachlan region, where runoff is highest, are relatively good because there are many calibration catchments there from which to estimate the model parameter values. The rainfall-runoff model verification analyses for the MDB with data from about 180 catchments indicate that the mean annual runoffs for ungauged catchments are under- or over- estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in more than half the catchments and by less than 50 percent in almost all the catchments.

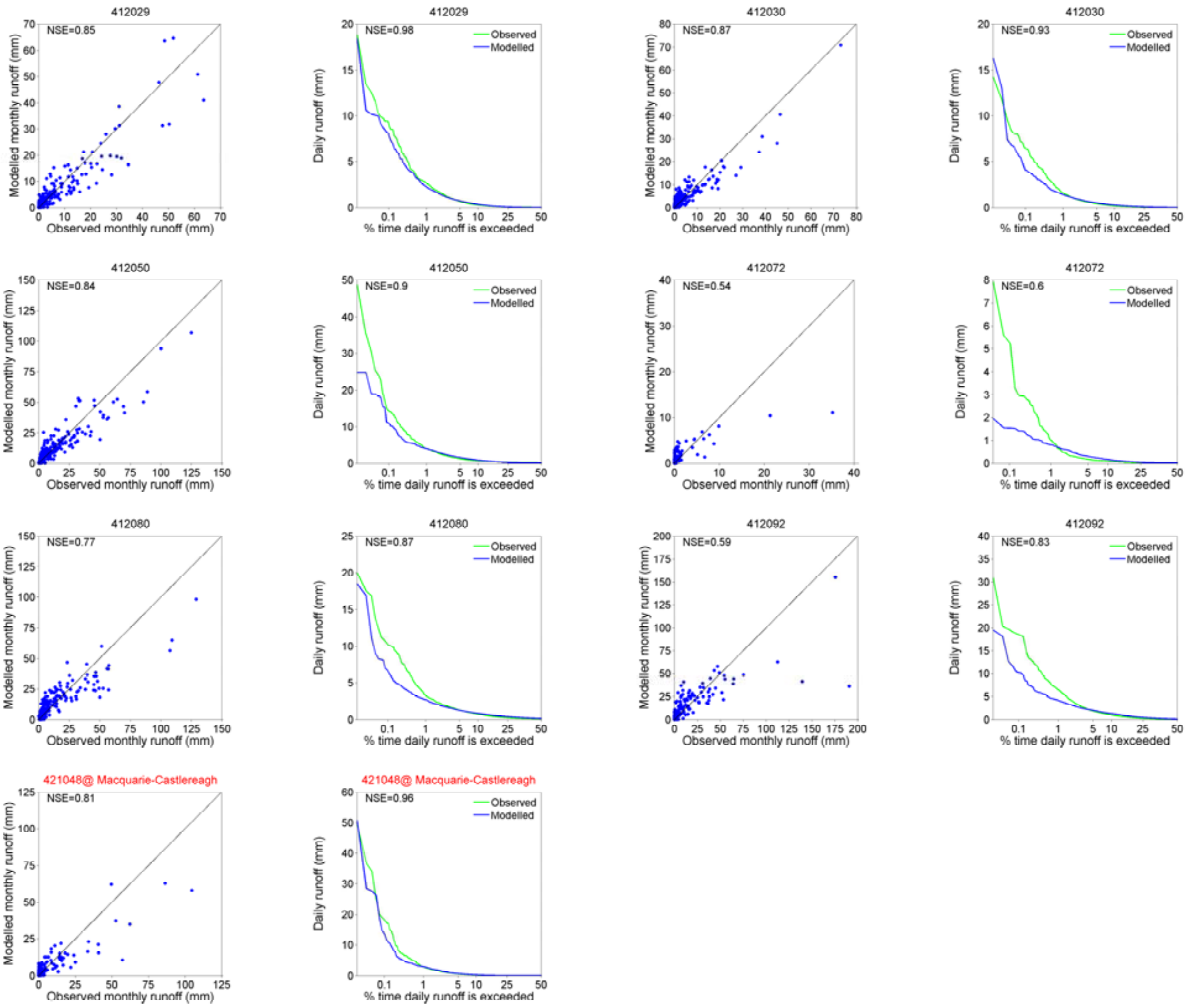

Figure 3-2. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

3.3 Modelling results

3.3.1 Scenario A – historical climate and current development

Figure 3-3 shows the spatial distribution of mean annual rainfall and modelled runoff for 1895 to 2006 across the Lachlan region, Figure 3-4 shows the 1895 to 2006 annual rainfall and modelled runoff series averaged over the region, and Figure 3-5 shows the mean monthly rainfall and runoff averaged over the region for 1895 to 2006.

The mean annual rainfall and modelled runoff averaged over the Lachlan region are 461 mm and 23 mm respectively. The mean annual rainfall varies from about 850 mm in the east to 300 mm in the west. The modelled mean annual runoff varies from about 130 mm in the east to less than 5 mm in the west (Figure 3-3). Rainfall is fairly uniform throughout the year and runoff is highest in the winter months (Figure 3-5). The Lachlan region covers about 8 percent of the MDB and contributes about 6.5 percent of the total runoff in the MDB.

Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure 3-4). The coefficients of variation of annual rainfall and runoff averaged over the Lachlan region are 0.28 and 0.82 respectively, slightly higher than the median values in the 18 MDB regions (the 10th percentile, median and 90th percentile values across the 18 regions are 0.22, 0.26 and 0.36 respectively for rainfall and 0.54, 0.75 and 1.19 for runoff).

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 8 percent and 24 percent lower respectively than the long-term (1895 to 2006) mean values. However, because of the inter-annual variability and the ten-year period used being relatively short as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the long-term (1895 to 1996) mean values, even at a significance level of $\alpha = 0.2$ (with the Student-t and Rank-Sum tests). Potter et al. (2008) present a more detailed analysis of recent rainfall and runoff across the MDB.

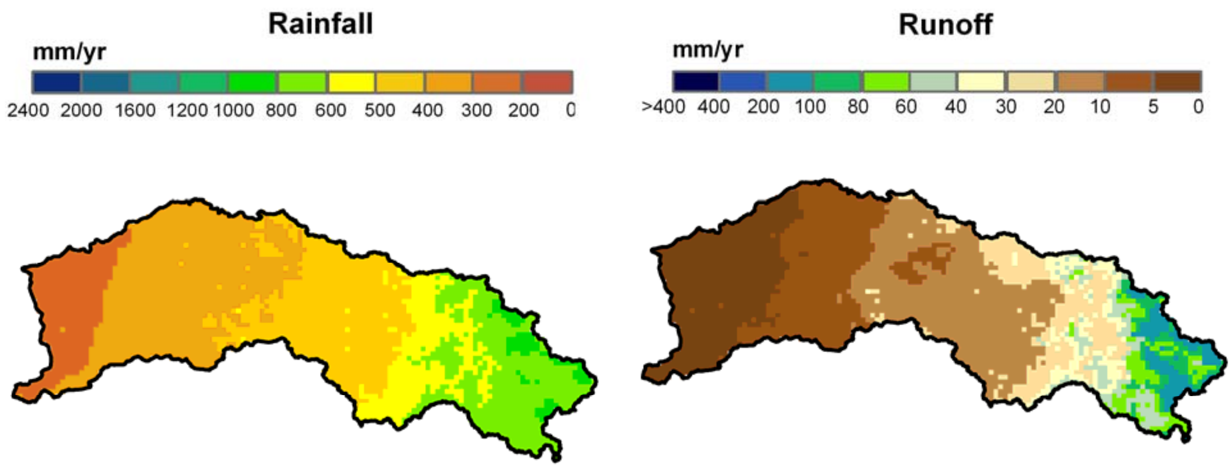

Figure 3-3. Spatial distribution of mean annual rainfall and modelled runoff averaged over 1895–2006

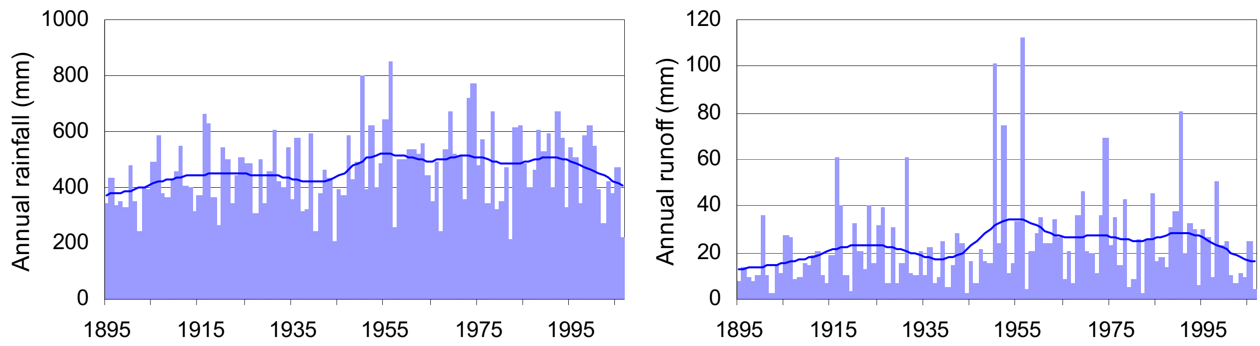

Figure 3-4. 1895–2006 annual rainfall and modelled runoff averaged over the region (the curve shows the low frequency variability)

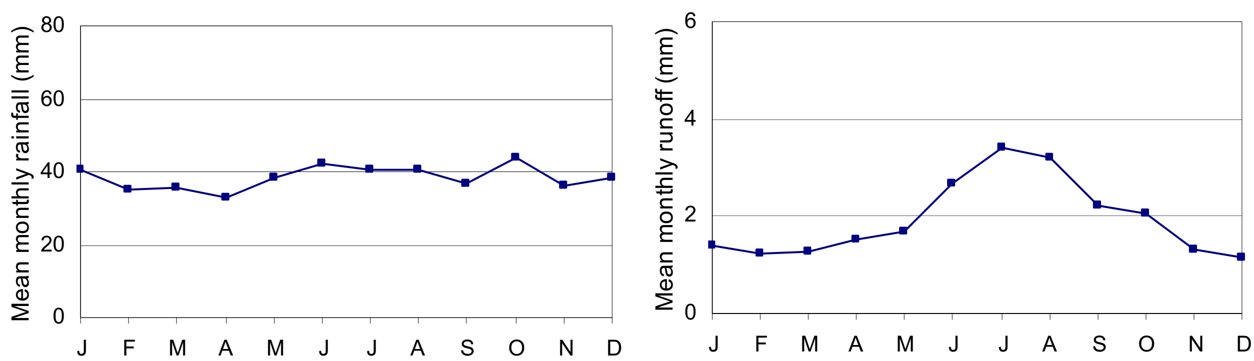

Figure 3-5. Mean monthly rainfall and modelled runoff (averaged over 1895–2006 for the region)

3.3.2 Scenario C – future climate and current development

Figure 3-6 shows the percentage change in the modelled mean annual runoff averaged over the Lachlan region for Scenario C relative to Scenario A for the 45 scenarios (15 Global Climate Models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and the percentage change in mean annual rainfall from the corresponding GCMs are also tabulated in Table 3-1.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the Lachlan region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from two-thirds of the GCMs shows a reduction in mean annual runoff, and rainfall-runoff modelling with climate change projections from one-third of the GCMs shows an increase in mean annual runoff.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios (Section 1.3.3), the biggest increase and biggest decrease in runoff comes from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from 60 percent of the GCMs indicates a decrease in mean annual runoff greater than 10 percent, and rainfall-runoff modelling with climate change projections from one-quarter of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other chapters, only results from an extreme 'dry', 'mid' and extreme 'wet' variant are shown (referred to as Cdry, Cmid and Cwet). Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table 3-1. Scenarios Cdry, Cmid and Cwet indicate a -34, -10 and +17 percent change in mean annual runoff. By comparison, the range based on the low global warming scenario is -12 to +4 percent change in mean annual runoff.

Figure 3-7 shows the mean annual runoff across the Lachlan region under Scenario A and scenarios Cdry, Cmid and Cwet.

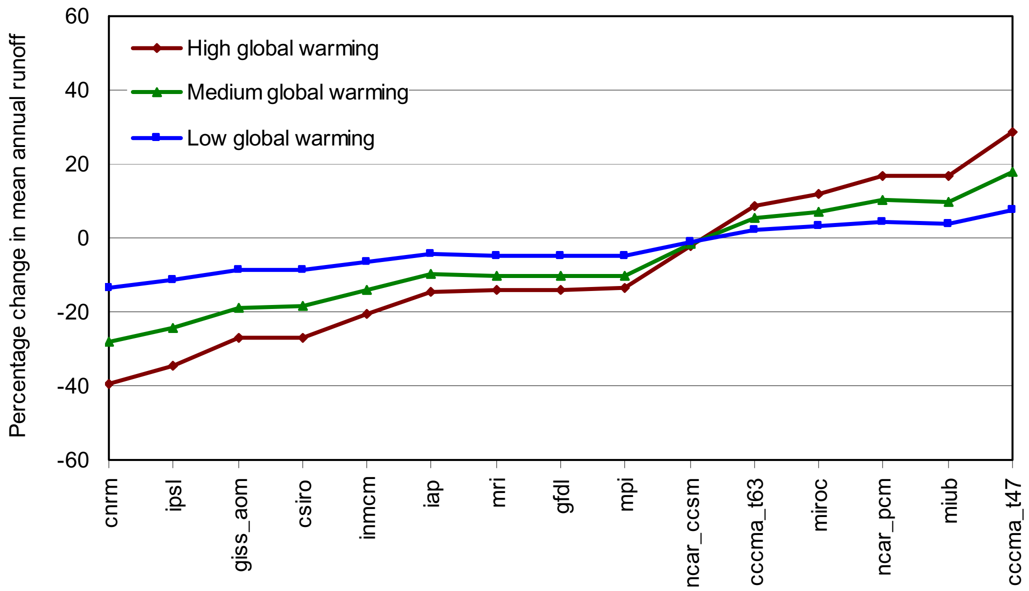

Figure 3-6. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A runoff

Table 3-1. Summary results under the 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and runoff under Scenario C relative to Scenario A)

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Runoff	GCM	Rainfall	Runoff	GCM	Rainfall	Runoff
cnrm	-13	-39	cnrm	-9	-28	cnrm	-4	-14
ipsl	**-17**	**-34**	ipsl	-11	-24	ipsl	-5	-12
giss_aom	-14	-27	giss_aom	-9	-19	giss_aom	-4	-9
csiro	-10	-27	csiro	-6	-19	csiro	-3	-9
inmcm	-4	-21	inmcm	-3	-14	inmcm	-1	-6
iap	-3	-14	mri	-2	-10	gfdl	-1	-5
mri	-4	-14	gfdl	-3	-10	mpi	-2	-5
gfdl	-5	-14	**mpi**	**-4**	**-10**	mri	-1	-5
mpi	-6	-13	iap	-2	-10	iap	-1	-4
ncar_ccsm	3	-2	ncar_ccsm	2	-2	ncar_ccsm	1	-1
cccma_t63	5	9	cccma_t63	3	5	cccma_t63	1	2
miroc	7	12	miroc	4	7	miroc	2	3
ncar_pcm	7	17	miub	5	10	miub	2	4
miub	**8**	**17**	ncar_pcm	4	10	ncar_pcm	2	4
cccma_t47	8	29	cccma_t47	5	18	cccma_t47	2	8

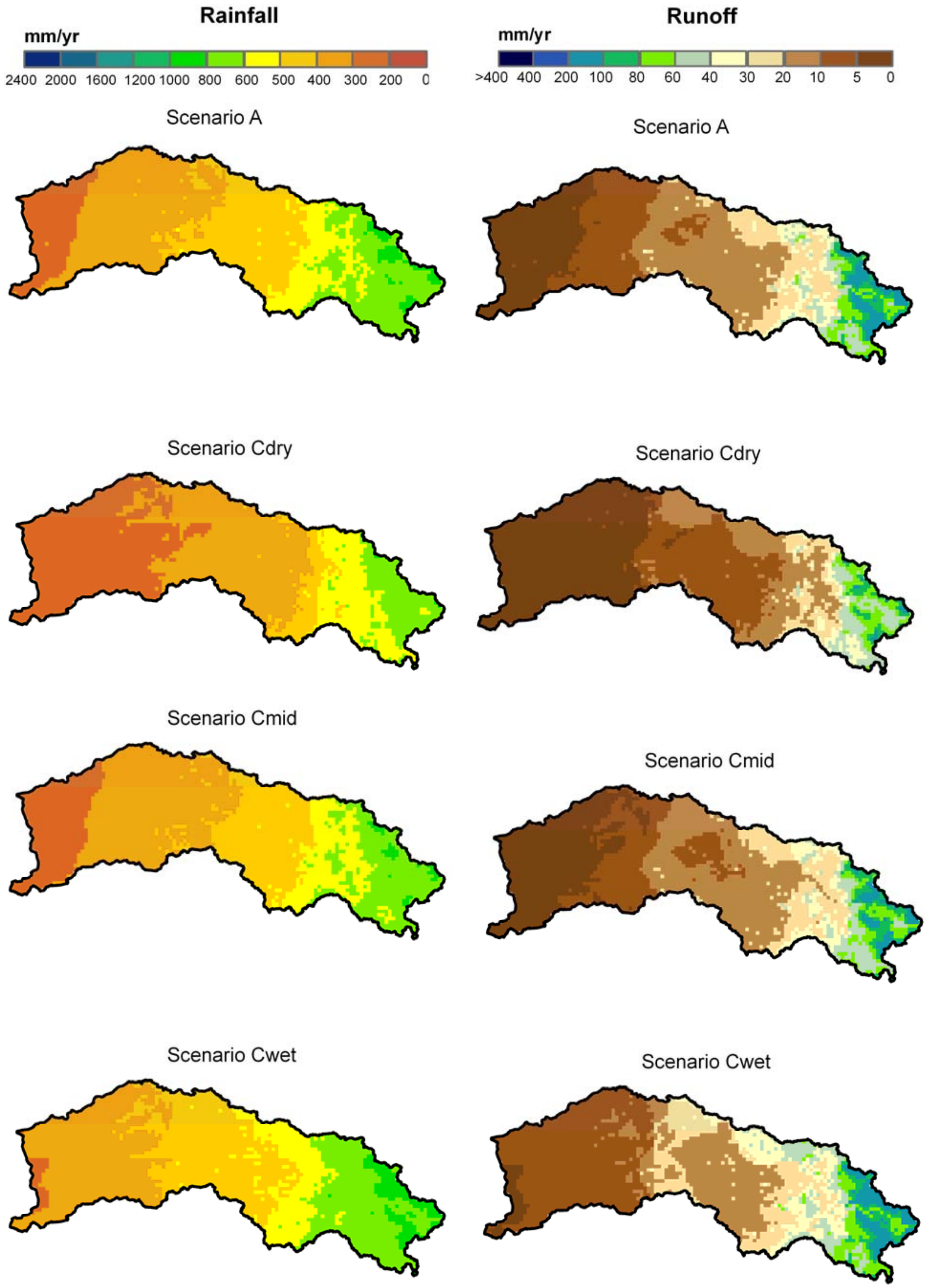

Figure 3-7. Mean annual rainfall and modelled runoff under scenarios A, Cdry, Cmid and Cwet

3.3.3 Summary results for all modelling scenarios

Table 3-2 shows the mean annual rainfall, modelled runoff and actual evapotranspiration under Scenario A averaged over the Lachlan region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios C and D relative to Scenario A. The Cdry, Cmid and Cwet results are based on the modelled mean annual runoff, and the rainfall changes shown in Table 3-2 are the changes in the mean annual value of the rainfall series used to obtain the Cdry, Cmid and Cwet runoff. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions.

Figure 3-8 shows the mean monthly rainfall and modelled runoff for scenarios A, C and D averaged over 1895 to 2006 for the region. Figure 3-9 shows the daily rainfall and flow duration curves for scenarios A, C and D averaged over the region. The modelling results for all the subcatchments in the Lachlan region are summarised in Appendix A.

The Cmid (or Cdry or Cwet) results are from rainfall-runoff modelling using climate change projections from one GCM. As the Cmid scenario is chosen based on mean annual runoff (see Section 3.3.2), the comparison of monthly and daily results in Scenario Cmid relative to Scenario A in Figure 3-8 and Figure 3-9 should be interpreted cautiously. However, the C range results shown in Figure 3-8 are based on the second driest and second wettest results for each month separately from the high global warming scenario, and the C range results shown in Figure 3-9 are based on the second lowest and second highest daily rainfall and runoff results at each of the rainfall and runoff percentiles from the high global warming scenario. The lower and upper limits of C range are therefore not the same as the Cdry and Cwet scenarios reported elsewhere and used in the river system and groundwater models. Although two-thirds of the GCMs show a reduction in mean annual rainfall, more than two-thirds of the GCMs indicate that the extreme rainfall that is exceeded 0.1 and 1.0 percent of the time will be more intense (Figure 3-9).

Scenario B (recent climate and current development) modelling is not carried out for the Lachlan region because the mean annual rainfall and modelled runoff for the ten-year period 1997 to 2006 is not statistically significantly different to the long-term (1895 to 1996) mean values. The Scenario B results would therefore be essentially the same as the Scenario A results.

The modelling results indicate a median estimate of a 10 percent reduction in mean annual runoff by ~2030 (Scenario C). However, there is considerable uncertainty in the climate change impact estimate with extreme estimates ranging from -34 percent to +17 percent.

The projected growth in commercial forestry plantations in the Lachlan region is negligible. The total farm dam storage volume over the entire Lachlan region is projected to increase by 36,000 ML by ~2030. The best estimate of the combined impact of climate change and farm dam development is a 12 percent reduction in mean annual runoff, with extreme estimates from -35 percent to +15 percent (Scenario D).

Table 3-2. Water balance over the entire region by scenario

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	461	23	437
		percent change from Scenario A	
B	–	–	–
Cdry	-17%	-34%	-16%
Cmid	-4%	-10%	-3%
Cwet	8%	17%	7%
Ddry	-17%	-35%	-16%
Dmid	-4%	-12%	-3%
Dwet	8%	15%	7%

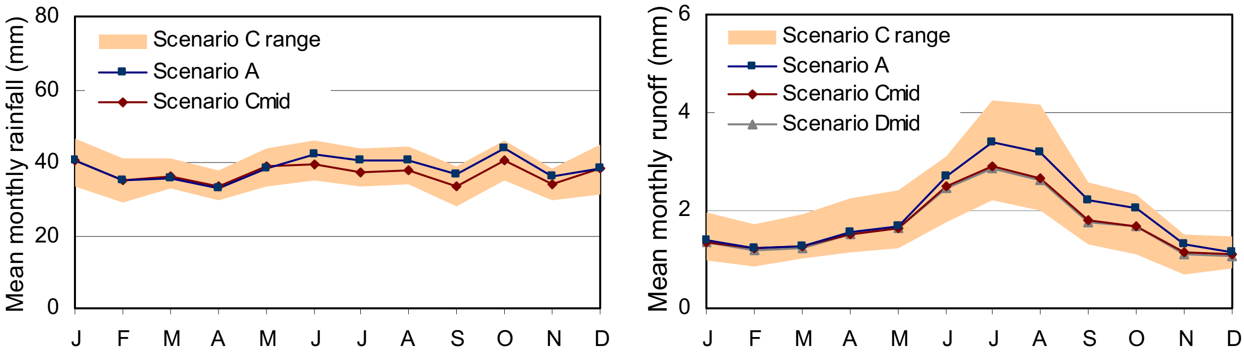

Figure 3-8. Mean monthly rainfall and modelled runoff under scenarios A, C and D averaged over 1895–2006 across the region (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

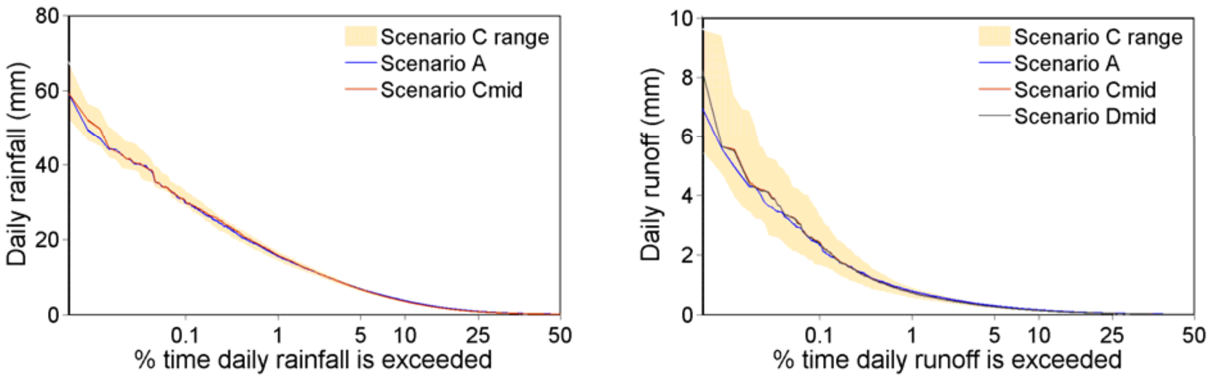

Figure 3-9. Daily flow duration curves under scenarios A, C and D averaged over the region (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

3.4 Discussion of key findings

The mean annual rainfall and modelled runoff averaged over the Lachlan region are 461 mm and 23 mm respectively. The mean annual rainfall varies from about 850 mm in the east to 300 mm in the west. The modelled mean annual runoff varies from about 130 mm in the east to less than 5 mm in the west. Rainfall and runoff are fairly uniform throughout the year. The Lachlan region covers about 8 percent of the MDB and contributes about 6.5 percent of the total runoff in the MDB.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 8 percent and 24 percent lower respectively than the long-term (1895 to 2006) mean values. However, because of the inter-annual variability and the ten-year period used being relatively short as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the 1895 to 1996 long-term (1895 to 1996) mean values, even at a significance level of $\alpha = 0.2$.

The runoff estimates for the eastern parts of the Lachlan region, where most of the runoff comes from, are relatively good because there are many calibration catchments there from which to estimate the model parameter values.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Lachlan region is more likely to decrease than increase. Two-thirds of the modelling results show a decrease in mean annual runoff and one-third shows an increase in mean annual runoff.

However, although two-thirds of the results indicate a decrease in mean annual rainfall and runoff, more than half of the results also indicate that the extreme rainfall will be more intense.

The median estimate is a 10 percent reduction in mean annual runoff by ~2030 relative to ~1990. However, there is considerable uncertainty in the modelling results with the extreme estimates ranging from -34 percent to +17 percent. These extreme estimates come from the high global warming scenario. As a comparison the range from the low global warming scenario is -12 to +4 percent change in mean annual runoff. The main sources of uncertainty are in the global warming projections and the global climate modelling of local rainfall response to the global warming. The uncertainty in the rainfall-runoff modelling of climate change impact on runoff is small compared to the climate change projections.

The projected growth in commercial forestry plantations in the Lachlan region is negligible. The total farm dam storage volume over the entire Lachlan region is projected to increase by 36,000 ML (or an increase of 14 percent of current farm dam storage volume) by ~2030. The best estimate of the combined impact of climate change and farm dam development is a 12 percent reduction in mean annual runoff, with extreme estimates ranging from -35 percent to +15 percent. The modelled reduction in mean annual runoff from the projected increase in farm dams alone is less than 2 percent, relatively small compared to the runoff reduction in the best estimate climate change projection (10 percent).

There is considerable uncertainty in the projection of future increases in farm dam development and the impact of these new farm dams on runoff. The increase in farm dams is estimated by considering trends in historical farm dam growth and current policy controls and there is uncertainty both as to how landholders will respond to these policies and how governments may set policies in the future.

3.5 References

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4 River system modelling

This chapter includes information on the river system modelling for the Lachlan region. It has four sections:

- a summary
- an overview of the regional modelling approach
- a presentation and description of results
- a discussion of key findings.

The information in this chapter comes from the calibrated IQQM model of the Lachlan River system of the New South Wales Department of Water and Energy (DWE) (DLWC, 2001).

4.1 Summary

4.1.1 Issues and observations

River system modelling for the Lachlan region considers ten modelling scenarios:

- Scenario O
  This scenario represents the latest version of the water sharing plan river system model supplied by DWE. It covers the original planning period 1 January 1898 to 30 June 2000 used by DWE to develop the Lachlan Regulated River Water Source Water Sharing Plan (WSP) (DIPNR, 2004).
- Scenario A0
  This scenario incorporates the Scenario O model but covers the longer common historical climate period (1 June 1895 to 30 June 2006). It does not include the effects of current groundwater extraction at dynamic equilibrium.
- Scenario A – historical climate and current development
  This scenario incorporates Scenario A0 and the effects of current groundwater extraction at dynamic equilibrium. It is a baseline for comparison with all other scenarios.
- Scenario P – without-development
  This scenario incorporates the model for Scenario A0 and covers the common historical climate period. Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Natural water bodies, fixed diversion structures and existing catchment runoff characteristics are not adjusted.
- Scenarios C – future climate and current development
  Scenarios Cwet, Cmid and Cdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A (Chapter 3). The level of development is the same as Scenario A, that is, the current level of development.
- Scenarios D – future climate and future development
  Scenarios Dwet, Dmid and Ddry incorporate Scenario C with flow inputs adjusted for 2030 projected development in farm dams, commercial forestry plantations and groundwater. Future groundwater effects on river reaches are also considered. The farm dam and commercial forestry plantation projections are discussed in Chapter 3 while groundwater development is discussed in Chapter 6.

The change in inflows between scenarios reported in this Chapter differs from the changes in runoff reported in Chapter 3. These differences are due to the difference in areas that are considered to contribute runoff to the surface water model. In Chapter 3 the entire region is considered while a subset of this area is considered here. These scenarios may not eventuate but they encompass consequences that might arise if no management changes were made. Consequently results from this assessment highlight pressure points in the system, both now and in the future. This assessment does not elaborate on what management actions might be taken to address any of these pressure points. The Lachlan region is described by the Lachlan River system model.

The Lachlan model:

- represents the 1999/2000 level of development. This includes farm infrastructure, irrigated areas and crop mix. The model is also calibrated to represent the farm management practices. The general security allocation is restricted to a maximum 75 percent of entitlement to match 1993/94 levels of average annual use. Modelled demands may not match history of use as farm development is not static over time
- simulates irrigation demands using a soil moisture accounting model with areas, soil depth, crop mixes, farm dams and farm infrastructure that best represents current levels of development
- the model also includes a risk function that adjusts areas planted according to water availability. Consequently the model represents the change in demand as a function of available resource and climatic conditions
- reflects town water supplies and stock and domestic demands with a fixed demand pattern that does not vary with water availability or climatic conditions. The only time that these demands are not met occur when supply storages reach dead storage capacity, as these are high security users.

The model used in this study differs from the model used to develop the WSP as it is configured for 1999/00 levels of development, while the WSP model was configured for 1993/94 levels of development. Due to this change in development, the entitlements used in the model differ from those reported in the WSP (as detailed in Chapter 2). Also, the WSP model uses a continuous accounting scheme whilst the model used here uses annual accounting.

Analysis of the without-development flows along the Lachlan system indicates that it changes from a gaining to a losing stream (point of maximum average annual flow) at the Nanami gauge (412057). The without-development average annual flow over the modelling period is 1139 GL/year.

4.1.2 Key messages

- Current average surface water availability is 1139 GL/year and on average about 321 GL/year (or 28 percent) of this water is used. This is a moderately high level of development and includes surface water diversions (292 GL/year) and eventual streamflow leakage to groundwater induced by current groundwater use.
- Flows in the Lachlan River are highly regulated (Wyangala Dam regulates 68 percent of all inflows) and general security water in the system is highly utilised (71 percent of the allocated general security water used).
- Current levels of groundwater extraction from the Upper and Lower Lachlan Alluvia are expected to eventually increase streamflow losses from the Lachlan River by about 50 percent over and above the natural streamflow loss to groundwater. Most of the additional loss will occur in the Upper Lachlan (while most of the natural losses will occur in the Lower Lachlan).
- Under the best estimate 2030 climate there would be an 11 percent reduction in water availability, a 13 percent reduction in end-of-system flows and an 8 percent reduction in diversions overall. Diversion impacts would differ between water products. General security water use would decrease by 2 percent in the Belubula system and 9 percent in the Lachlan system. High security town water supplies would not be impacted in either system. Other high security use would increase by 5 percent and 7 percent in the Belubula and Lachlan systems respectively due to demand increase, driven by climate change. The Lachlan River Environmental Contingency Allowance (ECA) would be reduced by 12 percent.
- The climate extremes for 2030 indicate:
  - under the wet extreme climate there would be increases of 6 percent in water availability, 9 percent in end-of-system flows and 4 percent in total diversions
  - under the dry extreme climate there would be decreases of 30 percent in water availability, 35 percent in end-of-system flows and 23 percent in total diversions
  - under the dry extreme 2030 climate high security town water supplies would not be met: a 2 percent reduction in supply would occur. There would be a 20 percent and 18 percent increase in use by other high security users in the Belubula and Lachlan systems respectively, but a 53 percent reduction in the ECA.

- Projected future development (additional groundwater extraction and farm dams) would reduce inflows (under the best estimate future climate) by 2 percent or 28 GL/year. Of this, about two thirds would be due to future farm dams and about one third due to future groundwater extraction. There would also be an additional 6 GL/year increase in streamflow leakage to groundwater in alluvial reaches (under the best estimate 2030 climate) due to projected increases in groundwater extraction. Diversions would reduce by an additional 2 percent to be 11 percent lower than current. The impact on average end-of-system flows would be a total reduction (development and climate impacts) of 15 percent. Development would impact on high security town water supplies under both the best estimate and the dry extreme 2030 climate. Development would also reduce the ECA by a further 4 percent in addition to the climate change impacts. The relative level of use would be 32 percent – this is a high level of development and is 4 percent higher than the current level.

4.1.3 Robustness

The model was run for an extreme climate scenario to assess how robustly it would behave. Typically the physical processes in the model, such as routing and storage behaviour, work through a full range of flow and storage conditions. However management rules in the model are closely tied to the historical data set that was used to develop them. When the historical data set is changed to represent much drier conditions there is no guarantee that models will behave robustly. Therefore it is important to check that models will perform reasonably when allocations and storages are zero or close to empty.

During this test scenario allocations were at zero percent in both the Lachlan and Belubula systems. All of the public storages were drawn down below dead storage capacity. The model behaved robustly during this extreme test.

The model response to increases and decreases in inflow was reasonable with the change in diversions and end-of-systems flows consistent with the change in inflow. Mass balance over the modelling period was zero for all scenarios (Appendix B).

4.2 Modelling approach

The following section provides a summary of the generic river modelling approach, a description of the Lachlan river model and how the river model was developed. Refer to Chapter 1 for more context on the overall project methodology.

4.2.1 General

River system models that describe current infrastructure, water demands, and water management and sharing rules are used to assess the implications of the changes in inflows on the reliability of water supply to users. Given the time constraints of the project, and the need to link the assessments to state water planning processes, it is necessary to use the river system models currently used by state agencies and the Murray-Darling Basin Commission. The main models in use are IQQM, REALM, MSM-Bigmod, WaterCress and a model of the Snowy Mountains Hydro-electric Scheme.

4.2.2 Model description

The Lachlan region is described by the Lachlan systems model (Figure 4-1). The Lachlan is modelled by an IQQM v7.61.2 implementation of the river system.

The model starts by representing headwater inflows from the Lachlan River into Wyangala Dam and the Belubula River into Carcoar Dam. The model ends at the Great Cumbung Swamp with Oxley gauge (412026) being the last gauge in the system. The river breaks out into Willandra Creek and eventually runs dry. Willandra Creek is not modelled beyond the effluent gauge. The Lachlan will flow into the Murrumbidgee River during extremely large floods. This connection is not considered in the model and consequently it is treated as a terminal system.

The model represents the Lachlan system with 230 links and 231 nodes arranged into 13 river sections. There are five public storages Wyangala Dam, Carcoar Dam, Lake Cargelligo, Brewster Weir and Lake Brewster (Table 4-1). Lake Cargelligo and Lake Brewster are off river re-regulating storages. There are also two floodplains included in the Lachlan model.

Water use is modelled by 48 nodes comprising 23 general security irrigators, seven high security irrigators, six town water supplies, seven high security stock and domestic demands and three wetland replenishments. The wetland replenishments are for off-river wetlands and occur for 60 days starting from February to mid-March. There is also water ordered to pass through the system as part of an ECA and also for water quality protection (Table 4-2).

The model includes minimum flow requirements below Wyangala Dam (70 ML/day and an optional 20,000 ML release in January for water quality), Bangaroo gauge on the Belubula River (10 ML/day), Brewster Weir (20 ML/day) and Booligal gauge (100 ML/day). There are several maximum flow constraints including Wyangala Dam (6600 ML/day), Jemalong Weir (2600 ML/day), Wallamundry Creek (390 ML/day), Goobang and Bumbuggan creeks (1200 ML/day), Willandra Creek (500 ML/day), Willandra Weir (1500 ML/day), Merrowie Creek (1600 ML/day) and Booligal (310 ML/day) (Table 4-3).

Surplus flow events are not allocated to consumptive users. There are two ECAs of 5000 ML/year released from Lake Brewster and Wyangala Dam subject to general security allocation level. An ECA is released from Lake Brewster and Wyangala Dam if the announced allocation at the start of the water year is 50 percent, or if the allocation reaches 75 percent during the water year. In addition to the ECA there is also a translucent release rule (translucency describes a process for passing inflows through a storage according to a range of criteria including seasonal flow and storage volume triggers) applied to Wyangala Dam that releases inflow to meet a target window at Brewster Weir. Translucent releases are made from Wyangala Dam from 15 May to 15 November, if the inflows to Wyangala Dam (since 1 January) have exceeded 250 GL.

Lachlan region general security users operate under two annual accounting schemes in the Lachlan and Belubula rivers. The maximum allocations for the Lachlan and Belubula systems are 75 percent and 100 percent respectively. The Lachlan maximum allocation is used to restrict general security users to 1993/94 levels of demand.

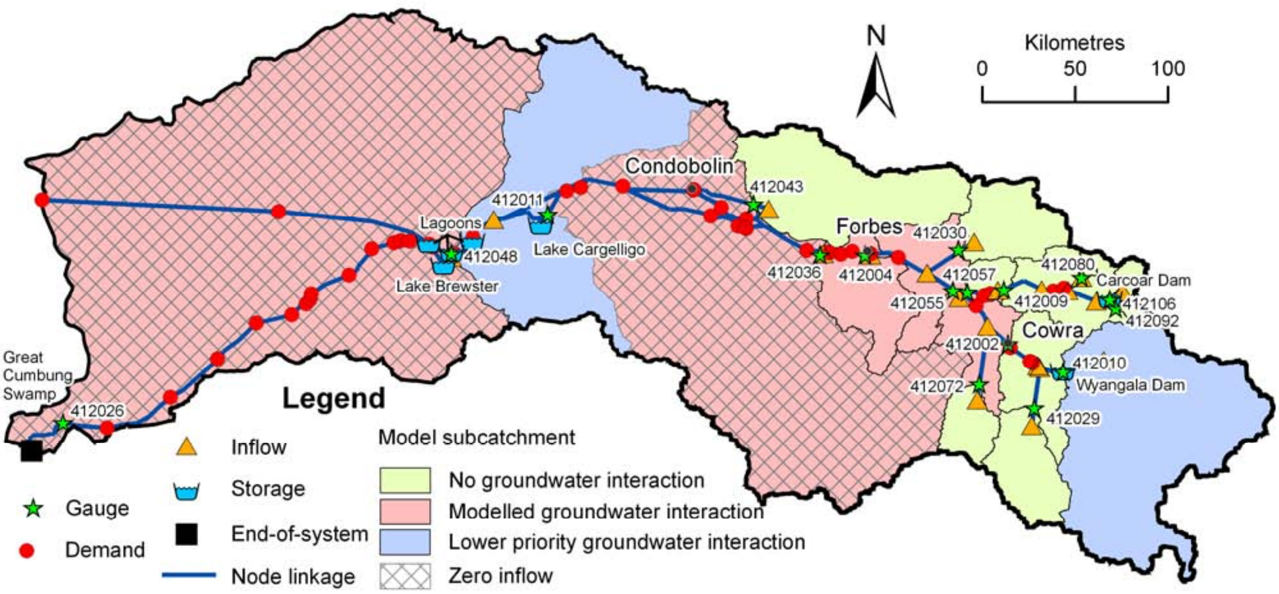

Figure 4-1. River system map showing subcatchments, inflow and demand nodes, storages and links

Table 4-1. Storages in the river system model

	Active storage	Average annual Inflow	Average annual release	Average annual net evaporation	Degree of regulation
	GL	GL/y			
Major supply reservoirs					
Wyangala Dam	1216	735.5	480.1	20.0	0.68
Lake Brewster	137	327.1	191.0	35.8	0.69
Lake Cargellico	43	120.8	77.6	11.3	0.74
Carcoar Dam	35.8	17.0	6.1	2.7	0.52
Brewster Weir	5.5	392.6	117.9	0.1	0.30
Natural water bodies					
Floodplains	7				
Region totals	**1223**	**735.5**	**480.1**	**20.0**	**0.68**

Table 4-2. Modelled water use configuration

	Number of nodes	Licence	Pump constraints	Model notes
		GL/y	ML/day	
Irrigation				
High security Belubula	1	0.476	864	Soil moisture accounting single store for each crop type
General security Belubula	1	24.14	400	
High security Lachlan	6	41.634	6,649	
General security Lachlan	22	627.758	24,999	
High security				
Town water supply Lachlan	6	10.45	39	Monthly demand pattern
Stock and domestic Belubula	2	0.798	1	Monthly demand pattern
Stock and domestic Lachlan	4	14	28	Monthly demand pattern
Wetland replenishment	3	27	450	Daily demand pattern
Environmental Contingency Allowance	2	10		Daily demand pattern in June
Water quality allocation	1	20		Time series file
Total	48	776.256	33,430	

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Table 4-3. Model water management

Minimum flow	
Wyangala Dam	70 ML/d
Release from Wyangala Dam	20,000 ML in January for water quality
Brewster Weir	Minimum flow requirement of 20 ML/d
End of Belubula system	Minimum flow requirement of 10 ML/d
Booligal gauge	Minimum flow requirement of 100 ML/d
Maximum flow constraints	
Wyangala Dam to Jemalong Weir	6,600 ML/d
Jemalong Weir and Willandra Weir	2,600 ML/d
Wallamundry Creek	390 ML/d
Goobang/Bumbuggan Creeks	1,200 ML/d
Willandra Creek	500 ML/d
Willandra Weir to Merrowie Creek	1,500 ML/d
Merrowie Creek to Torrigany split	1,600 ML/d
Torrigany split and Booligal	420 ML/d
Booligal	310 ML/d
Surplus flow sharing	
Surplus flows	Declared above a threshold and split 50% to general security users. Shared according to general security licence. There is no cap on usage.
Environmental Contingency Allowance	
Below Wyangala and Brewster Weir	5000 ML if allocation at start year > 50% or > 75% during the year
Translucent release	Release Wyangala inflows from 15 May to 15 November, if the inflow (since 1 January) exceeds 250 GL
Wetland replenishment	
Willandra Creek	150 ML/d for 60 days from 1 February
Merrowie Creek	150 ML/d for 60 days from 1 March
Merrimajeel Creek	150 ML/d for 60 days from 15 March
Accounting system	
1. Wyangala Dam, Brewster Weir, Lake Brewster and Lake Cargelligo	Annual accounting 75% max
2. Carcoar Dam	Annual accounting 100% max

4.2.3 Model setup

The original Lachlan river model and associated IQQM V7.61.2 executable code were obtained from DWE. The model was run for the original period of 1 January 1898 to 30 June 2000 and validated against previous results.

The time series rainfall, evaporation and flow inputs to this model were extended to cover the period 1 June 1895 to 30 June 2006.

A without-development version of the Lachlan model was created by removing Wyangala Dam, Carcoar Dam, Lake Cargelligo, Brewster Weir, Lake Brewster, all irrigators and fixed demands. Several of the regulated distributaries in the model were modified to match without-development distributary characteristics. A consequence of this is a different distribution of flows in the anabranches of the model. Natural floodplains were not removed from the model.

The Lachlan system contains a large amount of public storage. The initial state of these storages can influence the results obtained. As the Lachlan model starts with a warm-up period from 1 June 1895 to 30 June 1895 the initial state of all public storages needs to be determined. To do this the model was started with all of these storages empty and run up to 31 May 1895 and the final storage volumes were recorded. This was repeated with all of the storages initially full. The results of this analysis are presented in Table 4-4 and show that under both cases the storages converged to a similar result. Each storage was subsequently configured with these storage volumes for the commencement of all model runs.

The model was configured for an extreme dry climate scenario by applying seasonal factors to rainfall, evaporation and inflows (Table 4-5). The model was run and behaved robustly, allocations reached zero percent in both systems and all storages went below active storage volume.

Table 4-4. Model setup information

Model setup information		Version	Start date	End date
Lachlan	IQQM	7.61.2	01/01/1898	30/06/2000
Connection				
Lachlan River at Oxley	Lachlan outflows to the Great Cumbung			
Willandra Creek	Willandra outflows to Moornanyah Lake			
Baseline models				
Warm-up period	01/06/1895	30/06/1895		
Lachlan	IQQM	7.61.2	01/06/1895	30/06/2006
Connection				
Lachlan River at Oxley	Lachlan outflows to Great Cumbung Swamp			
Willandra Creek	Willandra outflows to Moornanyah Lake			
Lachlan modifications				
Data	Extend to 30/06/2006			
Inflows	No adjustment required			
Groundwater loss nodes	15			
Initial storage volumes (GL)				
Wyangala Dam	1024.6			
Lake Brewster	33.229			
Lake Cargellico	26.15			
Carcoar Dam	30.393			
Brewster Weir	3.779			
Warm-up test results				
Setting initial storage volumes	Storages commence empty	Storages commence full	Difference	Percent of full volume
	GL			percent
Storage volume at 31/05/1895				
Wyangala Dam	1024.6	1024.6	0	0%
Lake Brewster	33.229	33.229	0	0%
Lake Cargelligo	26.15	26.15	0	0%
Carcoar Dam	30.393	30.393	0	0%
Brewster Weir	3.779	3.779	0	0%
Natural water bodies	6.266	6.266	0	0%
Storage volume 30 May (1895-2006)	Mean	Median		
	GL			
Wyangala Dam	634.35	670.84		
Lake Brewster	33.57	33.58		
Lake Cargelligo	29.86	28.83		
Carcoar Dam	23.42	26.79		
Brewster Weir	4.21	3.80		
Natural water bodies	8.19	6.06		
Robustness test results				
Minimum allocation				
1. Wyangala Dam, Brewster Weir, Lake Brewster and Lake Cargelligo	0			
2. Carcoar Dam	0			
Minimum storage volume	ML			
Wyangala Dam (DSV 1000 ML)	995.3			
Lake Brewster (DSV 18,000 ML)	10,335.0			
Lake Cargelligo (DSV 17,000 ML)	12,173.0			
Carcoar Dam (DSV 200 ML)	178.5			
Brewster Weir (DSV 0 ML)	0.0			

Table 4-5. Rainfall, evaporation and flow factors for model robustness test

Season	Rainfall	Evaporation	Flow
DJF	0.99	1.06	0.95
MAM	0.98	1.06	0.90
JJA	0.79	1.05	0.34
SON	0.83	1.07	0.46

4.3 Modelling results

4.3.1 River system water balance

The mass balance table (Table 4-6) shows the net fluxes for the Lachlan river system. Fluxes for Scenario O (the original model scenario), Scenario A0 (without groundwater at dynamic equilibrium) and Scenario A (with groundwater at dynamic equilibrium) are displayed as GL/year, while all other scenarios are presented as a percentage change from Scenario A. Note the averaging period for Scenario O differs from all other scenarios.

The directly gauged inflows represent the inflows into the model that are based on data from a river gauge. The indirectly gauged inflows represent the inflows that are derived to achieve a mass balance between mainstream gauges. Diversions are listed based on the different water products in the region. End-of-system flows are shown for the Lachlan River at Oxley gauge (412026) and Willandra Creek where it leaves the Lachlan River. The change in storage between 30 June 1895 and 30 June 2006 averaged over the 111-year period is also included.

Appendix B contains mass balance tables for the 10 subcatchments in the model. The mass balance of each of these river reaches and the overall mass balance were checked by taking the difference between total inflows and outflows of the system. In all cases the mass balance error was zero.

Table 4-6. River system model average annual water balance under scenarios O, A0, A, C and D

	O	AO	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/01/1898	01/07/1895							
Model end date	30/06/2006	30/06/2006							
	GL/y			percent change from Scenario A					
Storage volume									
Change over period	1.8	-6.3	-6.5	1%	15%	29%	4%	18%	31%
Inflows									
Subcatchments									
Directly gauged	1036.9	1014.5	1014.5	7%	-11%	-31%	6%	-13%	-33%
Indirectly gauged	451.9	442.4	442.4	15%	-10%	-32%	12%	-13%	-34%
Sub-total	**1488.8**	**1456.9**	**1456.9**	**10%**	**-11%**	**-31%**	**8%**	**-13%**	**-33%**
Diversions									
Licenced private irrigation diversions									
High security Belubula (nominal volume 0.476 GL/y)	0.2	0.2	0.2	0%	5%	20%	0%	5%	20%
General security Belubula (nominal volume 24.14 GL/y)	2.3	2.4	2.4	0%	-2%	-6%	-1%	-3%	-8%
High security Lachlan (nominal volume 41.634 GL/y)	9.0	9.1	9.0	3%	7%	18%	3%	7%	17%
General security Lachlan (nominal volume 627.758 GL/y)	275.8	274.0	261.8	4%	-9%	-26%	2%	-13%	-29%
Sub-total	**287.4**	**285.6**	**273.4**	**4%**	**-9%**	**-24%**	**2%**	**-12%**	**-28%**
High security									
Lachlan town water supply (entitlement 10.45 GL/y)	10.0	10.0	9.9	0%	0%	-2%	0%	-1%	-3%
Belubula stock and domestic (entitlement 0.798 GL/y)	0.2	0.2	0.2	0%	0%	0%	0%	0%	0%
Lachlan stock and domestic (entitlement 14 GL/y)	8.7	8.7	8.7	0%	-1%	-1%	0%	-1%	-2%
Sub-total	**18.9**	**18.9**	**18.8**	**0%**	**-1%**	**-1%**	**0%**	**-1%**	**-2%**
Total Irrigation Diversions	**306.3**	**304.5**	**292.3**	**4%**	**-8%**	**-23%**	**2%**	**-11%**	**-26%**
High Security Environmental Use									
Wetland replenishment (entitlement 27 GL/y)	26.4	26.4	26.1	0%	0%	0%	0%	0%	0%
Environmental contingency flow (entitlement 10 GL/y)	5.5	5.5	4.9	15%	-12%	-53%	11%	-16%	-57%
Sub-total	**31.9**	**31.8**	**31.0**	**31.9**	**30.3**	**27.2**	**31.6**	**29.7**	**26.6**
Outflows									
End-of-system outflow to									
Lachlan River at Oxley	100.4	98.3	93.9	8%	-14%	-36%	5%	-17%	-38%
Willandra Creek	115.0	113.1	114.6	11%	-12%	-34%	8%	-14%	-36%
Sub-total	**215.4**	**211.5**	**208.5**	**9%**	**-13%**	**-35%**	**7%**	**-15%**	**-37%**
Net evaporation*									
Public storages	71.1	71.2	69.9	4%	3%	8%	2%	2%	7%
Natural water bodies	86.0	84.8	85.7	9%	-6%	-21%	8%	-8%	-24%
Sub-total	**157.1**	**156.0**	**155.6**	**7%**	**-2%**	**-8%**	**5%**	**-3%**	**-10%**
Other losses									
River groundwater loss	0.0	0.0	29.0	-3%	-6%	-1%	15%	15%	14%
Sub-total	**372.5**	**367.5**	**393.0**	**7%**	**-8%**	**-22%**	**7%**	**-8%**	**-23%**
Unattributed fluxes									
Unattributed flux	774.9	759.4	747.2	13%	-14%	-40%	11%	-16%	-42%

* Evaporation from private licensed storages (GL/year) is not included as it is already accounted in diversions

4.3.2 Inflows and water availability

Inflows

There are several ways that the total inflows into the river system can be calculated. The obvious way would be to sum all of the inflows in the model. This is 1457 GL/year for the Lachlan IQQM (Table 4-6). The table also shows that a large proportion of the inflow is indirectly gauged and therefore estimated as part of model calibration. The approach used to calibrate these inflows varies considerably between model implementations. In some cases inflows are inflated and subsequently compensated for by loss relationships. In other cases the losses are inherent in the inflows. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of the different approaches to calibration.

An alternative to simply totalling modelled inflows is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated. This is because all river models are calibrated to achieve mass balance at mainstream gauges. The without-development scenario removes the influences of upstream extractions and regulation and gives a reasonable indication of total inflows. However, the subcatchment inflows used as input to the model include existing land use (farm dams and forest cover) and groundwater use impacts. Additionally the calibrated reaches in the river model implicitly include losses to groundwater. Thus the without-development scenario is not a representation of pre-European settlement conditions.

The without-development model was run for current and future climate scenarios. Streamflow leakage induced by current groundwater use in Upper and Lower Lachlan alluvia is implicitly included in the river model calibration. An adjustment to the modelled without-development water availability is required to assess the total without-development surface water availability as this is water that is lost from the river due to groundwater extraction. No adjustments have been made for the impacts of existing farm dams or changes in forest cover in determining surface water availability for scenarios A and C. These impacts are not included as they are difficult to quantify and are not relevant for guiding future policy.

This can be repeated for each of the climate scenarios by running the without-development model with each of the scenario inputs. A comparison between scenarios for reaches along the Lachlan River is presented in Figure 4-2. This shows that the maximum average annual mainstream flow occurs in subcatchment 4120571 at the Nanami gauge (412057) with a value of 1139.2 GL/year for the without-development Scenario A.

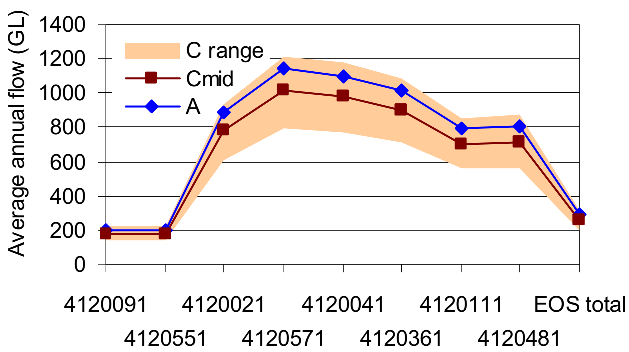


Figure 4-2. Transect of total river flow under without-development scenarios A and C

Water availability

Table 4-7 shows (in GL/year):

- the maximum mainstream flow under without-development scenarios A and C. The point of maximum water availability for the Lachlan Regulated River WSP (DIPNR, 2004) (that is for Scenario O and associated modelling period) was taken as flows at Nanami plus Goobang Creek inflows. The value in the WSP is 1212 GL/year. The assessed maximum mainstream flow of 1139 GL/year (Figure 4-2) differs from the WSP value because it does not include Goobang Creek inflows, is for without-development conditions and is for a longer modelling period that includes a significant drought
- the streamflow reductions (at the point of maximum flow) due to subcatchment inflow reductions caused by current groundwater use – in this case zero
- the streamflow reductions (at the point of maximum flow) caused by leakage induced by current groundwater use implicit in the river model calibration – in this case zero
- the total surface water availability which is the sum of the above three components.

Table 4-7. Annual water availability for without-development Scenario A and relative change under without-development Scenarios C

	A	Cwet	Cmid	Cdry
	GL/y			
Modelled without-development maximum average mainstream flow	1139.2	1211.5	1011.7	791.8
Mainstream flow reductions				
Due to reductions in inflows caused by current groundwater use	0.0	0.0	0.0	0.0
Due to leakage induced by current groundwater use implicit in model calibration	0.0	0.0	0.0	0.0
Total surface water availability	**1139.2**	**1211.5**	**1011.7**	**791.8**
		percent change from Scenario A		
Change in surface water availability		6%	-11%	-30%

A time series of total annual surface water availability under without-development Scenario A is shown in Figure 4-3. The lowest annual water availability was 54 GL in 1919 while the greatest annual water availability was 5143 GL in 1951. Figure 4-4 shows the difference in annual total surface water availability from without-development Scenario A to without-development Scenario C.

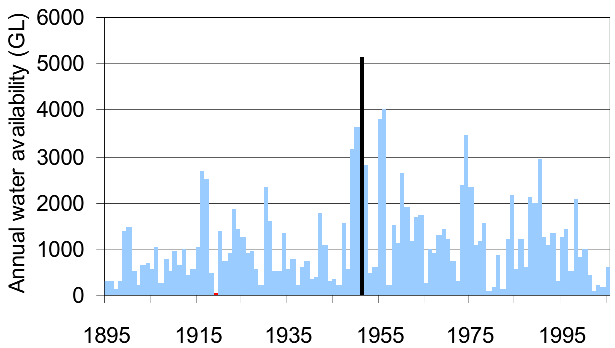


Figure 4-3. Without-development Scenario A water availability

 March 2008

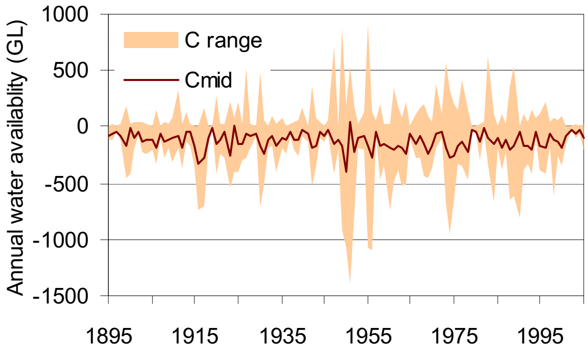


Figure 4-4. Time series of change in total surface water availability relative to without-development Scenario A under without-development Scenario C

4.3.3 Storage behaviour

The modelled behaviour of major public storages gives an indication of the level of regulation of a system as well as how reliable the storage is during extended periods of low or no inflows. Table 4-8 provide indicators that show for each of the scenarios the lowest recorded storage volume and the corresponding date for Wyangala Dam, Lake Brewster, Brewster Weir, Carcoar Dam and Lake Cargelligo. The average and maximum years between spills is also provided. The period between spills commences when the storage exceeds full supply volume and ends when the storage falls below 90 percent of full supply volume. The end condition is applied to remove the periods when the dam is close to full and oscillates between spilling and just below full which would otherwise distort the analysis.

Table 4-8. Details of dam behaviour

Wyangala Dam	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Minimum storage volume (ML)	999	999	987	988	980	963	928
Minimum storage date	21/5/81	21/5/81	13/12/80	13/12/80	11/6/05	24/5/04	24/5/04
Average years between spills	2.6	2.8	3.9	6.3	3.0	4.1	6.9
Maximum years between spills	15.8	15.8	15.9	32.4	15.8	18.3	32.4
Lake Brewster							
Minimum storage volume (ML)	17396	6140	7085	6354	6245	8328	5219
Minimum storage date	10/6/05	10/1/83	11/2/03	10/6/05	10/1/83	20/2/81	10/6/05
Average years between spills	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum years between spills	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Brewster Weir							
Minimum storage volume (ML)	0	0	0	0	0	0	0
Minimum storage date	22/5/05	29/5/05	21/06/1899	30/5/81	6/5/05	10/6/05	17/2/81
Average years between spills	0.3	0.2	0.3	0.4	0.2	0.3	0.4
Maximum years between spills	1.7	1.7	1.9	4.0	1.8	3.6	4.0
Carcoar Dam							
Minimum storage volume (ML)	934	1305	188	178	1291	187	182
Minimum storage date	14/5/15	14/5/15	19/2/15	30/1/42	14/5/15	19/2/15	30/1/42
Average years between spills	2.1	2.2	3.1	4.3	2.1	3.1	4.3
Maximum years between spills	15.7	15.7	18.4	21.3	15.7	18.4	21.3
Lake Cargelligo							
Minimum storage volume (ML)	16077	11442	10679	11131	11403	11864	10707
Minimum storage date	10/6/05	8/1/83	8/2/03	23/2/81	8/1/83	20/2/81	23/2/81
Average years between spills	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum years between spills	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note: Lake Cargelligo and Lake Brewster are off-river storages and as their inflow is regulated they do not spill. Hence the average spill and maximum years are not applicable (N/A).

The time series of storage behaviour for Wyangala Dam, Lake Brewster, Brewster Weir, Lake Cargelligo and Carcoar Dam for the maximum period between spills under each of the scenarios is shown in respective figures Figure 4-5 to Figure 4-9.

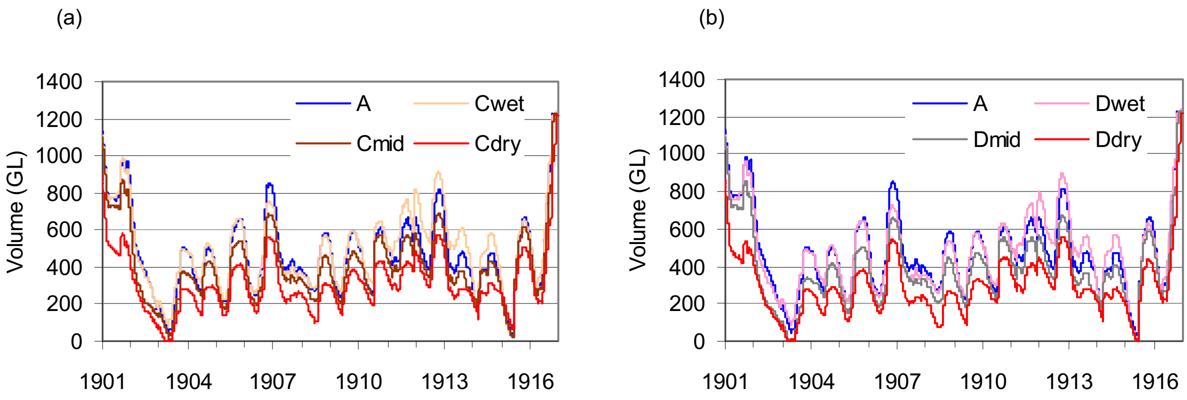


Figure 4-5. Wyangala Dam behaviour over the maximum days between spills under Scenario A with change in storage behaviour under (a) Scenario C and (b) Scenario D

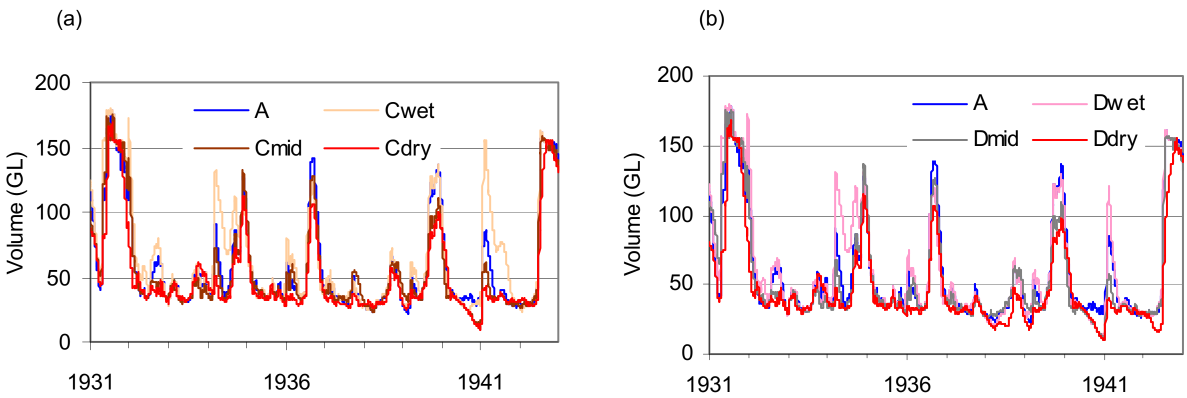


Figure 4-6. Lake Brewster behaviour over the maximum days between spills under Scenario A with change in storage behaviour under (a) Scenario C and (b) Scenario D

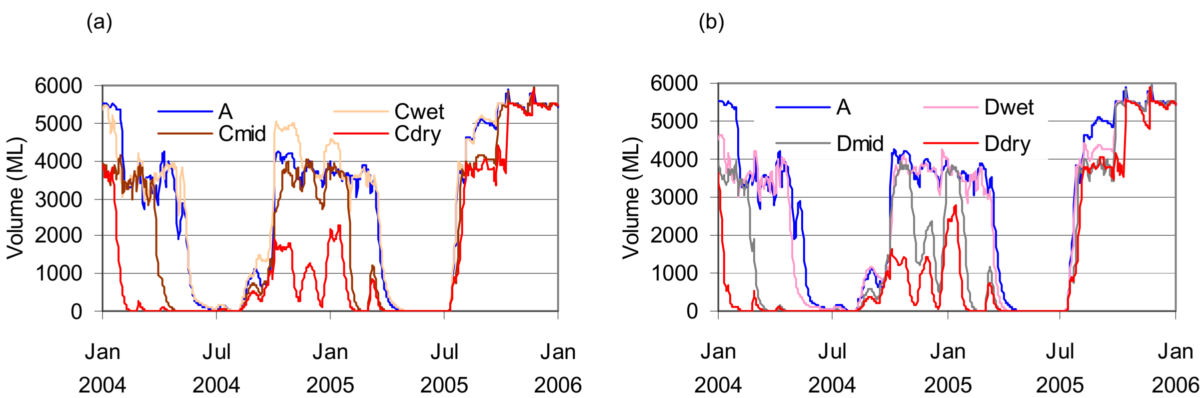


Figure 4-7. Brewster Weir behaviour over the maximum days between spills under Scenario A with change in storage behaviour under (a) Scenario C and (b) Scenario D

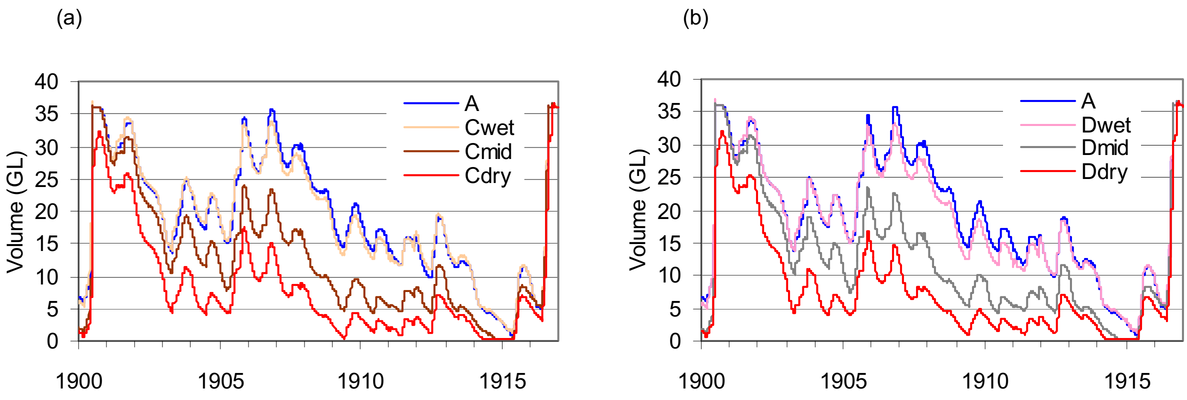


Figure 4-8. Carcoar Dam behaviour over the maximum days between spills under Scenario A with change in storage behaviour under (a) Scenario C and (b) Scenario D

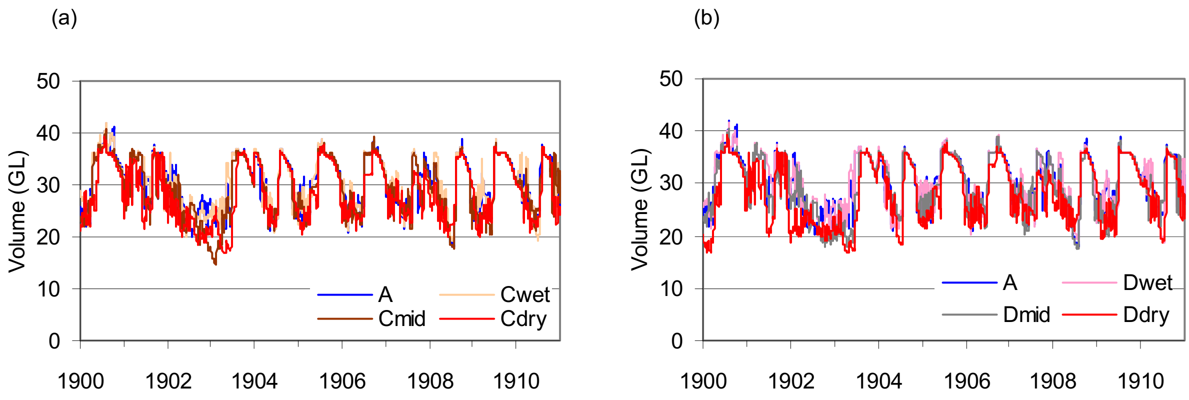


Figure 4-9. Lake Cargelligo behaviour over the maximum days between spills under Scenario A with change in storage behaviour under (a) Scenario C and (b) Scenario D

4.3.4 Consumptive water use

Diversions

Table 4-9 shows the total average annual diversions for each subcatchment (Figure 4-1) under Scenario A and the percentage change of all other scenarios compared to Scenario A.

Table 4-9. Change in total diversions in each subcatchment under scenarios C and D relative to Scenario A

Location	Reach	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
		GL/y	percent change relative to Scenario A					
Belubula	4120091	0.2	-1%	7%	17%	-1%	7%	17%
	4120551	2.5	0%	-2%	-6%	-1%	-3%	-7%
Upper Lachlan	4120021	7.2	0%	1%	3%	0%	0%	2%
	4120571	7.4	3%	-6%	-19%	1%	-9%	-23%
Mid Lachlan	4120041	29.9	4%	-6%	-16%	2%	-9%	-19%
	4120361	60.5	4%	-9%	-24%	2%	-12%	-27%
	4120111	59.0	4%	-7%	-21%	2%	-10%	-25%
Lower Lachlan	4120481	7.0	4%	-8%	-23%	2%	-11%	-26%
	4120261	111.8	3%	-10%	-27%	1%	-13%	-30%
	Willandra Creek	6.6	5%	-6%	-22%	3%	-9%	-26%
	Total	**292.3**	**4%**	**-8%**	**-23%**	**2%**	**-11%**	**-26%**

Figure 4-10 shows total average annual diversions under scenarios A, C and D for subcatchment reaches. Note the usage for reach 4120091 (Belubula) increases during dry climate conditions. This is due to a high security irrigator that is using more of their entitlement to meet increased crop demands caused by climate change.

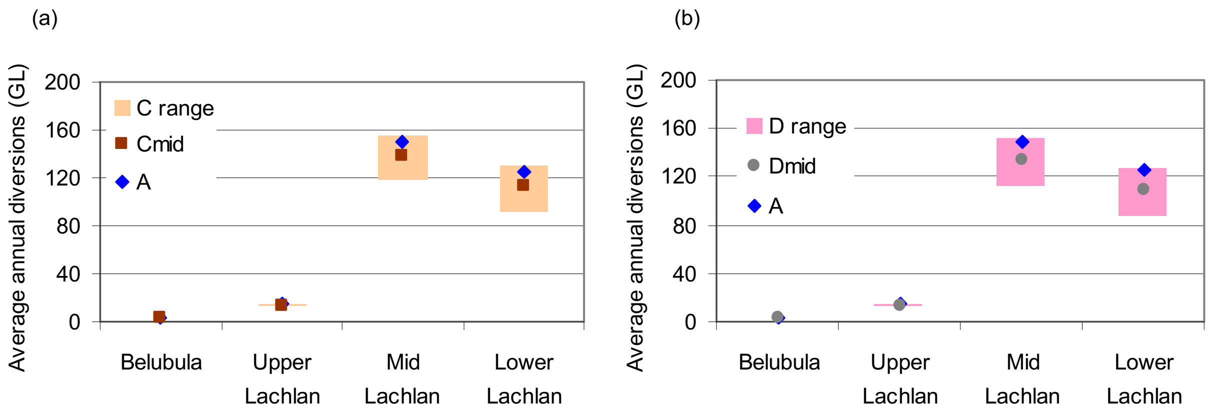


Figure 4-10. Total average annual diversions for subcatchments under (a) scenarios A and C and (b) scenarios A and D

Figure 4-11 shows the annual time series of total diversions under Scenario A and the difference from Scenario A under scenarios C and D. The maximum and minimum diversions under Scenario A are 451 GL in 1918 and 25 GL in 2004 respectively.

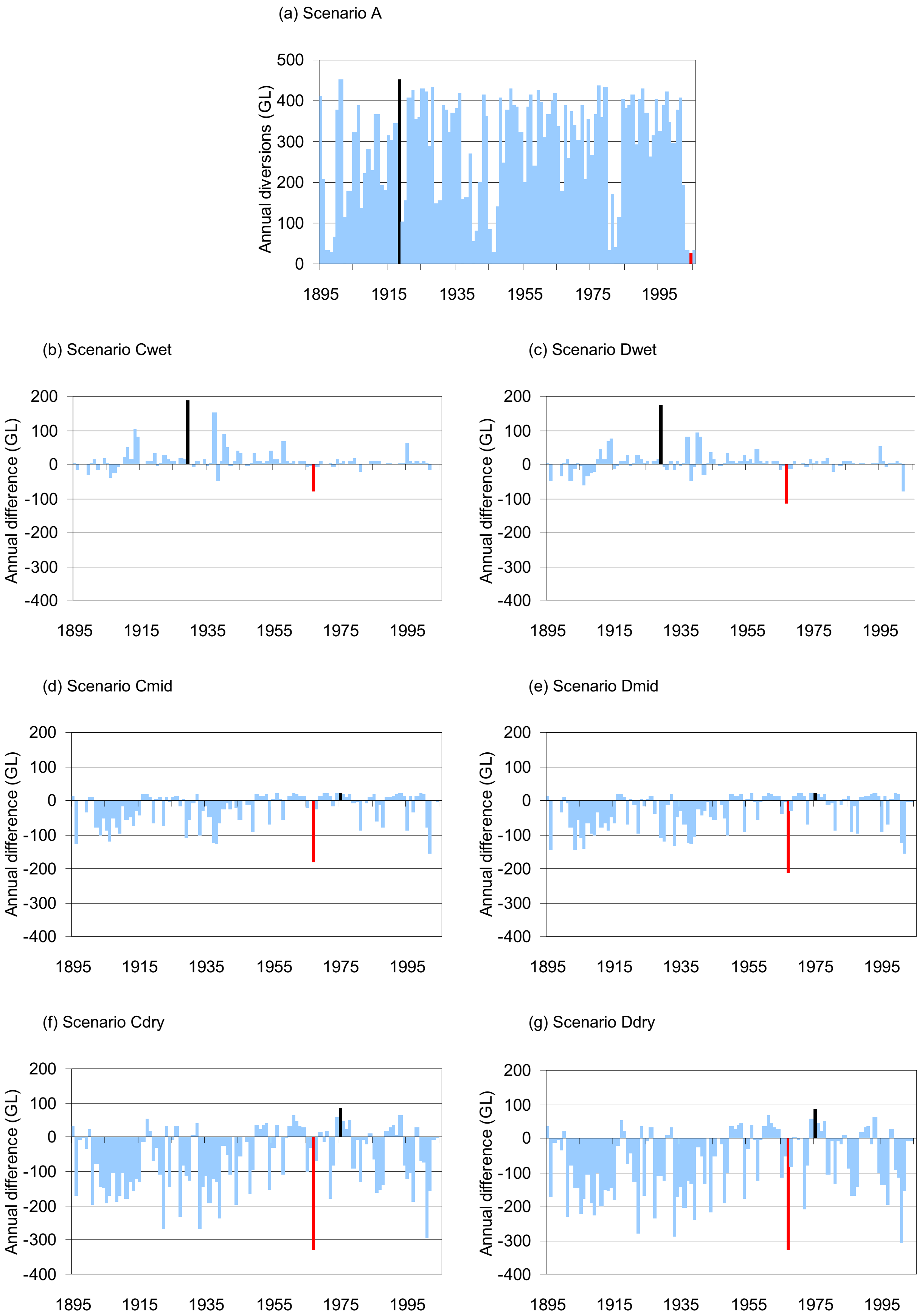


Figure 4-11. Total diversions under (a) Scenario A and difference between total water use under (b) Scenario Cwet, (c) Scenario Dwet, (d) Scenario Cmid, (e) Scenario Dmid, (f) Scenario Cdry, and (g) Scenario Ddry

Level of use

The level of use for the region is indicated by the ratio of total use to total surface water availability. Total use comprises subcatchment and streamflow use.

Subcatchment use includes:

- the inflow impacts due to groundwater use. There is no groundwater use impact implicit in the inflows during model calibration
- an adjustment of these impacts to transfer them to the point of maximum flow. This is done by multiplying all scenarios by the current conditions ratio of flow at the point of maximum flow (1139 GL/year) and total inflow (1457 GL/year).

Streamflow use includes:

- leakage to groundwater induced by groundwater use. This only includes groundwater use explicitly included in the river model as there is no groundwater use implicit in the river model calibration
- total net diversions, which are defined as the net water diverted for the full range of water products. Net diversions are used to reflect the change in mass balance of the system. They do not consider the difference in water quality that may exist between diversions and returns. Diversions for environmental use (see Table 4-6) are excluded from these calculations.

Table 4-10 shows the level of use indicators for each of the scenarios. The level of use is moderately high with 28 percent of the total available surface water resource being diverted for use. In the Lachlan Regulated River WSP (DIPNR, 2004) the Lachlan average water use is reported as 305 GL/year. The number reported in Table 4-6 is based on a longer period.

If the revised number is divided by the water availability in the WSP (1212 GL/year) this gives a relative level of development of 25 percent. Table 4-10 indicates a current level of use for the entire region of 28 percent. This is based on a different water year and includes consideration of groundwater developments and is assessed over a longer period.

Table 4-10. Relative level of use under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Total surface water availability	1139.2	1211.5	1011.7	791.8	1211.5	1011.7	791.8
	GL/y						
Subcatchment use							
Groundwater use impacts	0	0	0	0	8.3	8.3	8.3
Future farm dam impacts	-	-	-	-	12.4	14.4	13.4
Future plantation forestry impacts	-	-	-	-	0	0	0
Streamflow use							
Total Irrigation diversions	292.3	302.6	268.7	225.6	297.0	259.9	216.6
Leakage induced by groundwater use	29.0	28.0	27.3	28.5	33.2	33.4	33.1
Total use	**321.2**	**330.6**	**296.0**	**254.2**	**350.9**	**316.0**	**271.4**
	percent						
Relative level of use	28%	27%	29%	32%	29%	32%	35%

Use during dry periods

Table 4-11 shows the average use for surface water diversions, as well as the average annual diversions for the lowest one, three and five-year periods under Scenario A and the percentage change from Scenario A under each other scenario. These figures indicate the relative impact on surface water use during dry periods.

Table 4-11. Indicators of diversions during dry periods under scenarios A, C and D

Annual Diversion	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A					
Lowest 1-year period	25.1	3%	-13%	-19%	-5%	-15%	-28%
Lowest 3-year period	29.6	2%	-4%	-13%	-1%	-8%	-18%
Lowest 5-year period	137.8	-2%	-45%	-77%	-11%	-57%	-77%
Average	292.3	4%	-8%	-23%	2%	-11%	-26%

Reliability

The average reliability of water products can be indicated by the ratio of total diversions to the total long-term average diversion limit or equivalent benchmark. For the Lachlan region, general security water use is compared against licence volumes of 627.758 GL for the Lachlan system and 24.14 GL for the Belubula system; high security irrigation is compared against licence volumes of 41.634 GL for the Lachlan and 0.476 GL for the Belubula system; high security town water is compared against a licence volume of 10.45 GL and the other high security stock and domestic use is compared against licence volumes of 14 GL for the Lachlan and 0.798 GL in the Belubula system.

Table 4-12 shows the average reliability under Scenario A and the relative change under scenarios C and D.

Table 4-12. Average reliability of water products under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	ratio						
Licensed private usage							
High security Belubula (nominal volume 0.476 GL/y)	0.42	0.42	0.43	0.46	0.42	0.43	0.46
General security Belubula (nominal volume 24.14 GL/y)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
High security Lachlan (nominal volume 41.634 GL/y)	0.22	0.22	0.22	0.23	0.22	0.22	0.23
General security Lachlan (nominal volume 627.758 GL/y)	0.42	0.42	0.40	0.37	0.42	0.40	0.37
High security							
Lachlan town water supply (entitlement 10.45 GL/y)	0.95	0.95	0.95	0.94	0.95	0.94	0.93
Belubula stock and domestic (entitlement 0.798 GL/y)	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lachlan stock and domestic (entitlement 14 GL/y)	0.62	0.62	0.62	0.62	0.62	0.62	0.61
Wetland replenishment (entitlement 27 GL/y)	0.97	0.97	0.96	0.92	0.97	0.95	0.91
Environmental contingency flow (entitlement 10 GL/y)	0.49	0.52	0.46	0.36	0.51	0.45	0.35

There is a difference in most systems between the water that is available for use and the water that is actually diverted for use. These differences are due to under utilisation of licences and water being provided from other sources such as rainfall, surplus flows, on-farm storages and groundwater. The difference between available and diverted water will vary considerably across water products and time.

Figure 4-12 and Figure 4-13 show the difference between the maximum yearly allocated general security water and the general security use for the Lachlan and Belubula systems for each of the scenarios in volume reliability plots. The Lachlan system is limited to a maximum allocation of 75 percent (471 GL).

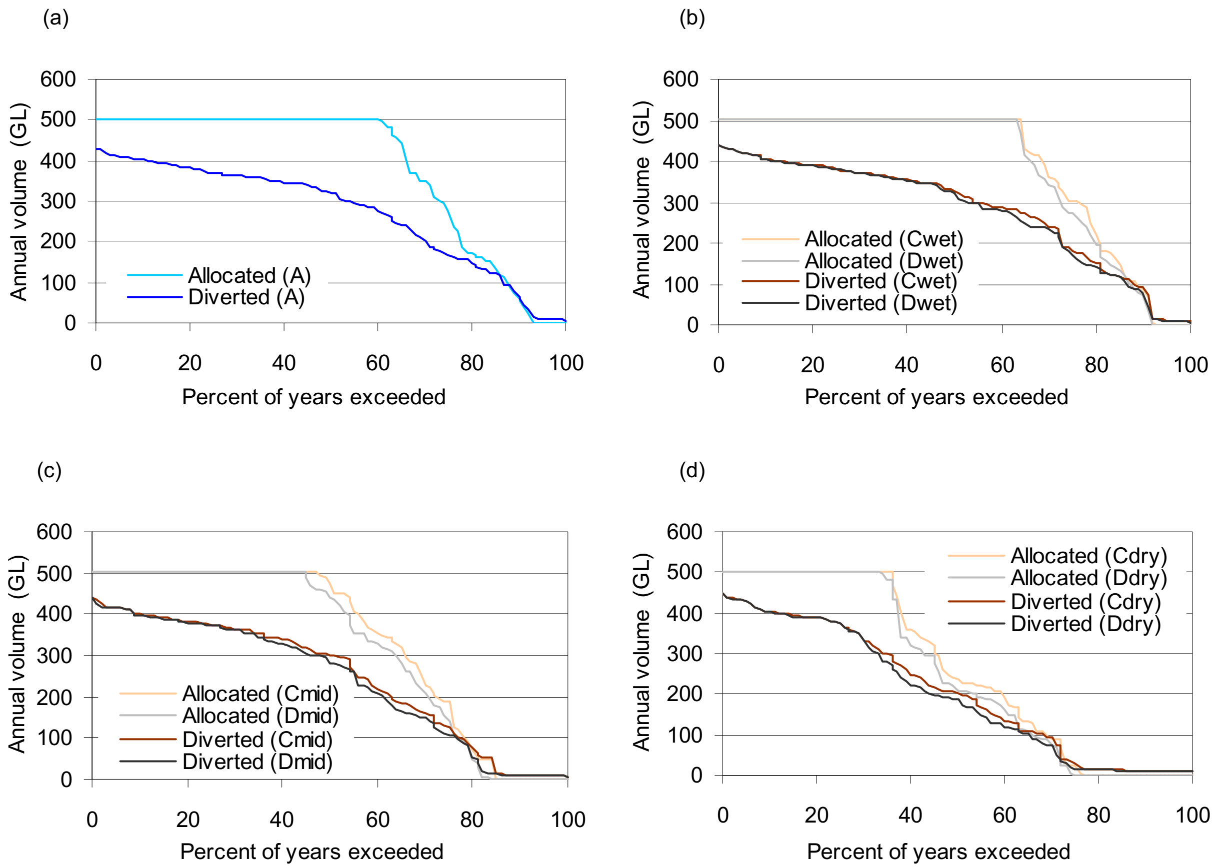


Figure 4-12. Lachlan general security reliability under scenarios (a) A, (b) Cwet and Dwet, (c) Cmid and Dmid, (d) Cdry and Ddry

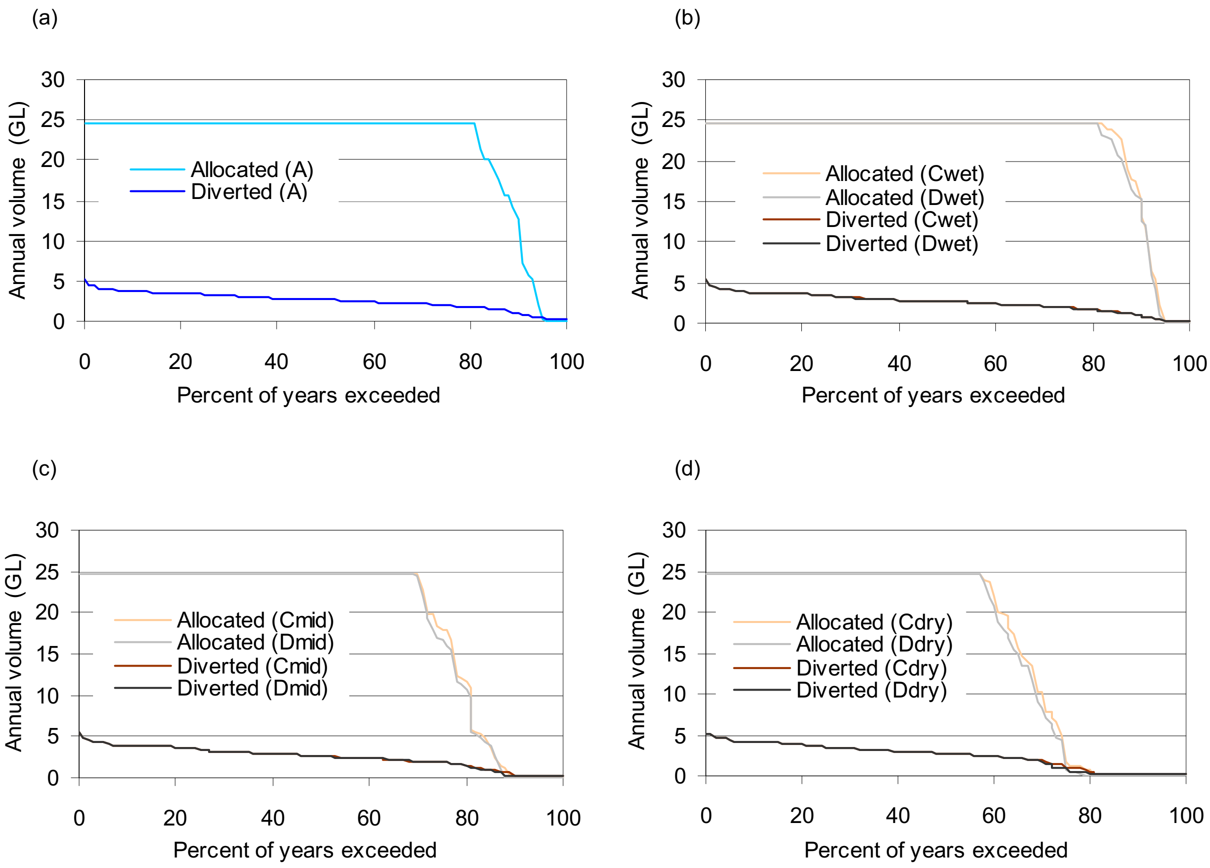


Figure 4-13. Belubula general security reliability under scenarios (a) A, (b) Cwet and Dwet, (c) Cmid and Dmid, (d) Cdry and Ddry

Table 4-13 shows the average annual difference between general security water use and allocated water in both the Lachlan and Belubula systems. This table gives an indication of the level of utilisation of the various water products.

Table 4-13. Summary of average irrigation diversion utilisation under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Lachlan irrigation diversions							
Allocated water	384.0	393.0	341.3	266.1	386.1	329.1	254.8
Diversion	270.9	281.2	247.4	204.6	275.7	238.7	195.8
Difference	113.1	111.7	93.9	61.5	110.4	90.4	59.0
Belubula irrigation diversions							
Allocated water	21.9	22.2	19.4	16.7	22.1	19.2	16.5
Diversion	2.5	2.5	2.5	2.4	2.5	2.5	2.4
Difference	19.3	19.7	16.9	14.3	19.5	16.7	14.1

4.3.5 River flow behaviour

There are many ways of considering the flow characteristics in river systems. For this report three different indicators are provided: daily flow duration, seasonal plot and daily event frequency. These are considered for two locations in the river: mid-river and end-of-system.

Mid-river flow characteristics

The flow regime will vary depending on which location in the river is selected. The location of the middle of the system for this analysis is defined as the position where the river changes from a gaining to a losing stream. The selection of this site is discussed in Section 4.3.2. This is the Nanami gauge (412057) for the Lachlan river system.

Figure 4-14 shows the daily flow duration curves under scenario A and P and the range of impacts under scenarios C and D. The flow duration curves show the change in frequency between scenarios for a given flow. The vertical difference between flow duration curves shows the change in mass between scenarios although care needs to be taken as the plots use a logarithmic scale that distorts the difference of lower flows.

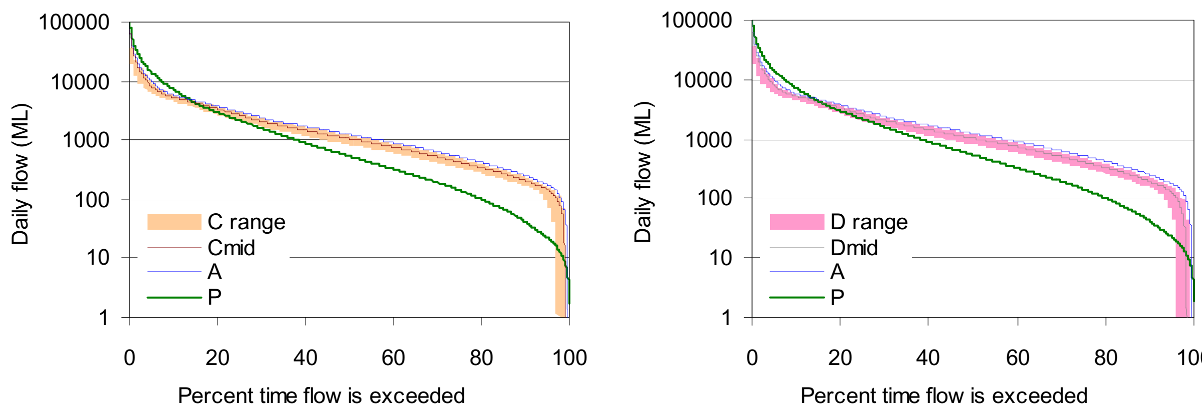


Figure 4-14. Daily flow duration curves for mid-river at Nanami gauge (412057) under scenarios P, A, C and D

Figure 4-15 shows the average monthly flow under scenarios P and A. The plot shows that on average the flow is similar in each month, that is, there is not much seasonality in any of the scenarios, including without-development. The effects of regulation are not apparent in this diagram. The current flows are consistently marginally less than without-development as most usage is downstream of Nanami gauge. All of the Scenario D impacts are less than or equal to without-development conditions.

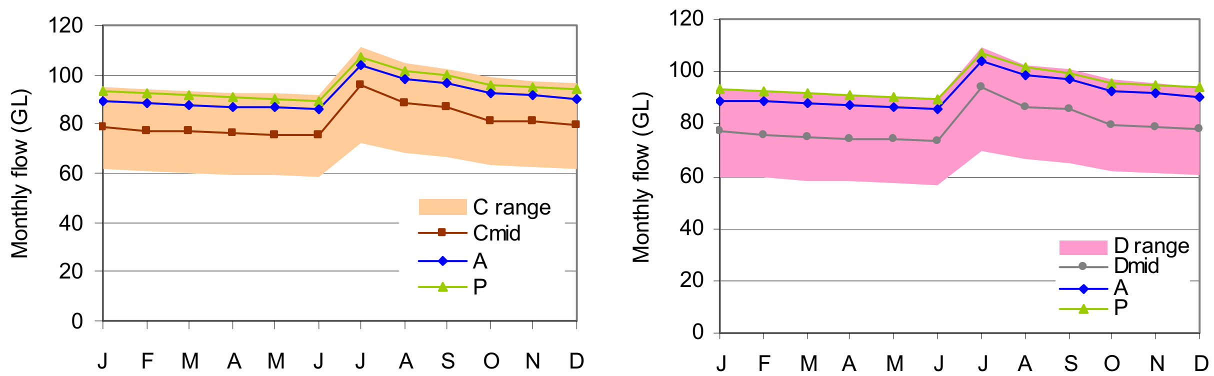


Figure 4-15. Average monthly flow for mid-river at Nanami gauge (412057) under scenarios P, A, C and D

Table 4-14 shows the size of daily events with two, five and ten-year recurrence intervals under scenarios P, A, C and D. This analysis estimates the average peak daily flow and not the peak flow for a day, which is considerably higher in most river systems. The table shows that from with-development to Scenario A there has been a 48 percent reduction in the size of two-year events and approximately a 35 percent reduction in the larger five and ten-year return interval events.

Table 4-14. Daily flow event frequency at Nanami gauge (412057) under scenarios P, A, C and D

Return interval	P	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
years	ML/d		percent change from Scenario A					
2	63,084	32,602	48%	-11%	-38%	40%	-15%	-41%
5	108,182	68,731	41%	-9%	-36%	38%	-9%	-38%
10	146,310	96,513	31%	2%	-40%	31%	-7%	-40%

End-of-system flow characteristics

Figure 4-16 and Figure 4-17 show the flow duration curves for the Oxley gauge (412026) and Willandra Creek distributary.

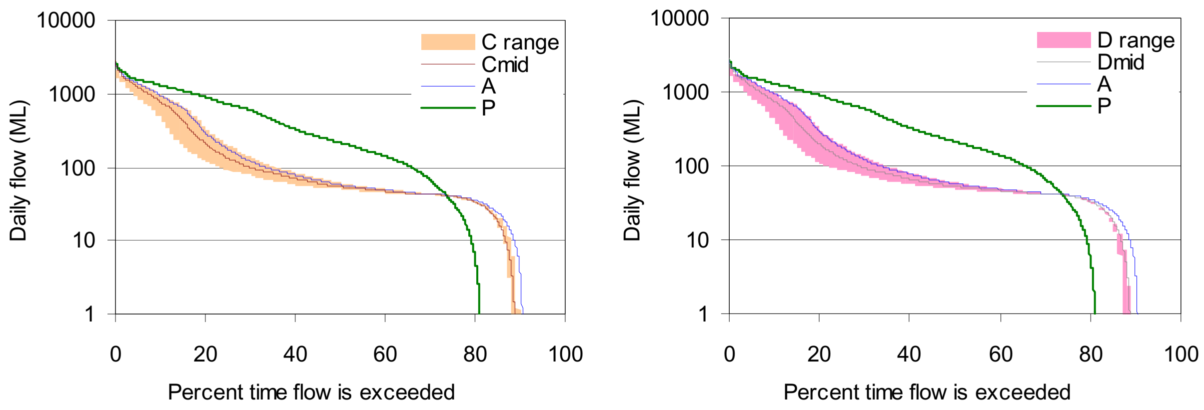


Figure 4-16. Daily flow duration curves for the lower end of flows for Oxley gauge (412026) under scenarios P, A, C and D

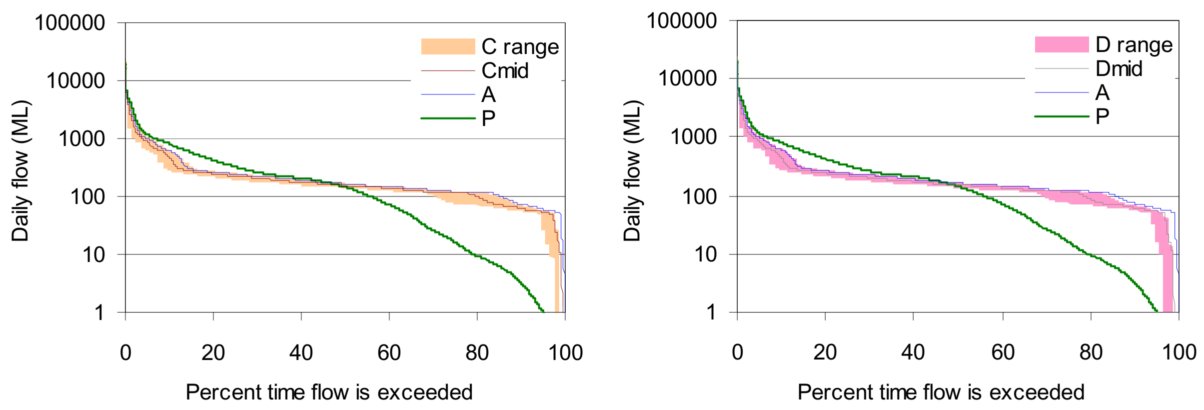
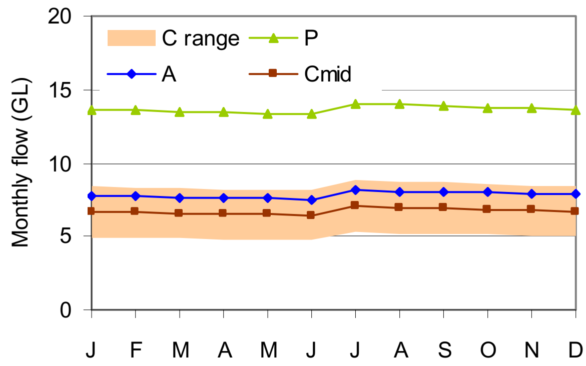


Figure 4-17. Daily flow duration curves for lower end of flows for Willandra Creek under scenarios P, A, C and D

Figure 4-18 and Figure 4-19 give the mean monthly flow under scenarios P, A, C and D for each of the end-of-system flow gauges. They show that there is not much seasonality at the end-of-system gauges under any of the scenarios. They also show the large change in end-of-system flows at Oxley compared to without-development under all scenarios.



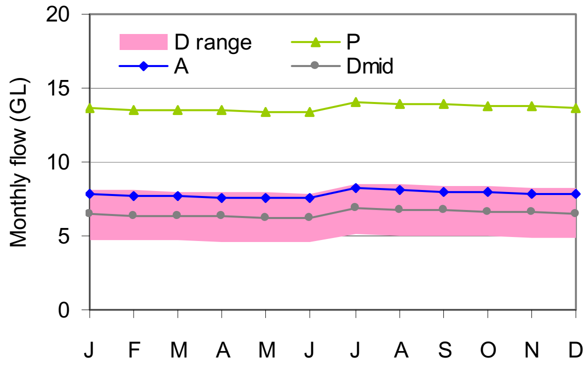
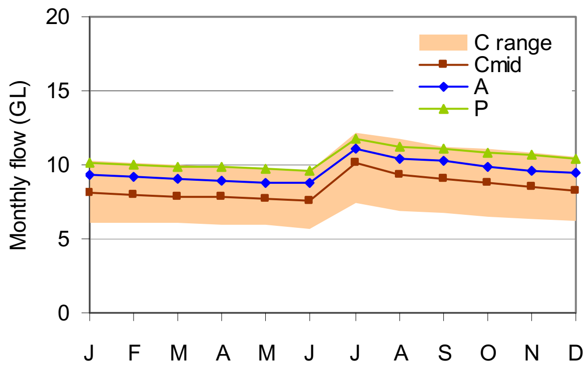


Figure 4-18. Seasonal flow curves at Oxley gauge (412026) under scenarios P, A, C and D



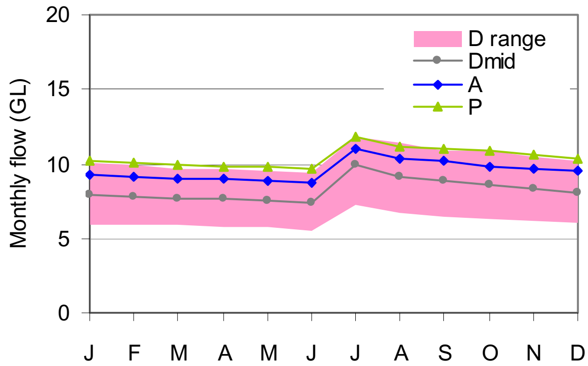


Figure 4-19. Seasonal flow curves at Willandra Creek under scenarios P, A, C and D

The percentage of time that flow occurs for these scenarios is presented in Table 4-15. 'Cease-to-flow' is when model flows are less than 1 ML/day.

Table 4-15. Percentage of time flow occurs at the end-of-system under scenarios P, A, C and D

Outflow name	P	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Lachlan River at Oxley	81%	90%	90%	89%	88%	89%	89%	88%
Willandra Creek	95%	100%	100%	99%	99%	100%	99%	98%

4.3.6 Share of available resource

Non-diverted water shares

There are several ways of considering the relative level of impact on non-diverted water and diversions. Table 4-16 presents two indicators for relative impact on non-diverted water:

- the average annual non-diverted water as a proportion of the maximum mainstream average annual flow
- as proportion of the maximum mainstream average annual flow under Scenario A.

Table 4-16. Relative level of available water not diverted for use under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Non-diverted water as a percentage of total available water	72%	73%	71%	68%	71%	68%	65%
Non-diverted share relative to Scenario A non-diverted share	100%	101%	99%	95%	98%	95%	90%

Combined water shares

Figure 4-20 combines the results from water availability, level of development and non-diverted water. The size of the bars indicates total water availability and the subdivision of the bars indicates the diverted and non-diverted fractions.

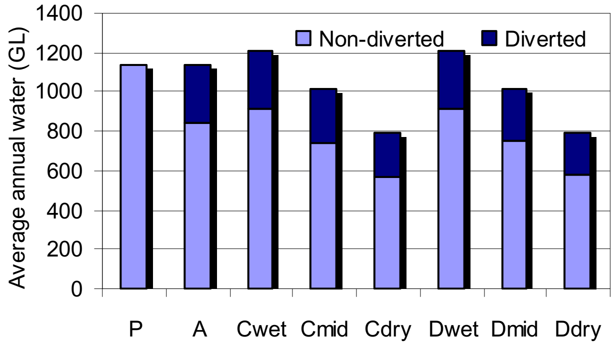


Figure 4-20. Comparison of diverted and non-diverted shares of water under scenarios P, A, C and D

4.4 Discussion of key findings

4.4.1 Scenarios

The Lachlan model was setup by DWE to operate over the period 1 January 1898 to 30 June 2000. The results from this study are presented for the common modelling period 1 July 1895 to 30 June 2006. The Lachlan Regulated River WSP (DIPNR, 2004) is based on the original modelling period. Results presented in the DIPNR report may differ from numbers published in this report due to the different modelling period. Table 4-6 shows that there is a 2 percent decrease in inflows for the common modelling period compared to what was used to develop the water sharing plan.

The A0 and A scenarios are presented so that the impacts of current levels of groundwater extraction at dynamic equilibrium can be considered. The time to dynamic equilibrium is discussed in Chapter 6. Table 4-6 shows a 29 GL/year increase in loss to groundwater. This means that the results for scenarios A0 and A are slightly different.

Additional farm dam development (see Chapter 3) is estimated to decrease inflows by 17 GL/year. In addition, future groundwater development in the headwater catchments causes a further 11 GL/year reduction in inflows (discussed in Chapter 6). The combined impacts are a 2 percent reduction in total net diversions and a 2 percent reduction in end-of-system outflows. The impacts of the best estimate 2030 climate scenario are much greater with an 11 percent reduction in inflows. Consequently for the best estimate 2030 climate scenario the combined impacts of development and future climate are a 10 percent reduction in total net diversions and a 15 percent reduction in end-of-system flows.

4.4.2 Storage behaviour

For current levels of development and historical climate, the maximum years between spills for Wyangala Dam is 16 years (the period spans the Federation drought). The average years between spills are considerably less at three years which is reduced by the wetter conditions after 1950. Additionally Wyangala Dam regulates 68 percent of the inflows. This shows that Wyangala Dam has a high degree of regulation.

4.4.3 Consumptive use

There is no major impact on high security users as general security allocations are predominantly above zero in both the Lachlan and Belubula systems (Figure 4-12 and Figure 4-13). When there is a general security allocation the high security users will receive their full entitlement. Due to carry-over reserve in the resource assessment, water is reserved to ensure that high security irrigation and town water supply requirements are met. In all cases in the Lachlan system all storages are drawn below active capacity (Table 4-8). In the Belubula system, Carcoar Dam is drawn below active storage for the best estimate and dry 2030 climate scenarios. The major impact of storages being drawn below active storage capacity is firstly felt by high security irrigation, then ECA (not considered as a consumptive use in Table 4-6) and finally by town water supplies (Table 4-6). Where storages are drawn below active storage capacity larger reserves would need to be held to ensure high security requirements are met through the extreme dry periods. To maintain high security irrigation requirements an even larger reserve would be required. Holding larger reserves will reduce the reliability of general security users.

The relative use of water is largely maintained through all scenarios (Table 4-10). This is largely driven by the translucent flow requirements that require targeted inflows be released through Wyangala Dam. Translucency describes a process for passing inflows through a storage according to a range of criteria including seasonal flow and storage volume triggers. This helps to maintain the balance of impacts between consumptive and non-consumptive users, indicating that the Lachlan has robust environmental flow rules that maintain shares despite change in climate and development.

The allocation of general security entitlements in the Lachlan is limited to 75 percent in the Lachlan Regulated Rivers WSP and this level of allocation is delivered in 60 percent of years (Figure 4-12). The reliability of general security entitlements in the Belubula system is reasonably high with full allocation provided in 80 percent of years (Figure 4-13). The reduction of this in the extreme dry 2030 climate scenarios is respectively 50 percent and 30 percent for the Lachlan and Belubula systems. However the impacts on general security users are less as under utilisation of allocated water is taken up. This is pronounced in the Belubula system where usage is considerably less than allocation. Only at very low allocations does usage match allocation.

4.4.4 Flow behaviour

The impact of current development on average end-of-system flows for the Lachlan at Oxley gauge (412026) is considerably more than the reduction in inflows due to climate change and development (Figure 4-18). The average annual flows leaving Willandra Creek are similar to without-development conditions (Figure 4-19). The best estimate and dry extreme 2030 climate scenarios produce less flow consistently across all months. The extreme wet 2030 climate scenario with development has only slightly more flow than current development across all months.

The 100 ML/day minimum flow requirements at Booligal helps to maintain low flows at both Oxley gauge and Willandra Creek. On top of this there are extractions for Willandra wetlands that are treated as a use and are not accounted as flow to Willandra Creek. In reality, if these flows were taken into account even more flow would exit Willandra Creek, particularly in February to March when these releases are made.

The Lachlan has a significant amount of water allocated for the environment with 27 GL for replenishing wetlands and creeks, 10 GL ECA and 20 GL for water quality protection. Additionally surplus flows are not allocated for consumptive use. There are also translucent releases through Wyangala Dam to meet targets at Brewster Weir. These volumes of water and release rules help to maintain the non-diverted share of the water resource. However, there are large reductions in the size of two, five and ten-year events (Table 4-14). The translucent flow rules maintain events up to 8000 ML/day at Brewster Weir that equates to inflows of about 16,000 ML/day at Wyangala Dam which is smaller than the 2-year event. Consequently the reduction of event size at Nanami is caused by Wyangala Dam catching the larger events.

4.5 References

DLWC (2001) Lachlan River Valley, IQQM Cap Implementation Summary Report. Surface and Groundwater Processes Unit, Centre for Natural Resources, Department of Land and Water Conservation, Sydney.

DIPNR (2004) Water Sharing Plan for the Lachlan Regulated River Water Source 2003. Effective 1 July 2004 and ceases ten years after that date. Department of Infrastructure, Planning and Natural Resources, Sydney. NSW Government Gazette.

5 Uncertainty in surface water modelling results

This chapter describes the assessment of uncertainty in the surface water modelling results. It has four sections:

- a summary
- an overview of the approach
- a presentation and description of results
- a discussion of key findings.

5.1 Summary

The uncertainty that is internal to the river model, as opposed to that associated with the scenarios, and the implications that this has for confidence in the results and their appropriate use, are assessed using multiple lines of evidence. This involves comparing: (i) the river model to historical gauged main stem flows and diversions, which are its main points of reference to actual conditions, and (ii) ungauged inferred inflows and losses in the model to independent data on inflows and losses to ascertain if they can be attributed to known processes. These two aspects of model performance were then combined with some other measures to assess how well the model might predict future patterns of flow.

5.1.1 Issues and observations

- Water accounts were assessed for the Upper Lachlan using data from 11 streamflow gauges located between Wyangala and Cargelligo Weir.
- The Lachlan region has a measurement network of a density similar to the Murray-Darling Basin (MDB) average. The Upper Lachlan above Cargelligo Weir appears sufficiently well gauged for reliable modelling. Uncertainty is greater for the Lower Lachlan and large losses occur due to floodplains and wetlands and in areas where there are no measurements of inflows.
- The hydrology of the Upper Lachlan region is well understood given the available data. The system is gaining above Nanami and losing below Forbes.

5.1.2 Key messages

The following conclusions are made regarding the river model for the Lachlan region:

- Assessment of river model uncertainty was limited to the Upper Lachlan. Overall the quality of the model appears good and suitable for the purposes of this project.
- The uncertainty around groundwater exchanges appears small in the Upper Lachlan. Uncertainty related to groundwater exchanges could not be assessed for the Lower Lachlan (where these interactions may be more important) due to data limitations.
- The greatest uncertainty is associated with climate projections. This uncertainty is amplified by the construction and testing of the model over a relatively narrow climate range.
- Projected changes due to development are small and of similar magnitude to the internal uncertainty in the model.

5.2 Approach

5.2.1 General

A river model is used as described in Chapter 4 to analyse expected changes in water balance, flow patterns and consequent water security under climate and/or development change scenarios. Uncertainty in the analysis can be external or internal:

- *External* uncertainty is external to the model. It includes uncertainty associated with the forcing data used in the model, determined by processes outside the model such as climate processes, land use change and water resources development.
- *Internal* uncertainty relates to predictive uncertainty in the river model that is an imperfect representation of reality. It can include uncertainty associated with the conceptual model, the algorithms and software code it is expressed in, and its specific application to a region (Refsgaard and Henriksen, 2004).

Full measurement of uncertainty is impossible. The analysis discussed in this chapter focuses on internal uncertainty. When scenarios take the model beyond circumstances that have been observed in the past, measurable uncertainty may only be a small part of total uncertainty (Weiss, 2003; Bredehoeft, 2005). The approach to addressing internal uncertainty involved combining quantitative analysis with qualitative interpretation of the model adequacy (similar to 'model pedigree', cf. Funtowicz and Ravetz, 1990; Van der Sluijs et al., 2005) using multiple lines of evidence. The lines of evidence are:

- the quality of the hydrological observation network
- the components of total estimated stream flow gains and losses that are directly gauged, or can easily be attributed using additional observations and knowledge, respectively (through water accounting)
- characteristics of model conceptualisation, assumptions and calibration
- the confidence with which the water balance can be estimated (through comparison of water balances from the baseline river model simulations and from water accounting)
- measures of the baseline model's performance in simulating observed streamflow patterns
- the projected changes in flow pattern under the scenarios compared to the performance of the model in reproducing historical flow patterns for selected stations.

None of these lines of evidence are conclusive in their own right. In particular:

- the model may be 'right for the wrong reasons', for example, by having compensating errors
- there is no absolute 'reference' truth, all observations inherently have errors and the water accounts developed here use models and inference to attribute water balance components that were not directly measured
- adequate reproduction of historically observed patterns does not guarantee that reliable predictions about the future are produced. This is particularly so if model input data are outside historically observed conditions, such as in climate change studies like this.

Qualitative model assessment is preferably done by expert elicitation (Refsgaard et al., 2006). The timing of the project prevented this. Instead a tentative assessment of model performance is reviewed by research area experts within and outside the project as well as stakeholder representatives.

The likelihood that the river model gives realistic estimates of the changes that would occur under the evaluated scenarios is assessed within the above limitations.

Overall river model uncertainty is the combination of internal and external uncertainty. The range of results under different scenarios in this project provides an indication of the external uncertainty. River model improvements will reduce overall uncertainty only where internal uncertainty clearly exceeds the external uncertainty.

The implication of overall uncertainty on the use of the results presented in this study depends on: (i) the magnitude of the assessed change and the level of threat that this implies, and (ii) the acceptable level of risk (Pappenberger and Beven, 2006). This is largely a subjective assessment and no attempt is made to judge. A possible framework for users of the project results to consider the implications of the assessed uncertainties is shown in Table 5-1.

Table 5-1. Possible framework for considering implications of assessed uncertainties

	Low threat	High threat
Low uncertainty	Current water sharing arrangements appear sufficient for ongoing management of water resources.	Current water sharing arrangements are likely to be inadequate for ongoing management of water resources, as they do not adequately consider future threats.
High uncertainty	Current water sharing arrangements appear sufficient for ongoing management of water resources, but careful monitoring and adaptive management is recommended.	Current water sharing arrangements may be inadequate for ongoing management of water resources. Further work to reduce the major sources of uncertainty can help guide changes to water sharing arrangements.

5.2.2 Information sources

Information on the gauging network was obtained from the Water Resources Station Catalogue (www.bom.gov.au/hydro/wrsc) and the Pinneena 8 Database (provided on CDROM by New South Wales Department of Water and Energy (DWE)). A report that included the results of IQQM model calibration for the Lachlan River was provided (DLWC, 2001). Time series of water balance components as modelled under the baseline scenario (Scenario A) and all other scenarios were derived as described in Chapter 4. The data used in water accounting are described in the following section.

5.2.3 Water balance accounting

Generic aspects of the water accounting methods are described in Chapter 1. This section includes a description of the basic purpose of the accounts, which is to inform the uncertainty analysis carried out as part of this study using an independent set of the different water balance components by reach and by month. The descriptions in Chapter 1 also cover the aspects of the remote sensing analyses to estimate wetland and irrigation water use, as well as the calculations for attribution of apparent ungauged gains and losses. Aspects of the methods that pertain specifically to the current region are presented below.

Framework

Streamflow data availability limitations meant water accounts could only be established for five successive reaches above Cargelligo Weir to cover the top half of the region. The data were complete enough for accounting for the water years 1990/91 to 2005/06 for all reaches with the exception of Reach 4 that only had data until 2002/2003.

The subcatchments used in runoff estimation are shown in Figure 5-1 and are related to model reaches in Table 5-3 (Appendix A). A number of gauges along the lower Lachlan could have been active during this period (Figure 5-2 and Table 5-4), but could not be used as local runoff estimates were not available for the contributing areas.

Diversion data

Total annual diversion data were available for the water years 1990/91 to 2005/06 and covered the five accounting reaches.

Wetland and irrigation water use

The result of the remote sensing classification (Chapter 1) is shown in Figure 5-1. Irrigation areas were identified in the reaches with water accounts. Important wetland areas were identified in water account reaches 4 and 5. Irrigation and wetland areas were also identified in the two westernmost modelled subcatchments but there was no adequate streamflow data for water accounts.

Table 5-2. Comparison of water accounting reaches with reach codes used in the river model

Water accounting reach	Subcatchment code(s)	Downstream gauge
1	4120021	Lachlan River @ Cowra
2	4120571	Lachlan River @ Nanami
3	4120041	Lachlan River @ Forbes (Cottons Weir)
4	4120361	Lachlan River @ Jemalong Weir
5	4120111	Lachlan River @ Cargelligo Weir
Not assessed		Reason
	4120100, 4120290	Contributing head water catchment (to Reach 1)
	4120720, 4120920, 4121060, 4120800, 4120091, 4120551	Contributing head water catchment (to Reach 2)
	4120300	Contributing head water catchment (to Reach 3)
	4120430	Contributing head water catchment (to Reach 5)
	4120481, 4120261	Insufficient stream flow data

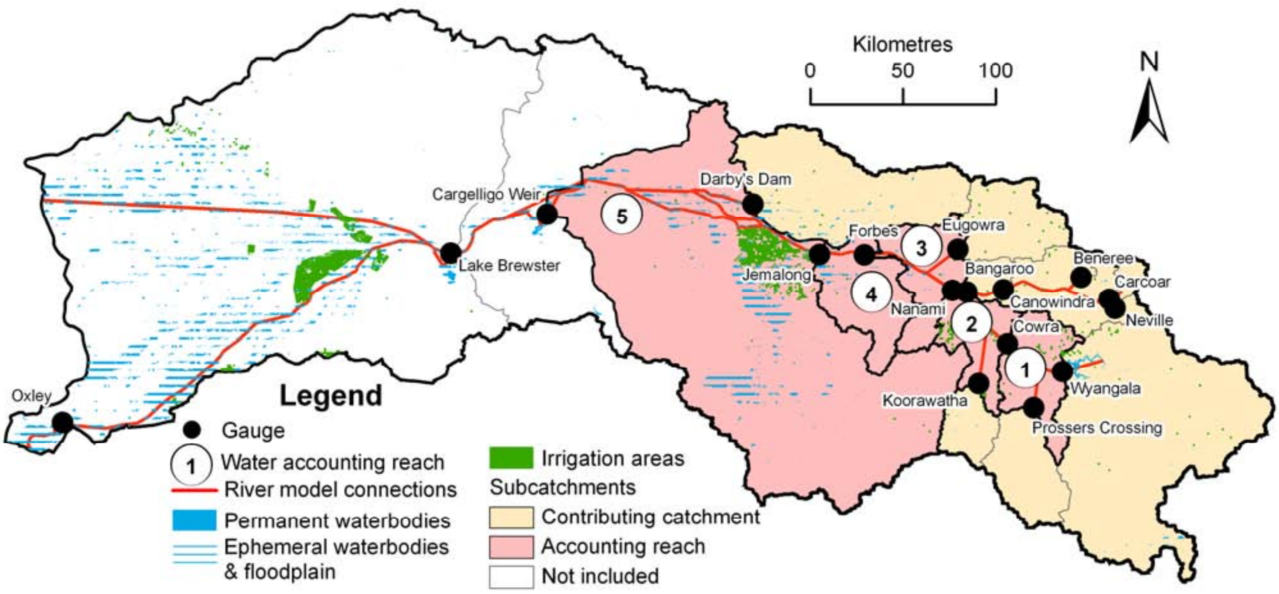


Figure 5-1. Map showing the subcatchments used in modelling, with the reaches for which river water accounts were developed ('accounting reach') and contributing head water catchments with gauged inflows ('contributing catchment'). Black dots and red lines are nodes and links in the river model respectively.

Calculation and attribution of apparent ungauged gains and losses

Calculation and attribution of apparent ungauged gains and losses were undertaken according to the methods described in Chapter 1.

5.2.4 Model uncertainty analysis

The river model results and water accounts were used to derive measures of model uncertainty. The different analyses are described below. In the interest of brevity details of the equations used to calculate the indicators are not provided here but can be found in Van Dijk et al. (2008). Calculations were made for each reach separately but summary indicators were compared between reaches.

Completeness of hydrological observation network

Statistics on how well all the estimated river gains and losses were gauged – or where not gauged, could be attributed based on additional observations and modelling – were calculated for each reach:

- The volumes of water measured at gauging stations and off-takes, as a fraction of the grand totals of all estimated inflows or gains, and/or all outflows or losses, respectively.
- The fraction of month-to-month variation in the above terms.
- The same calculations as above, but for the sum of gauged terms plus water balance terms that could be attributed using the water accounting methods.

The results of this analysis for annual totals are shown in Appendix C.

Comparison of modelled and accounted reach water balance

The water balance terms for river reaches were compared for the water accounting period as modelled by the baseline river model (Scenario A) and as accounted. Large divergence is likely to indicate large uncertainty in reach water fluxes and therefore uncertainty in the river model and water accounts.

Climate range

If the model calibration period is characterised by climate conditions that are a small subset or atypical of the range of climate conditions that was historically observed, this probably increases the chance that the model will behave in unexpected ways for climate conditions outside the calibration range. The percentage of the overall climate variability range for the 111-year climate sequence that was covered by the extremes in the calibration period was calculated as an indicator.

Performance of the river model in explaining historical flow patterns

All the indicators used in this analysis are based on the Nash-Sutcliffe model efficiency (NSME; Nash and Sutcliffe, 1970). NSME indicates the fraction of observed variability in flow patterns that is accurately reproduced by the model. In addition to NSME values for monthly and annual outflows, values were calculated for log-transformed and ranked flows, and high (highest 10 percent) and low (lowest 10 percent) monthly flows. NSME cannot be calculated for the log-transformed flows where observed monthly flows include zero values or for low flows if more than 10 percent of months have zero flow. NMSE is used to calculate the efficiency of the water accounts in explaining observed outflows.

This indicates the scope for model improvements to explain more of the observed variability. If NSME is much higher for the water accounts than for the model, it suggests that the model can be improved to reduce uncertainty. If similar, additional hydrological data may be required to support a better model.

A visual comparison of streamflow patterns at the end-of-reach gauge with the flows predicted by the baseline river model and the outflows that could be accounted was done for monthly and annual time series and for monthly flow duration curves.

Scenario change-uncertainty ratio

Streamflow patterns simulated for any of the scenarios can be used as an alternative model of historical streamflow. If these scenario flows explain historically observed flows about as well or better than the baseline model, then it may be concluded that the modelled scenario changes are within model ‘noise’, that is, smaller or similar to model uncertainty. Conversely, if the agreement between scenario flows and historically observed flows is poor – much poorer than between the baseline model and observations – then the model uncertainty is smaller than the modelled change, and the modelled change can be meaningfully interpreted.

The metric used to test this hypothesis is the change-uncertainty ratio (CUR). The definition was modified from Bormann (2005) and calculated as the ratio of the NSME value for the scenario model to that for the baseline (Scenario A) model. A value of around 1.0 or less suggests that the projected scenario change is not significant when compared to river model uncertainty. A ratio that is considerably greater than 1.0 indicates that the future scenario model is much poorer at producing historical observations than the baseline model, suggesting that the scenario leads to significant changes in flow. The CUR is calculated for monthly and annual values, in case the baseline model reproduces annual patterns well but not monthly patterns. The same information was plotted as annual time series, monthly flow duration curves and a graphical comparison made of monthly and annual change-uncertainty ratios for each scenario.

5.3 Results

5.3.1 Density of the gauging network

Figure 5-2 shows the location of streamflow, rainfall, and evaporation gauges in the region. Table 5-3 provides information on the measurement network. The Lachlan region has rainfall, streamflow and evaporation gauging networks that are of similar density as the MDB average; 11 of the 18 regions have a more dense observation network. The top half has better streamflow gauging than the bottom half of the region where there are a number of ungauged distributaries.

Table 5-3. Some characteristics of the gauging network of the Lachlan region (85,532 km^2) compared with the entire Murray-Darling Basin (1,062,443 km^2)

Gauging network characteristics	Lachlan		Murray-Darling Basin	
	Number	per 1000 km^2	Number	per 1000 km^2
Rainfall				
Total stations	483	5.65	6232	5.87
Stations active since 1990	205	2.40	3222	3.03
Average years of record	47		45	
Streamflow				
Total stations	76	0.89	1090	1.03
Stations active since 1990	62	0.72	881	0.83
Average years of record	21		20	
Evaporation				
Total stations	11	0.13	152	0.14
Stations active since 1990	8	0.09	104	0.10
Average years of record	34		27	

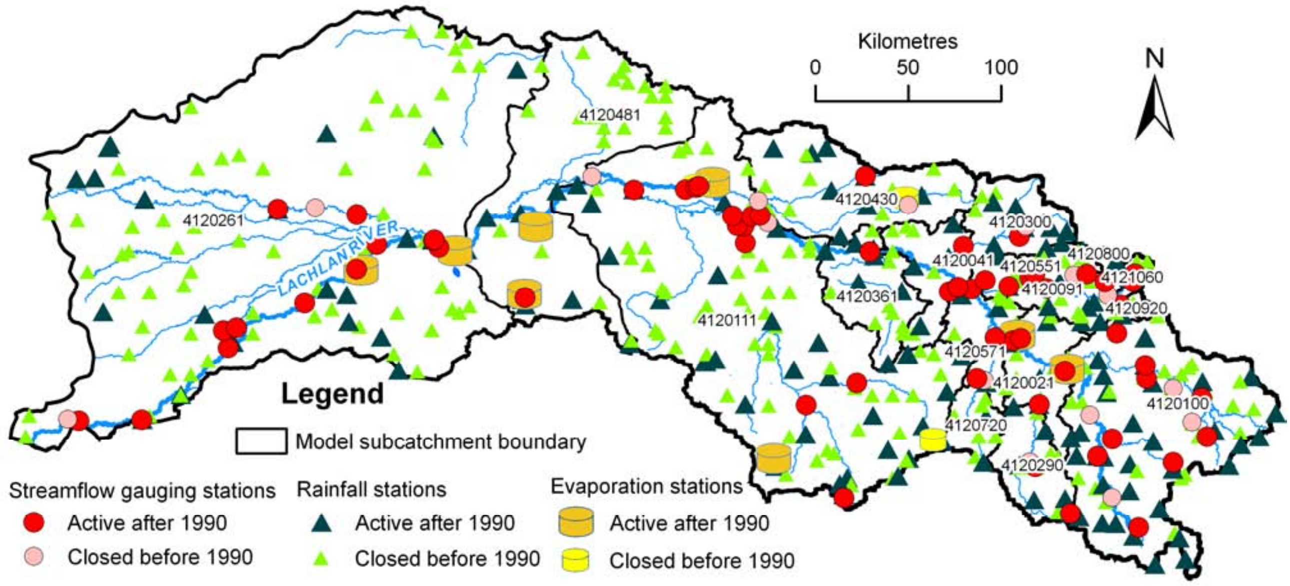


Figure 5-2. Map showing the rainfall, streamflow and evaporation observation network, along with the subcatchments used in modelling

5.3.2 Review of model calibration and evaluation information

Model description

An IQQM was developed and implemented (DLWC, 2001) for the Lachlan Valley from the headwaters of Wyangala and Carcoar Dams to the outlet of the Lachlan River near Oxley. The model aimed to:

- simulate daily hydrologic processes over periods in excess of a hundred years
- be used for Cap Implementation
- analyse the impacts of environmental flow and river operation rules to meet specific river flow objectives.

Groundwater is used by irrigators to balance shortfalls in surface water allocations. Groundwater use is not modelled in the Lachlan IQQM.

Model concepts, assumptions, calibration and performance assessment as reported in DLWC (2001) are reviewed in the remainder of this subsection.

Data availability

Rainfall data is required by IQQM to drive the soil moisture accounting and the module that assigns rainfall to storages and river reaches. Rainfall data is also required for generating catchment inflows using rainfall-runoff modelling.

Eight long-term rainfall stations with good quality and continuous data and stations nearby for ‘gap-filling’ were selected. Data from around fifty of the sites with long-term records were used to derive ‘gap-filled’ time series of daily rainfall to represent eight zones.

Evaporation data is required by IQQM to drive irrigation demand, for computing evaporation losses from reservoirs and for generating catchment inflows using rainfall-runoff models. Only a limited number of daily read evaporation gauges exist. The selection of appropriate gauges was based on the availability of records (>15 years), continuity and quality of data, and availability of nearby rainfall stations covering the long-term record. Three available short-term evaporation stations were selected for use in long-term evaporation generation: Wyangala Dam (063267), Cowra (063023) and Naradhan (075050). Long-term evaporation records were generated for the eight geographic zones in the valley using data from the three short-term evaporation stations, eight long-term rainfall stations and a simple evaporation generation module (DLWC, 1998).

Streamflow data was used for model calibration and for model simulations. Twenty-three streamflow gauging stations (Table 5-4) were selected on the main stream according to whether there was a good quality and long-term record, with a minimum number of missing periods.

There are also streamflow gauging stations located on most of the major tributaries. There were seven gauging stations selected for use in the model (Table 5-4) based on: the significance of flow contribution, availability of long-term, good quality records, and availability of nearby streamflow, rainfall and evaporation stations for rainfall-runoff modelling to fill gaps in the streamflow data and extend the record. No processing was done for the streamflow data from gauging stations along the main river. Gaps due to missing data remained.

Table 5-4. Streamflow gauging stations for which data was used in model calibration

Station No.	Operation Period	Location
Reach calibration		
412002	1893 to date	Lachlan River @ Cowra
412057	1958 to date	Lachlan River @ Nanami
412004	1892 to date	Lachlan River @ Forbes
412036	1941 to 1982	Lachlan River @ Jemalong Weir
412058	1958 to 1984	Lachlan River @ Island Creek Offtake
412006	1896 to 1939 1964 onwards	Lachlan River @ Condobolin Bridge
412034	1939 to 1964	Lachlan River @ Condobolin Weir
412021	1928 to 1990	Lachlan River @ Booberoi
412048	1955 to 1967	Lachlan River @ Brewster Weir
412038	1941 to 1986	Lachlan River @ Willandra Weir
412039	1941 onwards	Lachlan River @ Hillston
412078	1968 onwards	Lachlan River @ Whealbah
412005	1907 onwards	Lachlan River @ Booligal
412045	1952 onwards	Lachlan River @ Coorong
412097	1958 to 1967	Island Creek @ Lachlan Offtake
412023	1927 to date	Island Creek @ Fairholm
412044	1951 to 1963	Island Creek @ u/s Wallamundry Offtake
412015	1918 to 1960	Island Creek @ d/s Wallamundry Offtake
412016	1942 to date	Wallamundry Creek @ Offtake Island Creek.
412046	1917 to 1984	Wallaroi Creek @ Worrongorra Weir
412022	1928 to 1982	Booberoi Creek @ Lachlan Offtake
412009	1908 onwards	Belubula River @ Canowindra
412026	1930 to 1982	Lachlan River @ Oxley
Inflows		
412067	1913 onwards	Lachlan River @ d/s Wyangala Dam
412029	1980 onwards	Boorowa River @ Prossers Crossing
412030	1938 onwards	Mandagery Creek @ u/s Eugowra
412050	1955 onwards	Crookwell River @ Narrawa North
412028	1930 to 1998	Abercrombie River @ Abercrombie
412055	1956 to 1974	Belubula River @ Bangaroo Bridge
412092	1971 to 1993	Coombing Creek @ near Neville

Model calibration and validation procedures

A calibration process was developed to proceed sequentially down the river system and progressively eliminate unknowns. Specific parameters were estimated at each step and all other parameters replaced with observed data. All of the estimated parameters were brought together at the end of the process to see how well the overall model calibration reproduced historical information. The steps are summarised below:

- Flow calibration reproduced the observed flow hydrographs at key locations given observed storage releases, tributary inflows and water extractions. Routing parameters, transmission losses and ungauged inflows were calibrated during this step. The calibration period was generally 1941 to 1997 but varied between reaches within this period.
- Diversion (demand) calibration reproduced observed irrigation extractions given observed crop areas and the crop mix. Crop factors and irrigation efficiency, soil moisture store, initial rainfall losses were calibrated. The calibration period was 1992 to 1998.
- The area planting decision calibrated an irrigator's decision-making process to reproduce observed planted crop areas. Maximum and minimum area, the crop mix and the farmers' planting decision process were included in an attempted calibration. This calibration could not be carried out due to the lack of recent allocation constrained years, that is, it was impossible to separate farmer's planting behaviour from growth. Consequently areas were replaced by recorded values.
- Storage calibration reproduced observed volumes in the major on-river storages. This involved calibration of the processes relating to irrigation ordering and river operation. The calibration period was 1992 to 1998.

Estimates of the inflow contributed by the ungauged catchments were made during the flow calibration process using a correlation with streamflow gauging data from a nearby catchment. The calibration of diversions in the IQQM used total diversion figures rather than separating on-allocation and off-allocation data due to uncertainty in the data. The simplification was justified by an absence of on-farm storages in the Lachlan Valley.

Model performance

The performance of the IQQM in explaining observed data during the calibration periods was considered as a measure of model performance. A standardised quality assessment guideline was adopted with five confidence levels: very high (simulated value within 5 percent of observed value), high (5 to 10 percent), moderate (10 to 15 percent), low (15 to 20 percent) and very low (>20 percent).

Overall calibration of the model achieved a very high rating overall. This demonstrated the model's suitability for the intended purpose. Calibration achieved a very high rating for mid-range flows at Condobolin and a moderate rating for total flow at Booligal. The modelled diversions were generally a close match to the observed diversions (high rating). Modelled storage behaviour generally had a high quality rating, except for Lake Cargelligo where the rating was very low at the completion of storage calibration. This was due to its relative small size and its variable operation during the calibration period and was not expected to influence overall modelling.

Identified areas of weakness

A number of processes were not configured or simplified in the model:

- Unregulated licence usage was not represented explicitly in the model because of its relatively small impact on river flows and a lack of suitable data for model calibration. However, inflows to the regulated system would reflect the effects of unregulated licence activity especially in more recent years.
- Town water supplies were represented as a fixed annual demand with a monthly pattern of use.
- Stock and domestic licence usage was modelled using a fixed pattern of demand to represent the average use over the calibration period.
- Groundwater use was not represented due to insufficient data and the relatively small impact on river flows and diversions.
- Resource assessment testing (that is, comparison with announced allocations) had to be limited to short periods because of the difficulties in producing generic allocation rules for the whole calibration period.

5.3.3 Model uncertainty analysis

The indicators of model uncertainty and all other results based on water accounting are listed by reach in Appendix C. This section provides a summary of the results.

Completeness of hydrological observation network

The estimated fraction of all gains and losses that is gauged is shown for each reach in Figure 5-3. Conclusions follow:

- Water accounts were completed for the Lachlan River above Cargelligo Weir. Losses in the Lower Lachlan are high (Chapter 4) but accounting was not possible due to several ungauged distributaries and a wide floodplain. Ungauged losses in the lower part of the river system are very important.
- Most of the gains are well gauged; 77 to 95 percent of inflows into successive reaches appear to be gauged. Losses are reasonably well gauged but ungauged components increase from the highest (96 percent gauged) to the lowest reach (62 percent gauged) (Figure 5-3a).
- Attribution of gains and losses using SIMHYD estimates of local runoff, diversion data and remote sensing results helped to explain a considerable part of ungauged gains and losses. Results in the lowest reach (Reach 5) were the worst but 70 percent of all the reach water balance could still be attributed to irrigation, wetlands, and anabranch outflows (Figure 5-3b).

The five reaches included in water accounting are well gauged. The lower part of the Lachlan system is less well gauged and understood.

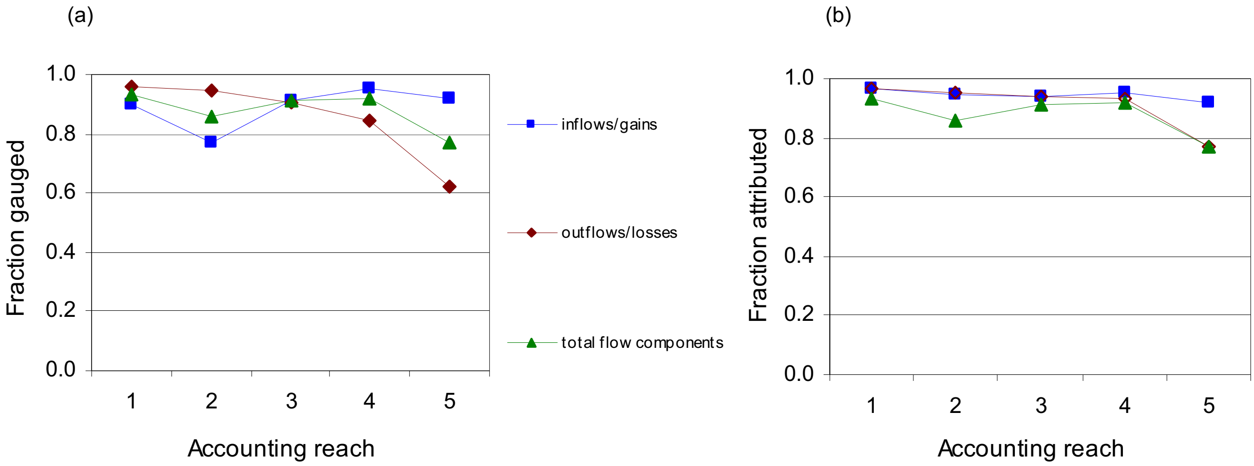


Figure 5-3. Patterns of indicators of the fraction of inflows/gains, outflows/losses and the total of water balance components that (a) is gauged or (b) could be attributed in the water accounts.

Comparison of modelled and accounted reach water balance

A summary of water balances for each reach as simulated by the river model and derived by water accounting is in Appendix C. The water balances are summarised into one water balance for all accounted reaches in Table 5-5. Observations and conclusions follow:

- The Upper Lachlan reaches above Nanami (Reaches 1 and 2) are gaining reaches. The system starts to lose more water than it gains below Forbes where most of the breakouts and irrigation extractions also occur (Appendix C).
- Groundwater exchanges are not calculated in the water accounting due to a lack of direct data. The river model includes an estimated net loss of 12 GL/year to groundwater (Chapter 4).

- The model and accounts differ in the definition of gauged tributary inflows and ungauged local inflows and therefore only their sum is considered here. The sum of local inflows and tributary inflows that was modelled (525 GL/year) is 181 GL/year or 53 percent greater than the accounted volume (344 GL/year). This is compensated in the water accounting by unattributed gains and measurement noise.
- Unattributed gains and measurement noise for the entire accounted system represent 282 GL/year or 22 percent of total apparent gains, whereas unattributed losses and measurement noise represent 447 GL/year or 34 percent of total apparent losses.
- Modelled main stem inflows to the Lachlan River at Wyangala and end-of-system outflows from Cargelligo Weir were 25 GL/year (+4 percent) and 79 GL/year (+14 percent) higher than observed streamflow, respectively. The difference for the other four main stem gauges varied from -40 GL/year to 184 GL/year, or up to 23 percent (Appendix C).
- Simulated and recorded diversions for the accounting period were within 1 percent or 1 GL/year.
- The sum of modelled river and floodplain losses and distributary outflows (134 GL/year) was similar to the river and floodplain losses estimated in the water accounting (106 GL/year). However, the model and the water accounts could not explain large losses: 308 GL/year for total modelled loss and 447 GL/year for total accounted loss, representing 24 percent of total modelled and 34 percent of total accounted losses. Some of the losses may represent measurement noise or error. Sizeable losses occur in each accounting reach but the greatest losses (231 GL/year) occur in Reach 5.

Table 5-5. Water balance comparison for accounted reaches and period, between water balance terms simulated by the river model, and those measured or attributed in water accounting. The absolute and relative difference between model and accounts is also listed.

Water balance (Jul 1990 – Jun 2006)	Model (A)	Accounts	Difference	Difference
	GL/y			percent
Main stem inflows	688	663	25	+4%
Tributary inflows	321	82	240	+294%
Local inflows	204	262	-58	-22%
Subtotal gains	**1213**	**1007**	**207**	**+21%**
Unattributed gains and noise	**59**	**282**	**-222**	**-79%**
End of system outflows	658	579	79	+14%
Distributary outflows	104	0	104	n/a
Net diversions	166	164	1	+1%
River flux to groundwater	12	0	12	n/a
River and floodplain losses	30	106	-77	-72%
Unspecified losses	308	0	308	n/a
Subtotal losses	**1278**	**849**	**428**	**+50%**
Unattributed losses and noise	**0**	**447**	**-447**	**-100%**

Climate range

Most components of the river model were calibrated for 1992 to 1998. The number of years in the entire 111-year record that were drier than those included in the calibration period was 15. Four years were wetter. The region-average rainfall range in the calibration period was 327 to 672 mm/year, compared to 205 to 847 mm/year for the 111-year period. The average in these calibration years was 10 percent higher than the long-term average. By comparison, the historical 111-year rainfall record had eight years that were drier and four years that were wetter than the extremes during the period of water accounting 1990 to 2006.

Overall, the calibration period represented long-term climate variability moderately well: 29 years out of the 111-year record were outside calibration range. The water accounting period 1990 to 2006 provides a reasonable representation of climate variability (12 out of 111 years outside accounting range).

Performance of the river model in explaining historical flow patterns

The better the baseline model simulates streamflow patterns, the greater the likelihood is that it represents the response of river flows to changed climate, land use and regulation changes (notwithstanding the possibility that the model is right for the wrong reasons through compensating errors). Appendix C lists indicators of the model's performance in reproducing different aspects of the patterns in historically measured monthly and annual flows in each reach (all are variants of Nash-Sutcliffe model efficiency).

Figure 5-4 shows the relative performance of the model in explaining observed streamflow pattern (as model efficiency) at the downstream gauge of accounted reaches where model simulated results were available.

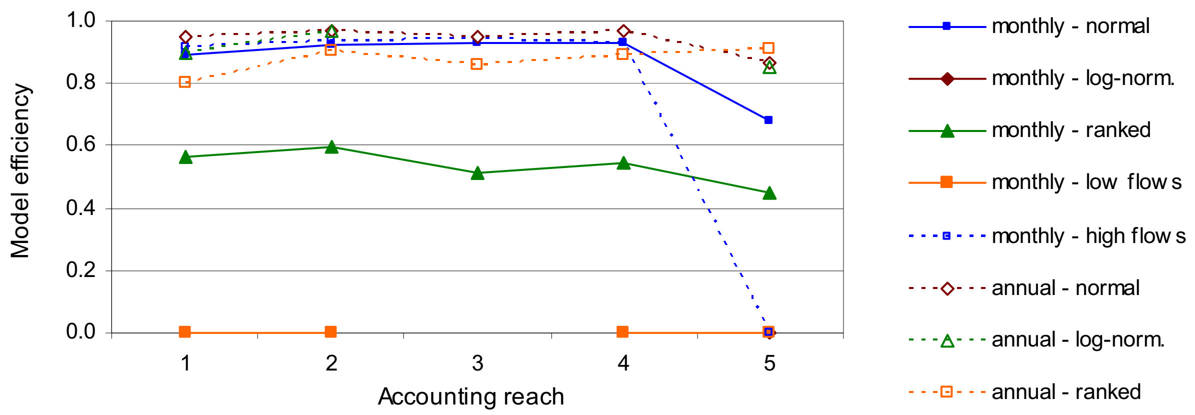


Figure 5-4. Changes in the model efficiency (the relative performance of the river model in explaining observed streamflow patterns) along the length of the river

Observations follow:

- The model performed very well in simulating monthly and annual flow patterns in the top four reaches (NSME 0.89–0.95) and reasonably well for Reach 5 (NSME=0.68–0.86). High flow patterns were also reproduced well in four reaches (NSME=0.92–0.94), but not in the last reach.
- The performance in simulating the 10 percent highest flows was very good for four reaches (NSME 0.92–0.94) and poor for the lowest reach (Cargelligo Weir). This was mainly due to overestimation of the three months with highest simulated flows (July to September 1990). Recorded flows for this period could also not be reconciled in water accounting and therefore are more likely to be associated with high flow rating issues at Cargelligo Weir (Appendix C).
- The 10 percent lowest monthly flows were reproduced poorly by the model for all reaches (NSME <0). The model appeared to underestimate flows for the few months with lowest flows, for example, in 2005 and low flow periods from 1990 to 1994 (Appendix C).

Scenario change-uncertainty ratio

A high CUR corresponds with a scenario change in flows that is likely to be significant given the uncertainty or noise in the model. A CUR of around 1.0 indicates that the modelled change has a similar magnitude to the uncertainty in the model. The CUR is shown for each reach for changes in monthly and annual total flows in Figure 5-5a and Figure 5-5b, respectively.

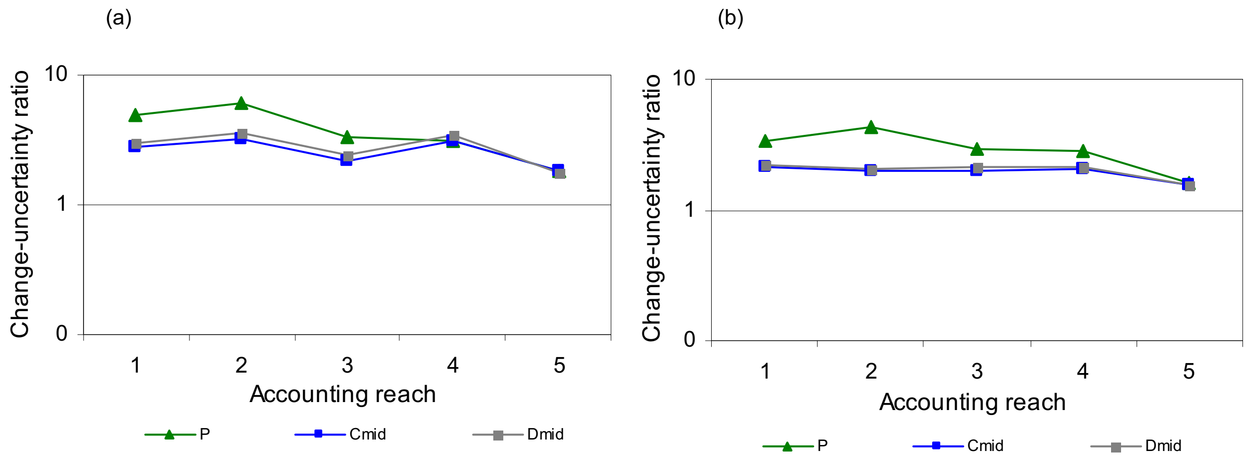


Figure 5-5. Pattern along the river (expressed as cumulative river catchment area) of the ratio of the projected change over the river model uncertainty for (a) monthly and (b) annual flows under scenarios P, C and D

Observations and conclusions follow:

- Simulated changes were generally more significant for monthly patterns than for annual patterns. However, annual totals were better simulated than monthly flows, meaning that an equal percentage change would be more significant for annual totals.
- The simulated change from without-development to current monthly flow patterns is of fair to high significance when compared to model performance for reaches 1 to 4 (above Jemalong weir) (CUR 2.9–6.1) and of modest significance for Reach 5 (Cargelligo weir) (CUR 1.6–1.8). The modelling provides evidence that flow patterns would be different without development. Flow duration curves in Appendix C suggest that there would have been more flow variability. Flow is maintained under current development at more than 10 GL/year for more than around 80 percent of the time, whereas this would occur for 50 to 60 percent of the time under pre-development conditions. Year-to-year variability would also have been greater under pre-development conditions.
- The CURs for the lowest reach (Cargelligo Weir) are related to the overestimation of observed flows by the model that leads to lower NSME values. This produces lower CURs where drier scenarios reduce this overestimation and therefore produce flow predictions that are closer to historically observed patterns.
- There is only a small difference between results for scenarios C and D. Consequently there is very little difference in CURs. Both wet scenarios have modest ratios (1.1–2.2); both mid scenarios have reasonably high ratios (1.6–3.6) and both dry scenarios show generally high ratios (3.5–11.3), except for Cargelligo Weir due to apparent bias in the modelled flows for this station.

Changes in flow under the scenarios have an uncertainty that is generally greater than the uncertainty in the model predictions.

5.4 Discussion of key findings

5.4.1 Completeness of the gauging network

The density of the Lachlan region's gauging network is similar to the MDB average. There are 76 stations with streamflow records of which 14 were decommissioned before 1990 (Section 5.3.1). Available gauge data for 30 stations were used in IQQM construction and calibration (Section 5.3.2). The density of rainfall and evaporation gauges in the Lachlan is slightly less than the MDB average. There are 205 active rainfall stations and 11 active evaporation gauges.

The gauging of water balance terms could only be assessed for the Upper Lachlan, using streamflow data from 11 gauges between Wyangala Dam and Cargelligo Weir.

Around 58 percent of the sum of apparent gains and losses for this part of the system was gauged, whereas another 14 percent could be attributed in water accounting. The remaining 28 percent of unattributed flows and measurement noise had similarly large gains and losses (Section 5.3.3).

The Lower Lachlan has some active gauges but accounts could not be completed due to the lack of local inflow estimates. Therefore, there are no statistics regarding the completeness of the gauging network for the Lower Lachlan. The very large losses in this part of the system associated with the extensive floodplains, wetlands and breakouts are inherently difficult to gauge and therefore total flow measurements are incomplete. The gauge at the end-of-system at Oxley was closed in 1982.

The Upper Lachlan is sufficiently well gauged for river modelling. Modelling in the Lower Lachlan is less certain.

5.4.2 Conceptual understanding of regional surface hydrology

The water accounts reported in this chapter accounted for 72 percent of the total water balance, varying from 77 to 93 percent between the five reaches (Section 5.3.3). The hydrology of the Upper Lachlan is understood quite well given the available data. The system is gaining above Nanami, and losing below Forbes, where losses occur to diversions and wetlands. About 41 percent of all diversions occur in the Upper Lachlan (Section 5.3.2). They represent about 16 percent of total Upper Lachlan inflows.

Lower Lachlan hydrology is less well understood: local inflows appear very small and large ungauged losses occur that may be associated with floodplain and wetland losses and with groundwater systems connected to a substantial length of the river. Around 59 percent of total diversions occur in this part of the system. Uncertainty in ungauged extractions and diversions may be relatively small considering the apparently small number of on-farm storages in the (Lower) Lachlan (Section 5.3.2).

Groundwater interactions are a potential source of uncertainty. These were modelled in the Upper Lachlan at 12 GL/year or 2 percent of total modelled losses. Groundwater interactions in the Lower Lachlan appear to be small (Chapters 4 and 6).

The greatest uncertainty in future inflows is caused by uncertainty in climate projections. This is amplified by a modest climate calibration range for most of the river model components which are lacking at the important drier end of the climate calibration range (Section 5.3.3). The second greatest source of uncertainty includes changes in system inflow response as a result of changes in vegetation cover and function. Plantation forestry and farm dams have little impact and therefore small uncertainty.

Unforeseen changes in river regulation, irrigation and development are possible. Diversions accounted for 16 percent of total inflows in the Upper Lachlan and therefore the greatest potential impact may be associated with changes in patterns in flow regulation and diversion rather than longer-term average volume changes.

5.4.3 Performance of aspects of the model

Reviews of the modelling pointed to uncertainties associated with, or improvements that could be made to, unregulated extraction in tributary reaches, town water supply and stock and domestic uses and groundwater use. The limited ability to calibrate the simulation of resource assessment and allocation announcements was also highlighted. However, water accounting for the Upper Lachlan suggests the model simulates average diversions over the accounting period ‘reasonably’ to ‘very well’ in this part of the system (Section 5.3.3).

Comparison of simulated flows with modelled flows at main stream gauges shows that the model generally reproduced monthly and annual flow ‘well’ and high flow patterns ‘very well and without bias’, but low flows were not reproduced well (Section 5.3.3). These findings confirmed prior model evaluation (Section 5.3.2). The model underestimated streamflow during periods with very low flows and this is related to discrepancies in the simulation of dam operation. While this does not affect assessments of total water availability, it places limitations on the conclusions that might be drawn regarding changes in low flows and the environmental consequences of these changes. High flows were simulated well.

Previous model evaluation suggested that model performance was rated as moderate in simulating end-of-system flows at Booligal which is near Oxley. Performance was rated as 'high' for model storage behaviour, except for Lake Cargelligo that, because of its relatively small size and variable operation during the calibration period, attracted a very low rating.

5.4.4 Implications for use of the results of this study

The overall internal model uncertainty is less than the external uncertainty of climate change. The model is suitable for the purpose of this project. The internal model uncertainty appears of similar or greater magnitude as the uncertainty in farm dam and plantation development. The Upper Lachlan groundwater interactions were small. Therefore, external uncertainty associated with future development in the Upper Lachlan appears less important than the uncertainty internal to the model. The internal model uncertainty could not be assessed for the Lower Lachlan where groundwater interactions may be greater (Chapter 4).

Wetland replenishment relies on peak flows. Current and previous evaluations of the river model suggest that the model can accurately simulate peak and average flows due to changes in rainfall. However, previous and current evaluations could not confirm whether or not the model is suited to make reliable predictions of (i) end-of-system flow changes at Oxley; and (ii) the 10 percent lowest flows, particularly during very dry periods.

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6 Groundwater assessment

This chapter describes the groundwater assessment for the Lachlan region. It has seven sections:

- a summary
- a description of the groundwater management units in the region
- a description of surface–groundwater connectivity
- an overview of the regional modelling approach
- a presentation and description of modelling results
- an assessment of water balances for lower priority groundwater management units
- a discussion of key findings.

6.1 Summary

6.1.1 Issues and observations

There are six groundwater management units (GMUs) that cover almost the entire Lachlan region. The assessments for the Upper and Lower Lachlan Alluvium GMUs are respectively based on use of a model developed specifically for the project and an existing numerical groundwater model. Assessments for the remaining GMUs are based on simpler water balance analyses.

6.1.2 Key messages

Total groundwater extraction in the Lachlan region in 2004/05 is estimated to have been 236 GL. This represents 14.1 percent of groundwater use in the Murray-Darling Basin (MDB), excluding use from the confined aquifers of the Great Artesian Basin (GAB). This level of groundwater use represents 45 percent of total water use in the region on average, and 90 percent of total water use in years of minimum surface water diversion. Most of the extraction (84 percent) was from the Upper Lachlan (31 percent) and Lower Lachlan (53 percent) Alluvium GMUs. For the Lower Lachlan Alluvium GMU 2004/05 extraction exceeded the long-term average extraction limit (LTAEL) due to supplementary licences with entitlements that decrease to zero by 2018. The reduction in entitlements to the LTAEL level is funded by the New South Wales and Australian governments under the 'Achieving Sustainable Groundwater Entitlements' program. The interim LTAEL for the water sharing plan was recently changed from 96 GL/year to 108 GL/year. This occurred after modelling was complete so that 96 GL/year was used for all modelling. The eventual total impact of this groundwater extraction (96 GL/year plus basic rights), together with that in the Upper Lachlan, on the Lachlan River is expected to be approximately 20 GL/year.

For the Belubula Valley GMU, groundwater extraction exceeds rainfall recharge several-fold. This is a very high level of development; however, due to the close connection between the surface water and groundwater in this area, the aquifer receives considerable recharge from streamflow. A single water sharing plan (WSP) is being considered for the Belubula Valley GMU and its associated streamflow which will ensure fuller accounting for all sources of water and comparison of extraction with total recharge from all sources.

Groundwater extraction outside of the Upper and Lower Lachlan Alluvium GMUs is expected to increase more than three-fold by 2030, with nearly all of the increase in the Lachlan Fold Belt GMU. This would mean total groundwater extraction for the region would be 440 GL/year – an increase of 86 percent over 2004/05 extraction levels. The total eventual impact of future groundwater extraction across the region will be an estimated additional 30 GL/year reduction in streamflow. Future groundwater extraction would (under the best estimate 2030 climate) represent 63 percent of total water use on average and 95 percent of total water use in years of minimum surface water diversion.

Groundwater modelling indicates that for the Lower Lachlan Alluvium GMU:

- Under the current climate, the current spatial pattern of extraction cannot be maintained at the interim LTAEL (96 GL/year plus basic rights for the modelled area). Average extraction (94 GL/year for the modelled area) is about 71 percent of the 'effective recharge' (recharge without lateral inflow). Effective recharge only exceeds extraction 44 percent of the time.
- This is a high level of development which will reduce groundwater levels by up to 10 m in some parts of the lower aquifer requiring responses from both groundwater users and groundwater managers in order to reduce extraction in areas of falling watertables. As the area of lowered watertable grows, additional recharge is likely to be induced from the Lachlan River, but the timeframe for this to occur is likely to be extremely long.
- The long-term (over 200 years) impact of extraction at the former LTAEL is expected to be about a 3 GL/year reduction on streamflow in the Lachlan River. This 3 GL/year is in addition to the 'natural' 42 GL/year streamflow loss to the GMU from the lower Lachlan River. The ultimate impact is likely to be much greater than this, but due to the large extent and thus slow response of the aquifer, it will take a long time for these greater impacts to occur.
- Under the best estimate 2030 climate there would be little change in rainfall recharge to this GMU; however, under the wet extreme 2030 climate there would be a 19 percent increase in rainfall recharge and under the dry extreme 2030 climate there would be a 34 percent reduction in rainfall recharge. Net river losses would be largely unaffected.

Groundwater modelling indicates that for the Upper Lachlan Alluvium GMU:

- Under the current climate, the LTAEL (61 GL/year for the modelled area) is about 117 percent of the current total groundwater recharge. Recharge exceeds extraction only 8 percent of the time. This is a very high level of development which will reduce groundwater levels by up to 20 m in some parts of the lower aquifer requiring responses from both groundwater users and groundwater managers in order to reduce extraction in areas of falling watertables. As the area of lowered watertable grows, additional recharge is likely to be induced from the Lachlan River, but the timeframe for this to occur is likely to be extremely long. Dynamic equilibrium with stable groundwater levels would be attained at an extraction rate of about 50 GL/year.
- The long-term (several decades) impact of groundwater extraction on streamflow in the Lachlan River is about 17 GL/year. This 17 GL/year is in addition to the 'natural' 8 GL/year streamflow loss to the GMU from the upper Lachlan River.
- Under the best estimate 2030 climate there would be little change in rainfall recharge to this GMU; however, under the wet extreme 2030 climate there would be a 14 percent increase in rainfall recharge and under the dry extreme 2030 climate there would be a 38 percent reduction in rainfall recharge. Net river losses would be unaffected.
- Groundwater extraction in the modelled area is projected to be 121 GL/year by 2030. This level of extraction cannot be maintained by the existing distribution of bores. The maximum level of extraction that could be maintained from the existing bores is about 67 GL/year. Prolonged extraction at the projected future level is predicted to remove an additional 4 GL/year from the river through induced leakage to groundwater.

6.1.3 Uncertainty

Both the priority of the GMU in the context of the overall project and the analysis methods used in the project have been ranked. Ideally the ranking of the analysis method matches the GMU priority so the GMUs that are likely to influence MDB-wide outcomes have more reliable information on groundwater availability and level of development.

The modelling approach used in this project uses a very long modelling time period (222 years) and models that have not previously been calibrated under steady-state conditions or have a small model extent, can become less than fit for this purpose. If the first of these conditions are not met, the modelled watertables may show drifts that are more associated with the calibration process than hydrological processes. If the second condition is not met, the boundary conditions imposed on the model may overly affect the groundwater balance and lead to spurious results.

The long modelling period is used so that over the first 111 years, the system is brought to a 'dynamic equilibrium', and then over the second 111 years, the system is run in sequence with the river models to provide input to groundwater–surface water interactions. In some cases, dynamic equilibrium is not reached within 111 years. The most likely cause is that extraction exceeds recharge from all sources for the model area, or for some components of the model area, and watertables gradually fall. This suggests that the modelled spatial pattern of extraction is not sustainable. In such cases, the modelling results will have implications for beyond the project and in particular for the sustainable extraction limit. Thus, it is important that the ranking of the assessment methods provides some information on the reliability of such information. For assessing water availability at the larger scale, a model may be fit for purpose for this project but less than adequate for addressing local management issues.

The ranking of analysis methods is: minimal (hydrogeological description), simple (simple water balance analysis) and medium to very thorough (numerical modelling). The rankings within the range medium to very thorough depend on (i) the quality of monitoring data (length of period and spatial distribution); (ii) the quality of extraction data (metered versus estimated); (iii) complexity of process representation; (iv) availability of field data independent of calibration; (v) explicit representation of surface water–groundwater connectivity; and (vi) level of independent peer review. Since at least three of these criteria are based on availability or quality of data, a good calibration fit in line with the best modelling guidelines may still not rank well. Also, the more mature a model, the more opportunities there are for obtaining a higher ranking because of data availability and peer review. A very thorough model should provide very good reliability in addressing issues of groundwater balance and hence extraction limits.

For the Lachlan region, both the groundwater models have been run with a steady-state 'without development' calibration. The current version of the Lower Lachlan model has not been used to prepare the groundwater sharing plan but still would have had a high level of prior scrutiny. Fair monitoring and extraction data existed for both models. Lateral flows represent less than 10 percent for the Upper Lachlan model, but the majority of the groundwater balance for the Lower Lachlan model. The Lower Lachlan model is based on a relatively coarse grid. Both models have been assessed as thorough. Thus, both models are adequate for providing information on water availability in the context of this project. Neither the Lower Lachlan model nor the Upper Lachlan model reached dynamic equilibrium.

The current form of the groundwater Lower and Upper Lachlan models produce results that have a low to moderate level of uncertainty due to the nature of model calibration. The level of calibration for both models may be able to be improved with more work, depending on the level of priority placed on achieving such a result within the broader context of water management across the MDB. The models are unsuitable for use as water allocation tools due to the fact that local aquifer use rules are not currently implemented and the redistribution of groundwater extraction, that would take place as pumping bores dry out, is not currently incorporated in a realistic manner. Notwithstanding the level of uncertainty surrounding the model, the level of analysis for the Lower Lachlan and Upper Lachlan Alluvium GMUs is commensurate with the priority ranking of these GMUs for the project objectives. Though some further calibration effort is required, these models are considered to be calibrated.

Model-based estimates of river interaction are particularly sensitive to the river cell conductance term assigned to the river boundary conditions. In the normal calibration process this parameter can be refined provided sufficient attention is paid to matching observed groundwater behaviour at close proximity to the river. In this regard it is noted that estimates of river cell conductance are more certain and hence the confidence of river interaction predictions are greater for the Upper Lachlan model as there are many more near-river observation bores used to calibrate this model compared to the Lower Lachlan model.

The two models could be configured in a manner that would illustrate an increased level of sustainable extraction. However, it was not the intention of the project to demonstrate upper bounds to possible groundwater extractions in any of the models that have been developed and used. The models that have been developed represent best estimates of the prevailing hydrogeological domain, including the existing bore distribution and their pumping levels. It is recognised that all groundwater model predictions have a level of uncertainty associated with the fact that the models are never uniquely calibrated.

There is considerable uncertainty in the future projections of groundwater development outside of the two modelled GMUs, but the estimates do show the importance of development in these areas. In particular, there is a large uncertainty introduced by the inability to estimate recharge to the Belubula Valley GMU aquifer from streamflow. The groundwater projections generally represent the upper limit of groundwater development, as developments can be constrained by pumping rules, groundwater quality and land suitability. However, the analysis of the impacts of this development on streamflow is considered conservative, due to the use of current entitlements, omitting subcatchments where the impact on streamflow is less than 2 GL/year (typically close to half the total impact) and the use of connectivity estimates based effectively on conservative 'best guesses'.

The level of analysis against each of the GMUs is at an acceptable level, except in two cases – the Upper Lachlan Alluvium GMU and the Belubula Valley Alluvium GMU.

6.2 Groundwater management units in the region

The Lachlan region contains six GMUs. Table 6-1 shows the priority and assessment rankings of each GMU. The priority ranking helps focus efforts on those GMUs which affect most the overall groundwater or surface water resource in the MDB. The priority rankings range from very low to very high in the context of the project and are based on the level of groundwater use, potential for growth in use and the potential for groundwater to impact on streamflow.

The groundwater assessment rankings reflect the availability of data and analysis tools as well as the priority of the GMU. They range from minimal to very thorough. A simple ranking for the GMUs in the Lachlan region denotes a simple water balance approach while a moderate to thorough rating denotes use of either an uncalibrated or calibrated numerical groundwater model without the supporting data nor the peer review that might be expected for a very thorough rating. The analysis method is consistent with the priority ranking for all of the GMUs listed in Table 6-1, except for the Upper Lachlan Alluvium GMU and the Belubula Valley Alluvium GMU. While these assessments are appropriate within the constraints of the project, additional work may be required for local management of groundwater resources.

Table 6-1. Categorisation of groundwater management units, including annual extraction, entitlement and recharge details

Code	Name	Priority ranking	Assessment ranking	Total entitlement	Current extraction* (2004/05)	Long-term average extraction limit***	Maximum likely extraction without plan revision
					GL/y		
N11	Upper Lachlan Alluvium	very high	thorough	191.99	72.73	91.55	191.99
N12	Lower Lachlan Alluvium	high	thorough	96**	125.7	108**	108 (plus basic landholder rights)**
N21	Belubula Valley Alluvium	high	simple	6.29	5.18	0.22	6.29
N801	Orange Basalt	low	simple	6.23	3.89	12.9	6.45
N802	Young Granite	low	simple	7.75	6.19	7.55	7.75
N811	Lachlan Fold Belt	low	simple	33.46	22.28	476.75	119.19

*Current groundwater extraction for Macro Groundwater Sharing Plan areas is based on metered and estimated data provided by New South Wales DWE. Data quality is variable depending on the location of bores and the frequency of meter reading.
** Source: DWE (pers. Comm.)
*** For Macro Groundwater Sharing Plan areas these limits are draft, as plans for these areas are not yet gazetted.

6.2.1 The Achieving Sustainable Groundwater Entitlements structural adjustment program

The Achieving Sustainable Groundwater Entitlements program (DNR, 2005) was announced in June 2005 to reduce entitlements in the Upper and Lower Namoi, Lower Macquarie, Lower Lachlan, Lower Murray, Lower Gwydir and Lower Murrumbidgee groundwater sources. The program does not consider the Upper Lachlan. The New South Wales and Australian governments jointly invested $110 million in this program to improve long-term sustainability of the six major groundwater systems in New South Wales. In June 2007, the Australian Government provided an additional $25 million to the program, bringing the Australian Government contribution to $80 million and total funding to $135 million.

The level of entitlements in these systems has been reduced to equal the long-term average extraction limit (LTAEL) within the WSPs for these areas. The extraction allowed from each system will be gradually reduced from current levels to the LTAEL over the ten years of each WSP.

The LTAEL form the assumed levels of extraction under Scenario D assessments and is also used for Scenario A in the Lower Lachlan Alluvium GMU assessments.

6.3 Surface–groundwater connectivity

The objectives of the surface–groundwater connectivity mapping are to provide a catchment context for groundwater–surface water interactions, constrain the surface water balance and constrain groundwater balances.

The main output is a map of groundwater fluxes (magnitude and direction) adjacent to main streams. The approach uses Darcy's Law and hence estimates hydraulic conductivity and groundwater gradients surrounding the streams. The method is dependent on availability of appropriate groundwater monitoring and on reported estimates of hydraulic conductivity. River levels and groundwater levels were compared at a single point in time to provide a snapshot of the direction and magnitude of the flow between surface water and groundwater.

The period selected for production of the flux map and associated calculations was February to April 2005 as this was the most recent date with a large quantity of available bore and river elevation data. The period represents a low flow period in the context of historical flows in the Lachlan River with an average depth of 0.5 m at Condobolin Bridge (stream gauge 412006). This 2005 stream depth compares with the range of average seasonal depths of 2 to 5 m over the period of record (1982 to 2007). There is a trend for the last five to six years to lower annual peak flows and shallower minimum annual depths.

An aquifer thickness of 15 m was applied to the upper aquifer between Lake Cargelligo and Merrowie Creek, 25 m to the reach between Lake Cargelligo and the Abercrombie River junction, and 20 m was applied above the Abercrombie Junction. A constant hydraulic conductivity value of 10 m/d was assigned to the entire length of the River.

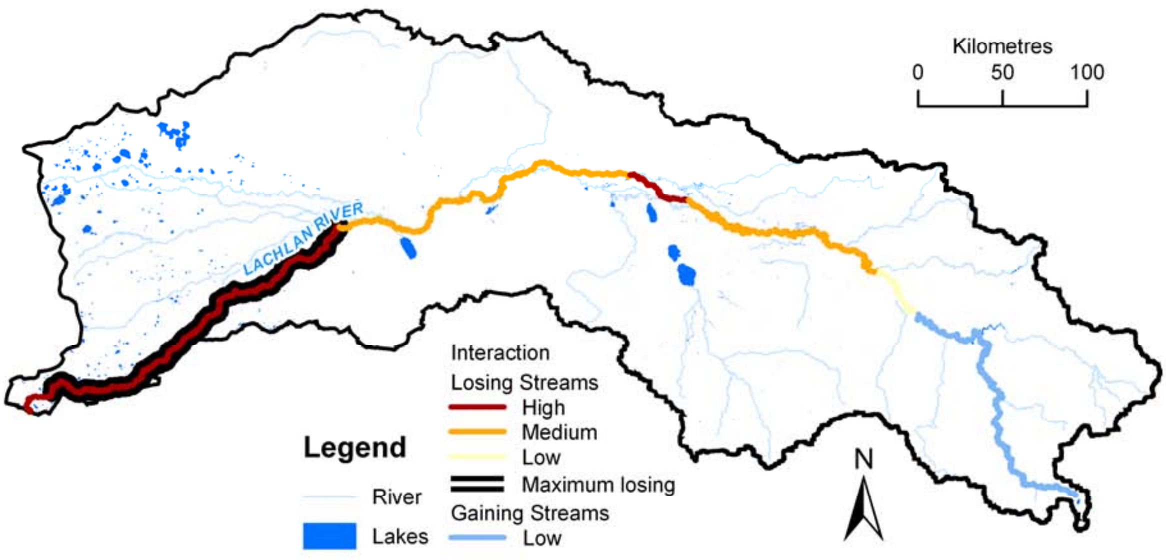

Figure 6-1. Map of surface–groundwater connectivity

Figure 6-1 shows the surface–groundwater connectivity results of the flux assessment.

The assessment found that the Lachlan River:

- is losing below Cowra
- sections just upstream of Condobolin and from downstream of Hillston exhibit maximum losing conditions
- is a low gaining stream above Cowra.

These results are consistent with other hydrogeological interpretations of the catchment.

Comparisons were made between river levels at two gauging stations and adjacent groundwater levels show how these fluxes change with time. Groundwater levels retained the same relative relationship with river stage in most reaches studied indicating that the nature of the surface–groundwater connection remained essentially stable over time. However, the rate of loss from the river has probably increased over the last five to ten years as groundwater levels have fallen due to the dry climatic conditions. This was tempered by observations that gaining conditions could be reversed over a short time in some river reaches due to flood events, indicating a more episodic influence on connectivity.

6.4 Groundwater modelling approach

A large proportion of the extraction of groundwater from the Lachlan region is from the Upper and Lower Lachlan Alluvium GMUs. Two groundwater models were used to assess the Lachlan region (see Figure 6-2). The Lower Lachlan model is under development by New South Wales Department of Water and Energy (DWE) and is being calibrated against measured groundwater hydrographs over the period July 1978 to June 2005.

The Upper Lachlan groundwater model was developed during the project using digital terrain models, recorded stream flow and climate parameters, and recorded pumping bore data. It was calibrated against measured groundwater hydrographs over the period 1998 to 2006. More detailed descriptions of each model are given below.

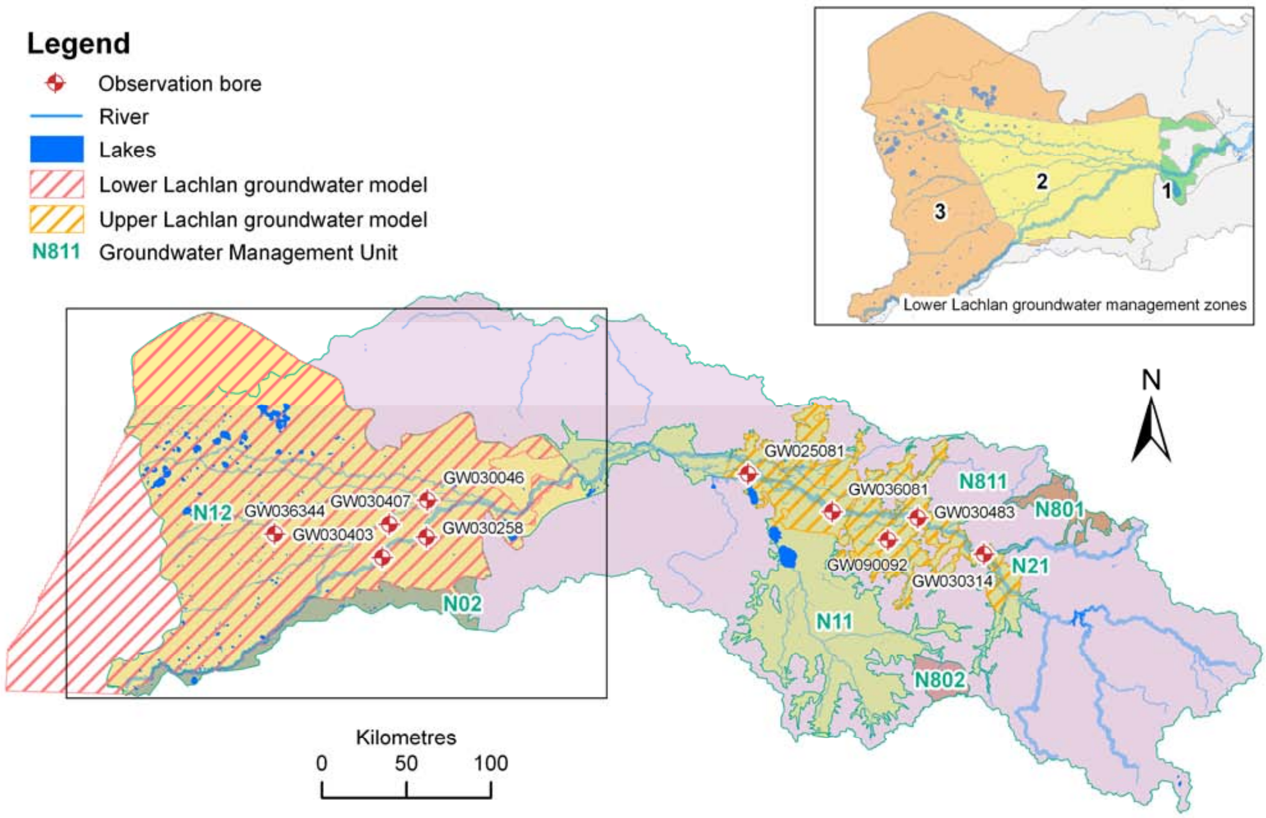

Figure 6-2. Map of groundwater management units and groundwater models in the Lachlan region, with inset showing the Lower Lachlan groundwater management zones

6.4.1 Modelling approach – Lower Lachlan

The Lower Lachlan groundwater model covers the lower end of the Lachlan region (Figure 6-2), all of the Lower Lachlan Alluvium GMU (N12) and a substantial area to the west of the GMU.

The aquifers of the Lower Lachlan area consist of unconsolidated alluvial sediments that form a broad alluvial fan at the point where the Lachlan River emerges onto the riverine plain near Hillston. The unconsolidated sediments are subdivided into a broad and highly heterogeneous shallow Shepparton Formation unconfined aquifer and underlying leaky confined aquifers in the Calivil Formation and Renmark Group. Groundwater is abstracted from all aquifers but primarily from the lower units. The Lachlan River and various anabranches, including Willandra Creek (an ancestral channel) are principal sources of aquifer recharge and are supported at times by flood events. Infiltration of irrigation accessions and rain are less significant. Groundwater flows from east to west across the model domain. The alluvial sediments form a relatively narrow aquifer at the upstream model boundary and the aquifers broaden towards the western downstream boundary. The Lower Lachlan GMU is located in the eastern part of the model domain. Its location is controlled by the distribution of irrigation quality groundwater. The region downstream of the management area has relatively high salinity and is precluded from use for domestic and irrigation purposes.

The Shepparton Formation lies completely above the watertable and is therefore unsaturated in eastern areas of the model domain. Groundwater extraction commenced in the 1860s with town water supply development and remained at low levels until the 1960s. Large-scale development for irrigation commenced in the early 1990s and increased steadily to current levels of more than 120 GL/year. Recent extraction has fallen.

Water level monitoring near extraction bores in the modelled area indicates that groundwater levels have declined significantly and continue to decline since extraction commenced. Levels are rising to the west of the region of groundwater extraction. This behaviour results from progressive hydrogeological re-equilibration to changes in river level caused by river regulation.

The Lower Lachlan model is a three-dimensional finite difference numerical framework developed in the MODFLOW simulation code. It consists of three layers corresponding to the principal hydrogeological units present in the Lower Lachlan area as follows:

- Layer 1 is the uppermost model layer that corresponds to the Shepparton Formation and is commonly exposed at the surface. It comprises of heterogeneous sediments including shoestring sands and significant sequences of impermeable silts and clays.
- Layer 2 corresponds to the Calivil Formation. It consists of sands and gravels that form a productive aquifer.
- Layer 3 represents the underlying Renmark Group sediments.

The main production aquifers in the model are sand and gravel zones in the Calivil and Renmark formations. The model is arranged over a mesh of square grid cells that measure 1000 m by 1000 m. It includes boundary conditions that define the interaction between the rivers and the groundwater system (river boundary cells). There are conditions that allow water to enter or leave the model domain through its external boundaries (both general head and constant head boundary conditions). The 'river boundary cell conductance terms' (used to regulate flow at the boundary) vary spatially across the model domain.

Recharge associated with downward percolation of water from the surface (that is, from rainfall, irrigation accessions and flood inundation) is applied to the top active cells in all model columns. The recharge flux is set at a fixed percentage of rainfall (1.0 percent of monthly rainfall) measured in gauges located within and near the model domain. The recharge rate is consistent with other models developed for similar hydrogeological settings within the MDB. The model is subdivided into recharge zones according to the rain gauge locations. An area surrounding the river includes periods of enhanced recharge flux that is used to represent the impacts of inundation during flood events. It was determined from a spatial analysis of historical flood maps. The magnitude of recharge applied at times of inundation was obtained as part of model calibration. Increased recharge due to irrigated accessions is not explicitly included in the model. Evapotranspiration fluxes from the water table are not included in the model.

DWE precluded rainfall recharge through the western area of the GMU (Zone 3, Figure 6-2) in assigning an extraction limit because the shallow aquifer was saline in this area. The water balances from the model outputs were calculated just for the area covered by Zones 1 and 2 and recharge was termed the 'total recharge'. An 'effective recharge' was derived (which consists of the total recharge minus the lateral inflow term) in recognition that the area outside Zones 1 and 2 contains saline groundwater.

The mass balance for the calibrated model is presented in Figure 6-3. Lateral groundwater flow out of the model ('mass out' in Figure 6-3) accounts for 61 percent of all discharge within the calibration period. This flow is predominantly across the western boundary. Inflow to the aquifer ('mass in' in Figure 6-3) is made up of fluxes from the rivers, recharge (rainfall recharge and flooding inundation recharge) and from 'general head boundary cells'. The recharge component shown in Figure 6-3 is made up of the flooding inundation, rainfall and irrigation recharge.

Figure 6-3. Mass balance for the Lower Lachlan calibration model

6.4.2 Modelling approach – Upper Lachlan

The Upper Lachlan model covers most of the Upper Lachlan Alluvium GMU and incorporates two aquifers. The Lachlan Formation consists of gravels and sands deposited in a palaeochannel that follows the present day Lachlan River. The Lachlan Formation underlies the lower permeability Cowra Formation that fills the rest of the valley. The majority of pumping bores target the Lachlan Formation due to its higher permeability.

The model extends between river gauges at Cowra and Condobolin Weir. The model grid consists of square cells (500 m by 500 m) and a finer grid (250 m by 250 m) at Jemalong Weir. The model includes three layers that represent the Upper Cowra Formation, Lower Cowra Formation and Lachlan Formation.

The Upper and Lower Cowra Formation layers are similar but a division was required to avoid overestimation of aquifer storage potential. The top layer was configured to act as an unconfined aquifer that has storage characteristics defined by a particular specified yield term. The Cowra Formation actually consists of shoestring sands, silts and clays and may not be unconfined. The Upper Cowra Formation was therefore assigned an arbitrary thickness of approximately 10 m near the centre of the valley. The base of the model and the boundary between the Cowra and Lachlan formation layers were contoured from bore logs and mapped outcrops.

The lateral boundaries of the model were assigned 'general head boundaries' that allow water to enter or leave surrounding aquifers. The Lachlan River is configured as a line of river cells that also allow for water to enter or leave the model. The river cells exist only in the top layer but the general head boundary cells exist in all three model layers.

Recharge and evapotranspiration fluxes were applied to replicate the combined impacts of rainfall recharge, irrigation accessions to groundwater and evapotranspiration from the watertable. Recharge fluxes were zoned by irrigation regions as identified in satellite imagery and management units. One percent of monthly rainfall was applied within the 'rainfall infiltration' areas. Two percent was applied in the hills runoff areas. One percent of monthly rainfall was used in the irrigated areas except during dry summer months when the recharge flux was increased to 12.3 mm. The incorporation of irrigation recharge has the effect of applying a small enhancement to aquifer recharge during the summer months in irrigated zones. Recharge fluxes included in the model are consistent with the recharge rates included in other groundwater models developed for similar hydrogeological settings.

The model includes a single evapotranspiration zone using 50 percent of average monthly recorded pan evaporation with a 2 m extinction depth. The mass balance for the calibrated model is presented in Figure 6-4. Evapotranspiration accounted for 50 percent of the water leaving the model. This was due to shallow groundwater. This value also accounts for groundwater use by vegetation.

Pumping was the second largest form of groundwater discharge within the calibrated model. Most extraction occurred during the second half of the calibration. Rivers replaced nearly half the water removed from the model.
An equivalent amount of water was not replaced and caused the watertable to drop. This volume not replaced is featured in Figure 6-4 as net storage. This figure shows that the groundwater levels in the Upper Lachlan system are dependent on the river, and indicate that increased pumping will either lead to increased withdrawal from the river or a drop in watertable.

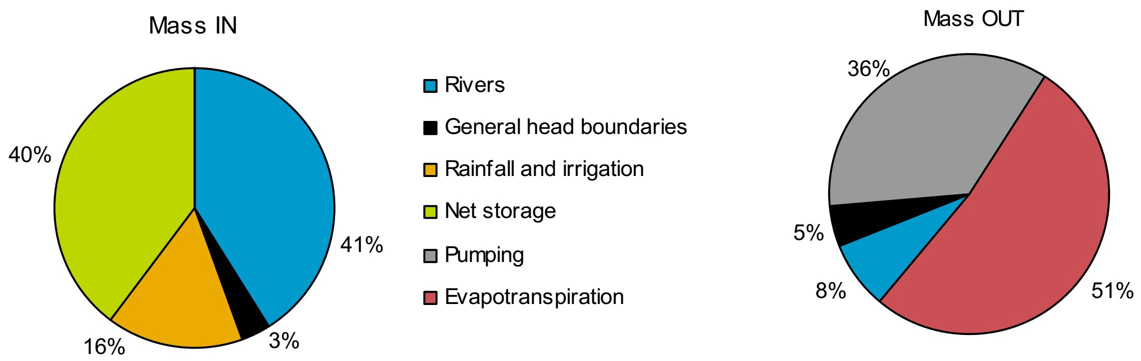

Figure 6-4. Mass balance for the Upper Lachlan calibration model

Water is extracted from the model at a maximum rate when the watertable is at the ground surface. The rate is zero when the watertable is 2 m below the surface. Evapotranspiration is therefore only active in those areas where the watertable is within 2 m of the ground surface.

The area around the river has watertables at or near the ground surface (top of model) and therefore has relatively high evapotranspiration fluxes. Most of the active evapotranspiration zones in the central and western parts of the model have watertables at marginally less than 2 m below the surface. Evapotranspiration appears to be focussed around the river upstream of Jemalong Weir.

River cells force water to enter or leave the model to maintain the specified river stage while evapotranspiration extracts water from the model in accordance with the watertable depth at the same cells. The net impact is that model-predicted river losses and evapotranspiration fluxes can become artificially inflated. Scenario results relating to model water balances are presented below with corrections made to both river recharge and evapotranspiration fluxes to avoid potential 'double-accounting' of losses to the river and evapotranspiration.

6.4.3 Climate impacts on dryland recharge

Both the groundwater modelling and the simple water balance described later require the application of Recharge Scaling Factors (RSFs). Values of diffuse dryland recharge were used to calibrate the original implementation of the groundwater model and for management of the other GMUs within the Lachlan region. The RSFs are used to multiply these values to provide estimates of dryland recharge under different climate scenarios to be used in further analyses. The RSF is 1.0 by definition for the historical climate and current development scenario (Scenario A). RSFs would be expected to be close to 1.0 for other climate scenarios. The impacts of climate change on recharge are reported as percentage changes from Scenario A.

The three variants of Scenario C (Cdry, Cmid and Cwet) represent a combination of global climate model (GCM) output, and rank mean annual runoff in order to reflect the range of predictions (Chapter 3). Groundwater recharge is not perfectly correlated with mean annual rainfall or runoff. Apart from mean rainfall, diffuse dryland recharge is sensitive to seasonal rainfall and potential evaporation, and to the extreme events or years that lead to episodic recharge. Extreme events become more important in semi-arid to sub-humid areas. A number of GCMs show an increase in extreme events, but the scenarios reflect mean annual runoff, which is more dependent on average and seasonal rainfall.

Recharge also depends on the land use and soils. These can be locally variable and reflect local spatial variation in RSFs. An estimate for a small GMU will be sensitive to these local variations, while in larger areas with a broader range of soils and land uses the estimates will be more robust. RSFs were estimated for all 15 GCMs under Scenario C.

In all cases, a one dimensional soil-vegetation-atmosphere water transfer model (WAVES; Zhang and Dawes, 1998) was used for selected points around the MDB for combinations of soils and vegetation. Spatial data on climate, vegetation and soils were then used to interpolate values to regions.

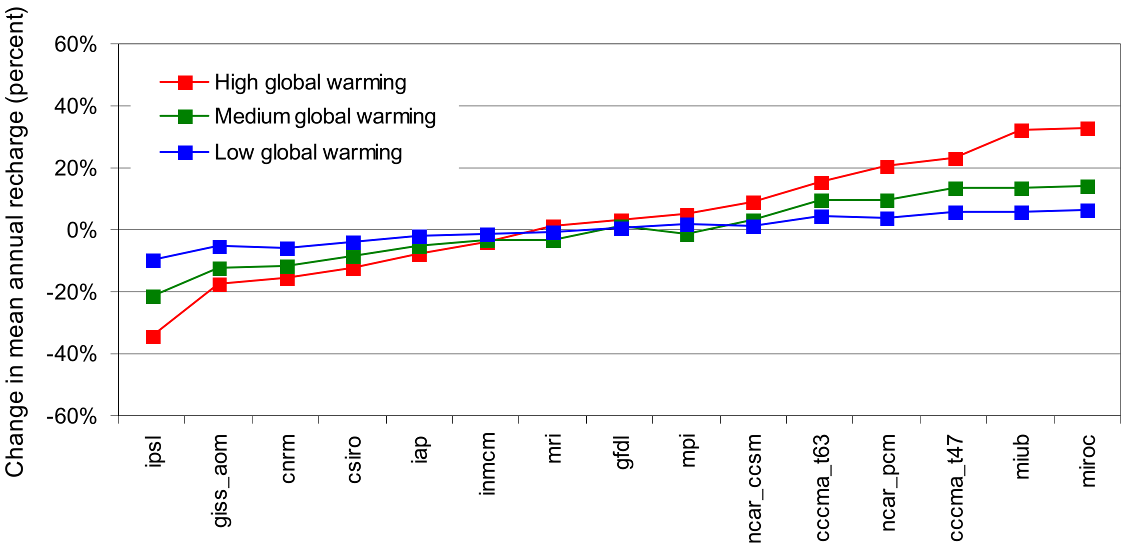

Figure 6-5. Percentage change in mean annual recharge under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A recharge

Figure 6-5 shows the percentage change in the modelled mean annual recharge averaged over the Lachlan region under the future climate and current development scenario (Scenario C) relative to the historical climate and current development scenario (Scenario A) under the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The figure shows that there is a wide variability between the GCMs and scenarios regarding climate change in the Lachlan region with about 45 percent of the scenarios predicting less recharge and the rest predicting more recharge. The high global warming scenario predicts both the highest and lowest change in recharge for the Lachlan region. The percentage change in the mean annual recharge and the percentage change in mean annual rainfall from the corresponding GCMs are tabulated in Table 6-2.

Only the 'dry', 'mid' and 'wet' Scenario C variants are shown in subsequent reporting of modelling results. These variants are based on the runoff modelling and are emboldened in Table 6-2. The choice of GCMs for surface runoff is comparable to those that would be chosen if recharge formed the basis of choice with the second highest, second lowest and median in surface runoff being respectively the fourth highest, lowest and the 35th percentile for RSF.

The large variability in RSFs is related to the large variability in rainfall produced by the various GCMs. Rainfall and RSFs are correlated, although not perfectly. Some GCMs that indicate reductions in rainfall lead to RSFs greater than 1.0. This is due to the more extreme events being more frequent, despite a reduction in mean rainfall.

The scenarios for further analysis for each GMU are shown in Table 6-3. Model area details are shown in Table 6-4. The RSFs are calculated by dividing the values in Table 6-3 by 100 and adding 1.

Table 6-2. Summary results from the 45 Scenario C simulations. Numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A. Those in bold type have been selected for further modelling.

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Recharge	GCM	Rainfall	Recharge	GCM	Rainfall	Recharge
ipsl	**-18%**	**-34%**	ipsl	-12%	-21%	ipsl	-5%	-10%
giss_aom	-15%	-18%	giss_aom	-10%	-12%	cnrm	-4%	-6%
cnrm	-13%	-15%	cnrm	-8%	-12%	giss_aom	-4%	-5%
csiro	-10%	-12%	csiro	-7%	-9%	csiro	-3%	-4%
iap	-4%	-7%	iap	-2%	-5%	iap	-1%	-2%
inmcm	-4%	-4%	inmcm	-2%	-3%	inmcm	-1%	-1%
mri	-4%	1%	mri	-2%	-3%	mri	-1%	0%
gfdl	-5%	3%	**mpi**	**-4%**	**-2%**	gfdl	-1%	1%
mpi	-6%	5%	gfdl	-3%	2%	ncar_ccsm	1%	2%
ncar_ccsm	3%	9%	ncar_ccsm	2%	3%	mpi	-2%	2%
cccma_t63	6%	16%	ncar_pcm	4%	9%	ncar_pcm	2%	4%
ncar_pcm	**7%**	**21%**	cccma_t63	4%	10%	cccma_t63	2%	5%
cccma_t47	8%	23%	miub	5%	14%	miub	2%	6%
miub	8%	32%	cccma_t47	5%	14%	cccma_t47	2%	6%
miroc	8%	33%	miroc	5%	14%	miroc	2%	6%

Table 6-3. Change in mean recharge for groundwater management units in the Lachlan region under Scenario C relative to Scenario A

Code	Name	Cdry	Cmid	Cwet
		percent change relative to Scenario A		
N11	Upper Lachlan Alluvium	-38%	-1%	14%
N12	Lower Lachlan Alluvium	-34%	-4%	19%
N21	Belubula Valley Alluvium	-40%	10%	30%
N801	Orange Basalt	-19%	-3%	21%
N802	Young Granite	-25%	0%	15%
N811	Lachlan Fold Belt	-22%	-4%	18%

Table 6-4. Change in recharge applied to model scenarios for modelled areas under Scenario C relative to Scenario A

Model zone	Cdry	Cmid	Cwet
	percent change relative to Scenario A		
Lower Lachlan	-35%	-4%	19%
Upper Lachlan	-35%	0%	13%

6.4.4 Scenario implementation

The objective of the numerical modelling is to assess the impacts (ground and surface water) of scenarios that alter groundwater extraction from the Lower and Upper Lachlan Alluvium GMUs. Groundwater impacts are represented by groundwater resource condition indicators. Surface water impacts are quantified by river losses to groundwater. Climate can affect the groundwater balance by changing dryland recharge, the area of irrigation and river flows. The impact of climate on diffuse dryland recharge is implemented through the application of a RSF (Section 6.4.3).

River and groundwater models are run in a sequence to simulate the effect of climate on surface–groundwater exchange fluxes and groundwater and surface water balances. The IQQM as implemented for the WSP (Chapter 4; DIPNR, 2003) includes surface–groundwater exchange fluxes within the unattributed losses and gains. The calibration periods for the groundwater and surface water models broadly coincide so the change in groundwater–surface exchange fluxes is assumed to be the same in each model. Extraction rates were assumed to be constant in all cases.

All model scenarios were run for 111 years of 'warm-up' followed by a further 111 years for the actual scenario. The warm-up model run establishes quasi steady-state or dynamic equilibrium conditions prior to the start of the scenario run. The warm-up models include initial conditions defined by the without-development steady-state model and the groundwater levels at the end of the warm-up model are used for the subsequent scenario runs.

The recent climate and current development scenario was not run in the Lachlan groundwater models because the average (1997 to 2006) rainfall and runoff are not statistically different to the long-term averages.

Lower Lachlan

The following scenarios were run in the model for the Lower Lachlan:

- *Historical climate and current development (Scenario A).* Extraction levels were set at the former proposed extraction limit for the aquifer (approximately 96 GL/year). Climatic stresses including rainfall recharge and flooding inundation were obtained from recorded data over the period 1895 to 2006. Extraction only reached 94 GL/year in the model due to the drying out of production bores in shallower layers and the inability of the model to redistribute this to other areas. River stage was obtained from an interpolation of stage heights obtained from the river model run over the same time and assumed climatic conditions. Flood inundation was assumed to have the same recharge characteristics as the calibration model during the 1990 flood event. Flood inundation and an associated increase in model recharge occurs when river levels exceed a trigger level.
- *Future climate and current development (Scenario C).* There are three different groundwater models for this scenario as dry, medium and wet variants are defined for Scenario C. River stage, recharge, inundation recharge and 'river bed conductance enhancement' are all calculated separately for these models given the climatic and river flow modelling results. Recharge fluxes are obtained by applying a scaling factor to the recharge fluxes included in Scenario A.
- *Future climate and future development (Scenario D).* Extraction is held at the former LTAEL – as for Scenario A. However, this scenario also includes changes in river flows due to upstream changes in farm dam development and upstream increases in groundwater extraction. Dry, medium and wet variants are defined using the same climatic assumptions as Scenario C. River stage, recharge and inundation recharge are all calculated separately for these variants given the climatic and river flow modelling results.

Upper Lachlan

The following scenarios were run in the model for the Upper Lachlan:

- *Historical climate and current development (Scenario A).* Extraction levels were set at the proposed extraction limit for the aquifer (approximately 65 GL/year). Climatic stresses including rainfall recharge and flooding inundation were obtained from recorded data over the period 1895 to 2006. River stage was interpolated from stage heights obtained from the river model run over the same time and assumed climatic conditions. River stage time series were calculated using the IQQM stages at key nodes for all river boundary cells.
- *Future climate and current development (Scenario C).* Three different scenario variants (dry, medium and wet) were modelled. River stage and recharge are calculated separately for each variant given the climatic and river flow modelling results. Recharge fluxes are obtained by scaling the recharge fluxes included in Scenario A.

- *Future climate and future development (Scenario D).* Extraction is at the LTAEL for the aquifer. In the Upper Lachlan (for the modelled area) this is assumed to be 121 GL/year. This scenario also includes changes in river flows due to upstream changes in farm dam development and upstream increases in groundwater extraction. Dry, medium and wet variants are defined using the same climatic assumptions as Scenario C. River stage, recharge and inundation recharge are all calculated separately for these variants given the climatic and river flow modelling results.

6.5 Modelling results

6.5.1 Time lags following development – Lower Lachlan

A without-development scenario was run (using the Scenario A climate data) to illustrate the net impact of groundwater extraction on river flows. Net impacts on the river were determined by comparing without-development and Scenario A river losses (Figure 6-6). No allowance was made for the impacts of changing land use on recharge (for example, land clearing) in the without-development scenario. The additional river flow, had there been no groundwater extraction over the duration of Scenario A, is indicated in Figure 6-6. This figure shows the warm-up period as well as the 'dynamic equilibrium' period for Scenario A. The impacts of groundwater development (as indicated by river loss) does not reach a dynamic equilibrium over the 222 years of the model run. Impacts rise steadily to 3.5 GL/year and high levels of interaction at dynamic equilibrium are suggested by the shape of the curve. The impact on the river represents a minor proportion of the total groundwater extraction included in the model. Other changes in the model mass balance components resulting from groundwater extraction include changes in fluxes of groundwater across the lateral model boundaries and changes in aquifer storage. Figure 6-7 shows the calculated changes in model fluxes brought about by the groundwater extraction included in Scenario A.

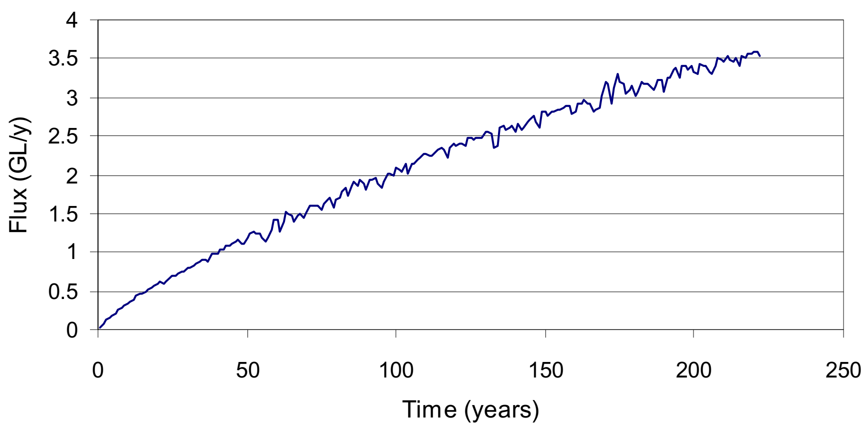

Figure 6-6. Reduction in river flow for the Lower Lachlan modelled area due to development under Scenario A

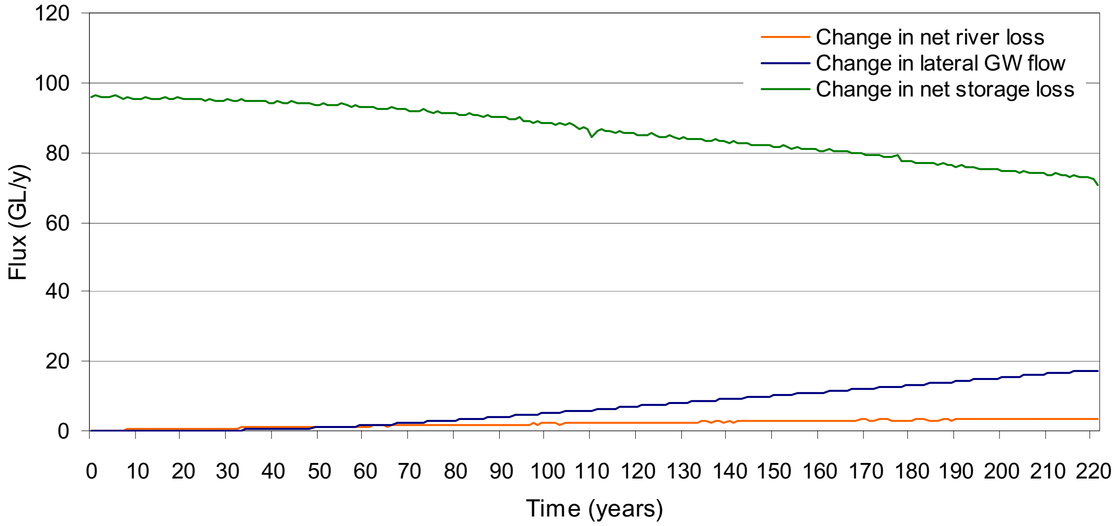

Figure 6-7. Mass balance changes for the Lower Lachlan modelled area caused by groundwater extraction under Scenario A

Figure 6-7 illustrates that groundwater storage changes are directly associated with falling groundwater levels caused by extraction. If the models were able to proceed to dynamic equilibrium the storage changes shown in Figure 6-7 would decline to zero and the fluxes associated with river interactions and lateral groundwater flows would increase so the combined effects were equal to the level of extraction (96 GL/year).

The only changes in mass balance fluxes at dynamic equilibrium that can account for or accommodate extraction are changes in evapotranspiration, changes in groundwater fluxes to and from surface water bodies and changes in fluxes into and out of deep surrounding aquifers. Deep aquifers are defined as aquifers that do not discharge naturally to surface water bodies in or surrounding the region. These flux changes are the fundamental mass balance components that are modified by extraction.

Changes in lateral groundwater flows at model boundaries represent the transfer of impacts from the model domain to the region surrounding the model. Eventually the area impacted will expand until changes in the fundamental mass balance components match the applied groundwater pumping stresses.

There is a potential for much larger river impacts in the Lower Lachlan and surrounding region than suggested by the fluxes presented in Figure 6-6. Evapotranspiration has low significance in the Lower Lachlan and there is no indication that fluxes to and from deeper aquifers are important so changes (at dynamic equilibrium) in groundwater–river interaction is likely to be the dominant impact of water extracted from the aquifer. The ultimate river impact at dynamic equilibrium therefore is almost 100 percent (96 GL/year) of the total extraction for the Lower Lachlan aquifer. Modelling indicated that true dynamic equilibrium and the full impact of groundwater pumping may not be reached for centuries.

6.5.2 Time lags following development – Upper Lachlan

A without-development scenario was run (using the Scenario A climatic data) to illustrate the net impact of groundwater extraction on river flows. Net impacts on the river were determined by comparing without-development and Scenario A river losses (Figure 6-8). No allowance was made for the impacts of changing land use on recharge (for example, land clearing) in the without-development scenario. The additional river flow, had there been no groundwater extraction over the duration of Scenario A, is indicated in Figure 6-8. This figure shows a warm-up period of about 50 years as well as a ‘dynamic equilibrium’ period. The impacts of groundwater extraction as indicated by a loss of river flow approaches a dynamic equilibrium at about 17 GL/year.

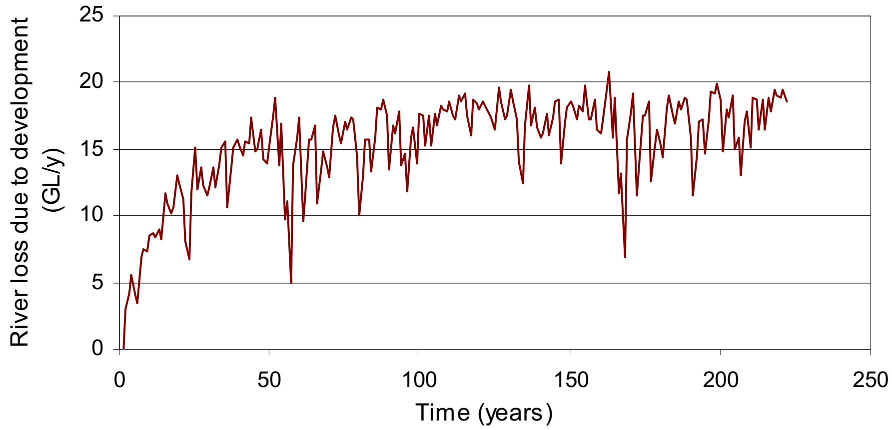

Figure 6-8. Reduction in river flow for the Upper Lachlan modelled area due to development under Scenario A

6.5.3 Groundwater levels – Lower Lachlan

Groundwater levels at the end of the model simulation period continued to fall and dynamic equilibrium was not reached despite the inclusion of a 111-year warm-up period. Groundwater levels in the east of the model had fallen over the model run while those in the west were relatively steady. The apparent sluggishness was due to the physical extent of the model and the fact that almost all of the applied pumping stresses are located in a relatively small sector of the model domain. As the model run proceeded, the disturbance due to extraction caused a 'cone of depression' to form which expanded radially from the centre of extraction. Groundwater levels continued to decline until the expanding cone of depression intersected a source of water capable of sustaining the extractions.

The predicted groundwater hydrographs were transformed to exceedance curves for easy comparison and show the percentage of time that a given groundwater level is exceeded, or alternatively, the groundwater level that is exceeded for any given percentage of time. There is effectively no difference between the predicted groundwater levels in the three model layers. This reflects the relatively high vertical conductivity in the model. Groundwater levels at the 50 percent exceedance level (median levels) are compared for each of the scenarios in Table 6-5. The differences between the groundwater levels at the various points do not vary that much with scenario. The lowest levels are generally predicted under scenarios Cdry and Ddry. The highest are predicted in scenarios Cwet and Dwet.

Table 6-5. Median groundwater levels in observation bores of the Lower Lachlan modelled area under scenarios A, C and D

	GW036344			GW030407		GW030403		GW030258		GW030046	
Scenario	Layer 1	Layer 2	Layer 3	Layer 2	Layer 3	Layer 2	Layer 3	Layer 2	Layer 3	Layer 2	Layer 3
	m AHD										
A	69.8	69.8	69.8	68.6	68.6	75.9	75.9	71.4	71.4	70	70
Cdry	68	68	68	66.5	66.5	73.7	73.7	69.4	69.4	68	68
Cmid	69.6	69.6	69.6	68.3	68.3	75.5	75.5	71.1	71.1	69.8	69.8
Cwet	71.1	71.1	71.2	69.9	69.9	77.2	77.2	72.5	72.5	71.2	71.2
Ddry	68	68	68	66.6	66.5	73.8	73.8	69.4	69.4	68	68
Dmid	69.7	69.7	69.7	68.5	68.5	75.8	75.8	71.2	71.2	69.9	69.9
Dwet	71.1	71.1	71.2	69.9	69.9	77.2	77.2	72.5	72.5	71.2	71.2

AHD: Australian Height Datum.

6.5.4 Groundwater levels – Upper Lachlan

Groundwater levels at the end of the model simulation period continued to fall and dynamic equilibrium was not reached despite the inclusion of a 111-year warm-up period (note however, that the streamflow losses do equilibrate (Figure 6-8)). Groundwater levels in the central part of the model have fallen over the duration of the model run suggesting that the model had not reached dynamic equilibrium prior to the start of the scenario runs.

The predicted groundwater hydrographs were transformed to exceedance curves for easy comparison and show the percentage of time that a given groundwater level is exceeded or alternatively, the groundwater level that is exceeded for any given percentage of time. Groundwater levels at the 50 percent exceedance level (the median) are compared for each of the scenarios in Table 6-6. The lowest levels are under scenarios Cdry and Ddry and the highest are under scenarios Cwet and Dwet. Table 6-7 represents the median difference between the Scenario A hydrographs and those for all other scenarios. Scenario D includes average water levels that are more than 30 m below those in Scenario A. This large difference in groundwater levels reflects that Scenario D includes much higher initial rates of groundwater extraction than scenarios A and C and this has led to greater drawdown and loss of water from storage.

Table 6-6. Median groundwater levels in observation bores of the Upper Lachlan modelled zone under scenarios A, C and D

	GW030314		GW030483		GW090092			GW036081		GW025081	
Scenario	Layer 2	Layer 3	Layer 2	Layer 3	Layer 1	Layer 2	Layer 3	Layer 2	Layer 3	Layer 2	Layer 3
	m AHD										
A	254.2	252.2	180.6	175.8	215.7	179.0	173.6	166.1	165.0	168.3	168.6
Cdry	253.1	250.8	180.3	172.5	215.6	175.4	170.0	163.7	162.6	166.6	166.9
Cmid	254.0	252.0	180.6	175.4	215.7	178.7	173.2	165.9	164.8	168.1	168.4
Cwet	254.7	252.8	181.2	177.7	215.7	181.1	175.7	167.6	166.5	169.3	169.6
Ddry	237.7	230.8	180.3	136.3	215.6	168.1	127.9	162.1	120.5	153.6	150.1
Dmid	237.5	231.4	180.3	138.9	215.7	168.5	130.5	162.1	122.1	155.4	151.6
Dwet	237.7	233.7	180.4	139.7	215.7	168.7	131.8	162.1	123.1	156.7	152.6

Table 6-7. Median groundwater level changes in the Upper Lachlan modelled area under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A					
Lachlan	187.0	-2.5	-0.3	1.4	-33.9	-32.1	-30.8
Cowra	189.7	-1.8	-0.2	1.1	-9.3	-8.9	-8.5
Average	**188.3**	**-2.2**	**-0.22**	**1.3**	**-21.6**	**-20.5**	**-19.7**

6.5.5 Groundwater balance – Lower Lachlan

The mass balance components for all scenarios covering the entire modelled area are summarised in Table 6-8. The gains to the mass balance for all scenarios consist of spatially distributed recharge associated with percolation of rainfall and irrigation accessions, losses of water from rivers and inflows from surrounding aquifers. The losses include groundwater discharge to rivers, groundwater fluxes out of the model domain to surrounding aquifers and the extraction of groundwater from wells. The data show that there is variability between scenarios and the dry scenarios have about 50 GL/year less gain compared to the wet scenarios. This translates to a much larger imbalance between the wet and dry scenarios (that is, about 60 GL/year compared with about 30 GL/year). The impacts of different future climates impose a greater variability on the water balance than the different development scenarios. Note also that the net river losses are essentially constant across all scenarios. A major feature of the water balance is the large change in storage associated with all scenarios coupled with a large deficit between lateral inflows and outflows.

Table 6-8. Average annual general water balances in the Lower Lachlan modelled area under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (gains)							
Rainfall and irrigation	110	72	107	133	72	107	133
River system	48	47	46	48	47	48	47
Lateral flow	198	204	198	193	205	198	193
Sub-total	**356**	**323**	**351**	**374**	**324**	**353**	**373**
Discharge (losses)							
Extraction	94	94	94	95	94	94	95
To rivers	3	2	3	3	2	3	3
Lateral flow	301	290	300	308	290	301	308
Sub-total	**398**	**386**	**397**	**406**	**386**	**397**	**406**
Change in storage	-42	-63	-46	-32	-62	-44	-33

The water balance for the Lower Lachlan Alluvium GMU management zones 1 and 2 was estimated from the model outputs as the modelled area is much larger than the GMU (see Table 6-1). This water balance shows a pattern similar to the whole modelled area, in that climate produces the major variability across the scenarios and that the imbalance is almost double between the wet and dry scenarios. Net river losses remain constant across all scenarios. A major feature of the GMU water balance is the large change in storage associated with all scenarios coupled with a large deficit between lateral inflows and outflows.

Table 6-9. Modelled average annual general water balances for the Lower Lachlan Alluvium groundwater management zones 1 and 2 under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (gains)							
Rainfall / Irrigation	88	58	87	107	58	87	107
From river	48	47	46	47	47	48	47
Lateral flow	13	11	12	13	11	12	13
Sub-total	**148**	**116**	**145**	**168**	**116**	**147**	**168**
Discharge(losses)							
Extraction	94	94	94	94	94	94	94
To rivers	3	2	3	3	2	3	3
Lateral flow	95	83	94	103	83	94	103
Sub-total	**192**	**179**	**190**	**200**	**179**	**191**	**200**
Change in storage	**-44**	**-63**	**-45**	**-32**	**-63**	**-44**	**-32**

Lateral groundwater flow into management zones 1 and 3 accounts for a relatively large proportion of the total recharge (about one-third) although total aquifer recharge from all sources is high compared to groundwater extraction rates. If water flowing into the GMU zones is saline then this recharge flux is also of little benefit in terms of fresh water replenishment of the aquifer.

Figure 6-9 compares the total annual recharge included in the Scenario A model and the groundwater pumping flux. Total recharge includes rainfall, flood inundation, leakage from rivers and lateral groundwater fluxes into the Lachlan region. Three plots of the total recharge flux are presented: (i) recharge to the whole model zone; (ii) recharge to the GMU management zones 1 and 2 only (that is, 'total recharge' to these); and (iii) 'effective recharge' (that is, total recharge minus lateral inflow).

In the above, the GMU area was restricted to that covered by management zones 1 and 2 of the Lower Lachlan Alluvium GMU. If the recharge across the entire model domain is considered then the recharge always exceeds the groundwater extraction rate of about 96 GL/year. However, when 'total recharge' to the smaller GMU is considered then groundwater extraction occasionally exceeds recharge. Finally, when 'effective recharge' to the GMU is considered, extraction exceeds recharge for a considerable period of time.

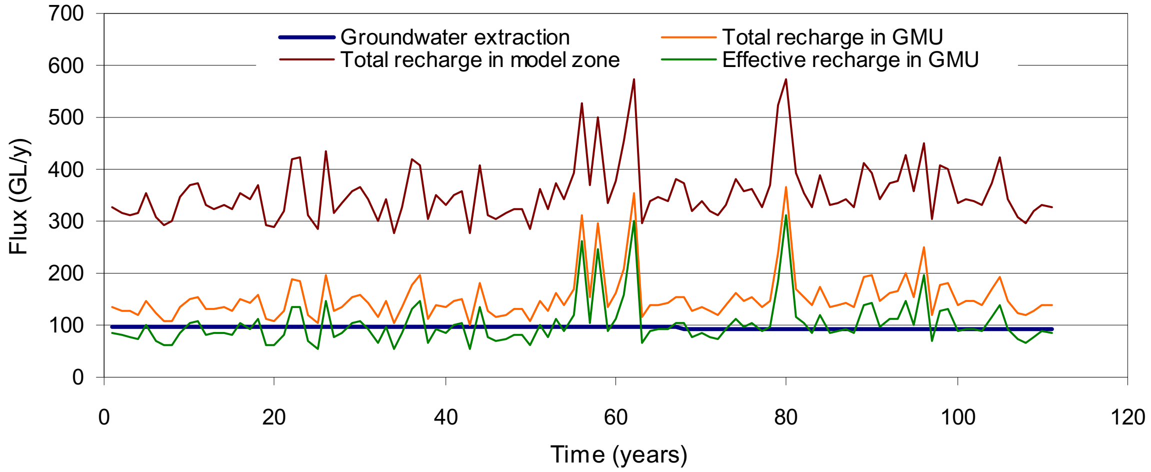

Figure 6-9. Total annual recharge compared to groundwater extraction in the Lower Lachlan under Scenario A

Table 6-10 provides an estimate of the proportion of time the total groundwater recharge exceeds groundwater pumping, as well as when the ‘effective recharge’ exceeds pumping. For the various development scenarios considered in this study total recharge exceeds extraction between 76 and 94 percent of the time, whereas, ‘effective recharge’ exceeds pumping between 16 and 68 percent of the time. The table also presents the average flux of water predicted to flow from the river to the aquifer. River losses are relatively constant at 43 to 45 GL/year depending on the scenario.

Table 6-10. Annual average combined recharge and net loss of river flow for the Lower Lachlan Alluvium GMU under scenarios A, C and D

Scenario	Total recharge	Recharge from river	Percent of years recharge exceeds pumping	Percent of years effective recharge exceeds pumping
	GL/y		percent	
A	152	35.6	100%	44%
Cdry	120.8	35	93%	16%
Cmid	148	34.1	100%	41%
Cwet	170.3	35.4	100%	68%
Ddry	121.3	35.4	93%	17%
Dmid	150.3	35.7	100%	43%
Dwet	170.2	35.3	100%	68%

There is negligible impact of groundwater extraction on river flows within the simulation period. The without-development model run showed net flux to the river and the difference in net river loss between the without-development run and Scenario A was 3 GL/year. However, there is a large imbalance in all scenarios and this will eventually be compensated by a recharge source. One possible recharge source is the river and therefore, river losses may increase in the future. This is tempered by the fact that the simulation period was 222 years and such losses could only occur after that time, according to the model.

Figure 6-10 provides exceedance curves for annual recharge for all scenarios. The data shows the variability in annual total recharge included in each scenario. Variability in total recharge between the various scenarios arises from:

- different rainfall recharge associated with the different climatic inputs to the scenarios
- different fluxes across head dependent boundary conditions included in the model
- different frequency and timing of flooding that leads to inundation and enhanced recharge.

The dominant factor out of these mechanisms is the variability of the frequency of flooding inundation included in the scenarios.

Inundation recharge is applied to the models at the times when the modelled river stage height exceeds a trigger level of 118.3 m AHD at gauge 412039. The ‘total recharge’ data for all scenarios shows that recharge will exceed: 98 GL/year for 90 percent of the time, 113 GL/year for 50 percent of the time and 149 GL/year for 10 percent of the time. ‘Effective recharge’ will exceed: 49 GL/year 90 percent of the time, 72 GL/year for 50 percent of the time and 105 GL/year for 10 percent of the time.

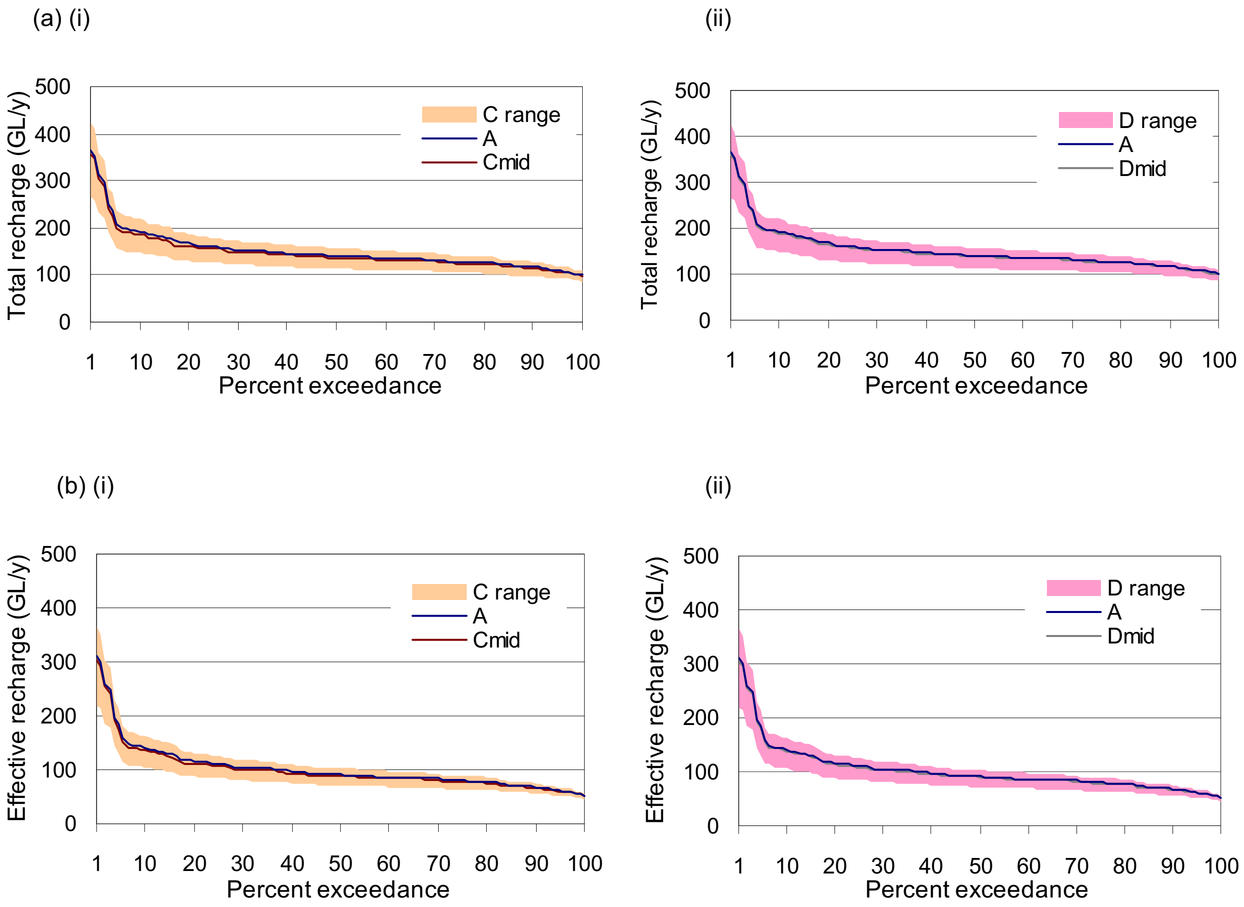

Figure 6-10. Exceedance probability curve for (a) total and (b) effective annual recharge to the Lower Lachlan Alluvium GMU under scenarios (i) C and (ii) D

6.5.6 Groundwater balance – Upper Lachlan

The inputs to the mass balance for all scenarios consist of spatially distributed recharge associated with percolation of rainfall and irrigation accessions, losses of water from rivers and inflows from surrounding aquifers. The outflow includes groundwater discharge to rivers and evapotranspiration and the extraction of groundwater from wells. Lateral fluxes of groundwater out of the model domain are insignificant in all scenarios considered.

Table 6-11 illustrates that although the model inputs specify an extraction rate of 120 GL/year for Scenario D, the model is only able to average 64 to 69 GL/year extraction for these scenarios. This discrepancy is caused by pumping resulting in drying of cells in the Cowra Formation and loss of groundwater production from these cells. With the current distribution of groundwater extraction wells the aquifer in the long-term is unable to support levels of extraction that are greater than about 67 GL/year without drying of parts of the aquifer.

The data also shows that river leakage into the groundwater system is the largest component of the recharge part of the water balance and that groundwater extraction exceeds total recharge for all scenarios. Net river losses are about 25 GL/year for scenarios A and C, and about 30 GL/year for Scenario D.

Table 6-11. Modelled average annual general water balance for the Upper Lachlan modelled area under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
				GL/y			
Recharge (gains)							
Rainfall/Irrigation	18	13	18	21	13	18	21
From river*	28	27	27	27	31	31	32
Lateral flow	6	6	6	6	10	9	9
Sub-total	**52**	**46**	**51**	**55**	**54**	**59**	**63**
Discharge (losses)							
Extraction	61	61	61	62	64	67	69
To river	3	2	2	2	2	2	2
Lateral flow	0	0	0	0	0	0	0
Evapotranspiration*	3	1	3	5	1	2	4
Sub-total	**67**	**64**	**66**	**69**	**67**	**71**	**75**
Change in storage	**-15**	**-18**	**-15**	**-14**	**-13**	**-12**	**-12**

*Evapotranspiration and river recharge fluxes have been adjusted to remove evapotranspiration from river cells.

Figure 6-11 compares the combined annual recharge included in the Scenario A model and the groundwater pumping flux. Combined recharge includes rainfall, leakage from rivers and lateral groundwater fluxes into the model region. The recharge fluxes plotted were corrected for anomalies associated with evapotranspiration applied to river cells. The effective (corrected) total recharge provides an appropriate estimate of the volumes of water that enter the aquifer. The figure indicates that groundwater pumping exceeds total effective recharge for most years over the duration of Scenario A.

Effective recharge (corrected for anomalous evapotranspiration and river losses) exceedance curves for all scenarios are shown in Figure 6-12. Differences between scenarios C and D recharge exceedance are largely due to the different groundwater extractions included in these scenarios. The D scenarios have higher initial extractions and this leads to increased fluxes into the model through lateral General Head Boundary Cells and increased recharge from rivers. Over the longer term, as extraction falls back due to drying of parts of the aquifer, these increased fluxes diminish.

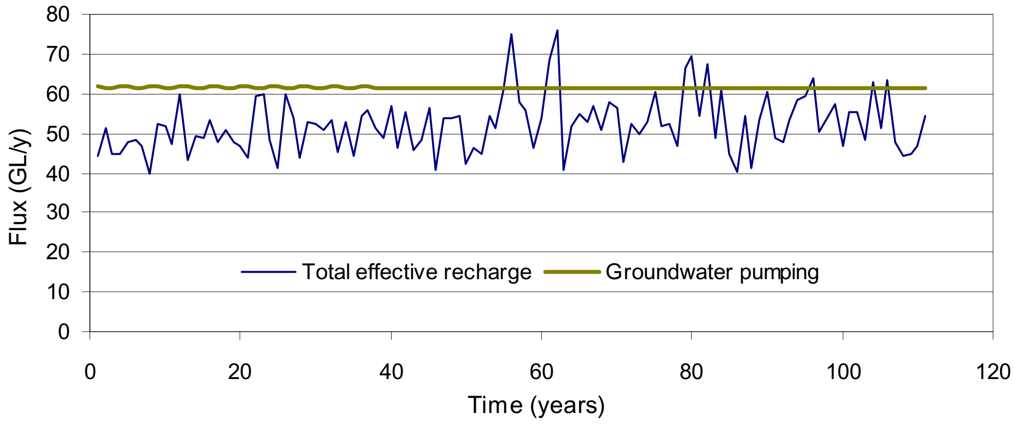

Figure 6-11. Combined annual effective recharge for the Upper Lachlan modelled area compared to groundwater extraction under Scenario A

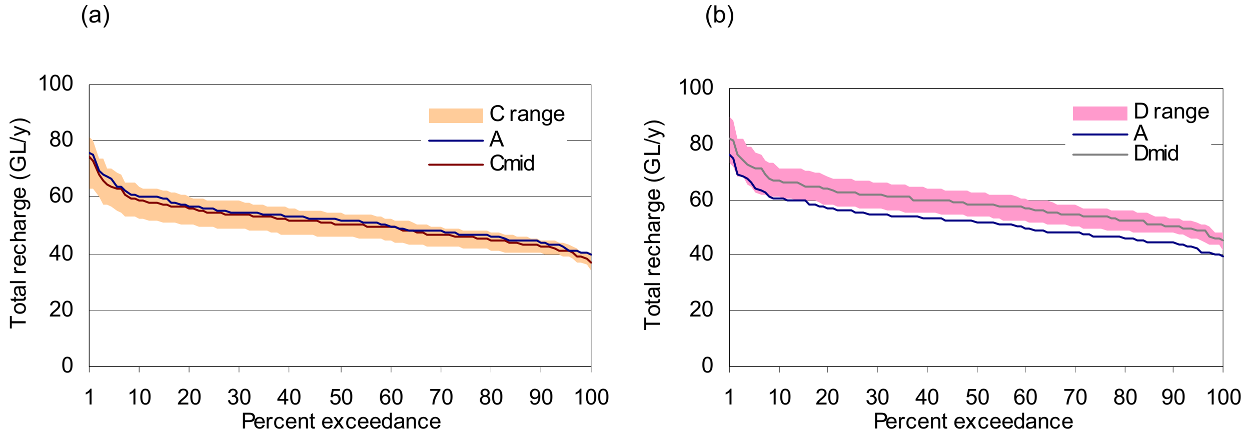

Figure 6-12. Exceedance probability curve for total annual effective recharge (minus evapotranspiration) for the Upper Lachlan modelled area under scenarios (a) C and (b) D

Figure 6-12 also shows that recharge will exceed 40 GL/year for 90 percent of the time and 46 GL/year for 50 percent of the time depending on levels of development and future climates.

Table 6-12 provides an estimate of the proportion of time when the total effective groundwater recharge (corrected for evapotranspiration from river cells) exceeds groundwater pumping for the various development scenarios. The extractions exceed total recharge almost all of the time. The effective groundwater recharge is not sufficient to meet groundwater extraction. This is reinforced by hydrograph plots and drawdown maps that show continued decline in groundwater levels (and associated change in storage) continuing throughout the scenario run.

Table 6-12. Annual average combined recharge, net loss of river flow and percent of years recharge exceeds pumping for the Upper Lachlan modelled area under scenarios A, C and D

Scenario	Total recharge*	Net river losses*	Percent of years recharge exceeds pumping
	GL/y		percent
A	52.2	25	8%
Cdry	46.2	25	2%
Cmid	51	25	7%
Cwet	54.7	25	18%
Ddry	54.1	29	14%
Dmid	58.7	29	15%
Dwet	62.9	30	25%

*Total recharge and net river losses have been corrected for evapotranspiration acting on river cells

6.5.7 Groundwater indicators

A range of groundwater indicators were derived for the models under the various scenarios. These indicators are defined in Table 6-13.

Table 6-13. Definition of groundwater indicators

Security indicator	Percentage of years in which extraction is less than the average recharge over the previous ten-year period. Values less than 100 indicate increasing risk of sustained long-term groundwater depletion and thus a lower security of the groundwater resource.
Environmental indicator	Ratio of average annual extraction to average annual recharge (E/R value). Values of more than 1.0 indicate a long-term depletion of the groundwater resource and consequential long-term environmental impacts.
Drought indicator	Difference in groundwater level (in metres) between the lowest level during each 111-year scenario simulation and the mean level under the baseline scenario. This is a relative indicator of the maximum draw-down under each scenario.

Lower Lachlan

Security and environmental indicators are presented in Table 6-14. The data shows that high security under all scenarios as total groundwater recharge always exceeds extraction. The difference from the exceedence curves Figure 6-10 is that the recharge in Table 6-14 was averaged over a ten-year period. The Environmental indicator for all scenarios is between 0.56 and 0.81. An increase in this value towards 1.0 represents a decrease of water for environmental purposes.

Table 6-14. Groundwater indicators for the Lower Lachlan modelled area under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Security indicator	100%	100%	100%	100%	100%	100%	100%
				ratio			
Environmental indicator	0.63	0.81	0.65	0.56	0.8	0.64	0.56

Upper Lachlan

Security, environment and drought indicators for the Upper Lachlan are presented in Table 6-15.

Table 6-15. Groundwater indicators for the Upper Lachlan modelled area under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Security indicator	0%	0%	0%	3%	7%	6%	25%
	ratio						
Environmental indicator	1.18	1.32	1.21	1.13	1.18	1.14	1.09
Drought indicator							
Observation bore	m						
GW090092 Lachlan	-9.76	-15.50	-10.27	-6.65	-47.80	-45.64	-45.35
GW090092 Cowra	-9.77	-10.98	-10.02	-6.59	-11.39	-10.92	-10.59
GW036081 Lachlan	-9.34	-12.34	-9.68	-6.76	-49.09	-49.17	-48.85
GW036081 Cowra	-4.72	-4.74	-4.72	-4.69	-4.76	-4.75	-4.73
GW030483 Lachlan	-8.22	-12.93	-8.75	-5.60	-41.42	-40.07	-39.57
GW030483 Cowra	-1.37	-1.44	-1.37	-1.32	-1.45	-1.39	-1.34
GW030314 Lachlan	-1.88	-3.18	-2.09	-1.36	-23.16	-21.80	-19.71
GW030314 Cowra	-0.79	-2.01	-0.99	-0.30	-17.06	-17.04	-16.88
GW025081 Lachlan	-4.12	-6.50	-4.36	-2.83	-26.41	-24.53	-23.30
GW025081 Cowra	-2.22	-4.62	-2.46	-0.88	-19.72	-17.76	-16.46
Average	**-5.18**	**-7.39**	**-5.43**	**-3.66**	**-22.42**	**-22.25**	**-21.17**

6.6 Water balances for lower priority groundwater management units

There are a number of lower priority GMUs in the Lachlan region (Table 6-1) that were assessed using simple water balance analyses.

6.6.1 Groundwater extraction

Estimated groundwater extraction from the lower priority GMUs within the Lachlan region is shown in Table 6-16. These estimates are for areas for which Macro WSPs are currently being developed on the basis of 1.5 ML/year for each stock and domestic bore (an assumption developed by DWE). Estimates of the current extraction and the likely maximum extraction volumes were provided by DWE. Long-term extraction limits have been set based on the calculation of rainfall recharge to each GMU.

Table 6-16. Estimated groundwater extraction from lower priority GMUs for the Lachlan region

Code	Name	Current extraction 2004/05	Total entitlement	Likely maximum use without plan revision
		GL/y		
N21	Belubula Valley Alluvium	5.2	6.3	6.3
N801	Orange Basalt	3.9	6.2	6.5
N802	Young Granite	6.2	7.7	7.7
N811	Lachlan Fold Belt	22.3	33.5	119.2
	Total	**37.5**	**53.7**	**139.7**

Groundwater extraction is forecast to grow in the future and almost all growth is predicted in the Lachlan Fold Belt GMU. The rate of this growth has not been determined and it is assumed (for the purposes of this analysis) that full growth will be achieved by 2030.

The 'likely maximum use without plan revision' is based on the historical development of irrigation, urban and stock and domestic water supply works. The growth rate within a region is estimated based on the rate of historical growth. All new domestic and stock water supply works will be drilled and constructed on separate properties and an average size for each property is calculated. The total additional stock and domestic requirement is then calculated based on assumed usage rates for domestic bores of 2.25 ML/year and for stock bores of 0.0088 ML/ha/year.

6.6.2 Estimates of rainfall recharge

Rainfall recharge is considered the largest factor within the water balance. The rainfall recharge component will be far more significant than other components of total water balance and is the focus of this assessment. The following data was provided by DWE.

The effect of different stresses on various components of the hydrologic cycle has been analysed using the recharge scaling factors (Section 6.4.3). When applied these scaling factors produced the results shown in Table 6-17.

Table 6-17. Scaled recharge for groundwater management units under scenarios A and C

Code	Name	Recharge	Scaled recharge		
		A	Cdry	Cmid	Cwet
		GL/y			
N21	Belubula Valley Alluvium	0.4	0.3	0.5	0.6
N801	Orange Basalt	21.5	17.5	20.9	25.9
N802	Young Granite	12.6	9.5	12.6	14.4
N811	Lachlan Fold Belt	955.5	748.6	917.7	1129.1
	Total	**990.0**	**775.9**	**951.7**	**1170.0**
	Percent change		-22%	-4%	+18%

Note: scenarios C and D have exactly the same scaling factors and therefore Scenario D is not reported.

The ratio of current (2004/05) groundwater extraction to recharge is displayed in Table 6-18. The ratio of extraction over recharge can be used as an indication of the potential level of stress within the aquifer. The estimates for the Macro WSP allocates 30 percent to 50 percent of recharge to environmental purposes (an E/R ratio of 0.3–0.5). The groundwater resources of the GMUs are being extracted at a rate greater than recharge is replenishing the groundwater where the ratio is greater than 1.0.

Groundwater extraction over recharge is highest within the Belubula Valley Alluvium GMU. Groundwater extraction within this GMU currently exceeds recharge however the E/R ratio is predicted to become even greater than 1 as recharge is reduced by climate change. The total recharge to the GMU may be higher as the recharge used in this analysis is an estimate of the rainfall recharge only. The Belubula River is connected to the adjacent groundwater system and is also a regulated river. As such, a component of river losses could contribute to total recharge.

A Macro WSP has been proposed for the Belubula Valley Alluvium GMU and its associated streamflow. This reflects the high degree of connection between the surface water and groundwater systems. The rate of extraction may be managed so the E/R ratio does not exceed 1.0 once this plan is implemented. The remaining GMUs display relatively minor climate change impacts.

Table 6-18. Comparison of 2004/05 groundwater extraction with scaled rainfall recharge under scenarios A, C and D

Code	Name	Current extraction 2004/05	E/R	Scaled E/R					
			A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
		GL/y	ratio						
N21	Belubula Valley Alluvium	5.2	11.7	19.4	10.6	9.0	23.5	12.8	10.9
N801	Orange Basalt	3.9	0.2	0.2	0.2	0.2	0.4	0.3	0.3
N802	Young Granite	6.2	0.5	0.7	0.5	0.4	0.8	0.62	0.5
N811	Lachlan Fold Belt	22.3	<0.1	<0.1	<0.1	<0.1	0.2	0.1	0.1

All GMUs are predicted to experience substantial growth in groundwater extraction by 2030. The projected extraction results in an increase in the ratio of extraction to recharge. However, considering the relatively low level of current estimated groundwater extraction (except for the Belubula Valley Alluvium GMU) for these GMUs, the increases are not significant and remain below the environmental guidelines as outlined by DWE. The exception is the Young Granite GMU under the two dry future scenarios.

The increase in E/R for the Belubula Valley Alluvium GMU due to projected extraction is also qualified by the impending development of a Macro WSP.

6.6.3 Impact of extraction on streamflow

Stream impacts outside of the Lower and Upper Lachlan Alluvium are shown in Table 6-19. These estimates are based upon the following assumptions:

- connectivity is the same as estimated by the Murray-Darling Basin Commission (2007) and does not change with extraction
- current groundwater extraction is equal to current entitlements and full stream impact has been realised
- future extraction under Scenario D is the maximum likely extraction without plan revision
- groundwater extracted does not return to aquifers (for example, via irrigation of crops)
- the full impacts of extraction on streams will occur within 100 years.

The assumption regarding future extraction is an upper limit as future extraction will be limited by extraction rules under the Macro WSP, groundwater quality and land suitability. Conversely the impact of this extraction is considered to be an underestimate for the following reasons:

- current use is smaller than current entitlements
- full impact of current extraction will not have been fully realised
- connectivity factors are generally considered underestimates.

Table 6-19. Surface-groundwater connectivity showing an estimate of the volumetric impact extraction has on streamflow in groundwater management units under Scenario D

Code	Name	Current Entitlements	Future Extraction	Difference	Connectivity	Stream Impact
		GL/y			percent	
N21	Belubula Valley Alluvium	6.29	6.29	0.00	0.15%	0.00
N801	Orange Basalt	6.23	6.44	0.21	0.30%	0.06
N802	Young Granite	7.75	7.75	0.00	0.25%	0.00
N811	Lachlan Fold Belt	33.46	119.19	85.73	0.30%	25.72
	Total	**53.73**	**139.67**	**85.94**		**25.78**

The impacts of groundwater extraction on streamflow listed in Table 6-19 are distributed to the relevant surface water subcatchments or stretches of river. Streamflow losses of less than 2 GL/year in a subcatchment (Table 6-20) would be difficult to observe and thus only subcatchments where the estimated impact from groundwater extraction exceeds a 2 GL/year reduction in streamflow are considered further. Calculation using original future extraction data showed this cut-off discounts about 15 GL/year of impacts reducing the total estimated impact from about 16 GL/year (Table 6-19) to about 11 GL/year.

The estimated losses in each subcatchment were used to modify daily flow duration curves (Figure 6-13), and Scenario D inflows for the relevant subcatchments in the river model (Chapter 4). Figure 6-13 shows the flow duration curves for the scenarios Cmid, Dmid and modified Dmid. Scenario Dmid is the impact before groundwater extraction is included and 'Dmid modified' includes extraction. The difference between Cmid and Dmid can be largely attributed to farm dams. The effect of groundwater extraction can be compared to that of farm dams. The percentage of low flows decreases in the affected subcatchments. These reductions would make flow in these streams even more ephemeral affecting near-river ecosystems and flow in the main channel.

Table 6-20. Subcatchments with surface water impacts greater than 2 GL/year under Scenario D

Subcatchment number	Scenario D stream impacts
	GL/y
4120100 Total	5.8
4120481 Total	4.8
Total	**10.6**

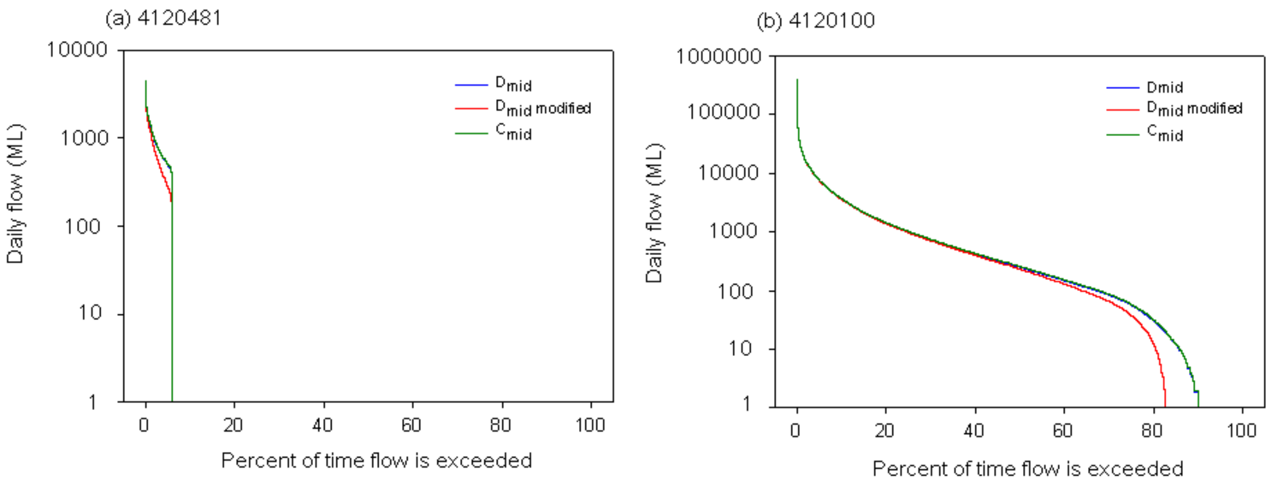

Figure 6-13. Daily flow duration curves for subcatchments (a) 4120481 and (b) 4120100. The scenarios shown are Cmid (climate change and current farm dam development), Dmid (climate change, future farm dam development and current groundwater development) and Dmid modified (climate change, future farm dam development and future groundwater development)

Adjustments were made in river reaches to reflect the impact of groundwater extraction in the modelled Upper and Lower Lachlan Alluvium GMUs in addition to the adjustments in the river model to reflect the increased groundwater extraction in lower priority GMUs. This led to an increase in river leakage of 20 GL/year under Scenario A and 24.1 GL/year under Scenario Dmid. The former is referred to as a 'double accounting' term as it represents the discrepancy between the surface water balance representation of the current river model and that once the full impacts of current groundwater extraction are realised. These river impacts are described in Chapter 4 and summarised in Table 6-21.

Table 6-21. Impacts of groundwater extraction on streamflow for groundwater management units in the Lachlan region under scenarios A, C and D

Code	Name	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
					GL/y			
N11	Upper Lachlan Alluvium	17	17	17	17	21	21	22
N12	Lower Lachlan Alluvium	3	2.4	1.5	2.8	2.8	3.1	2.7
	Lower priority GMUs	0	0	0	0	25.8	25.8	25.8
	Total	**20**	**19.4**	**18.5**	**19.8**	**49.6**	**49.6**	**49.6**

6.7 Conjunctive water use indicators

Groundwater can provide a more secure water source during drier periods. Irrigators may elect to change from surface water to groundwater during years of low flow where such exchanges are feasible. The lower surface water diversions in low flow years even without the exchange opportunity mean that groundwater forms a higher proportion of total diversions in those years. Table 6-22 shows these ratios for years of lowest surface water use up to the average surface water use. These are calculated from the lowest 1-, 3- and 5-year surface water diversions for each scenario (Chapter 4) together with the 2004/05 groundwater extraction totals for the entire region for scenarios A and C and the estimated 2030 groundwater extraction totals for the entire region for Scenario D.

Average groundwater extraction is 45 percent of total annual water use under current conditions in the Lachlan region and as much as 90 percent in years of minimum surface water use. The situation is similar under the best estimate 2030 climate. There is expected to be 86 percent expansion in groundwater extractions mainly for stock and domestic in the fractured rock areas under Scenario D. This leads to a decrease in river flows but the exchange is not one for one. Some of the water that is extracted would have otherwise been used for plant transpiration or would have perhaps moved to another groundwater system and this is expressed as a connectivity factor of less than one. Therefore groundwater use would be 63 percent of the total annual water use on average under Scenario D, or 95 percent in years of minimum surface water use. The most severe case would occur under the dry extreme 2030 climate Scenario D. In the year of minimum surface water use groundwater use would be 96 percent of the total annual water use in the region.

These results show that groundwater forms an important source of water for the region in average flow years but is extremely important in drier years. This significance would increase under the drier future conditions.

Table 6-22. Ratio – shown as a percentage – of groundwater extraction to total water (surface and groundwater) for low surface water use periods under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Lowest 1-year period	90%	92%	92%	90%	96%	95%	95%
Lowest 3-year period	89%	90%	89%	89%	95%	94%	94%
Lowest 5-year period	63%	88%	76%	64%	93%	88%	78%
Average	45%	51%	47%	44%	67%	63%	60%

6.8 Discussion of key findings

6.8.1 Lower Lachlan groundwater model

Groundwater modelling demonstrated that total recharge to the GMU management zones 1 and 2 exceeds the level of groundwater extraction between 75 and 94 percent of the years in the model scenarios depending on which climate assumption is used. The median total recharge to the GMU is greater than 113 GL/year across all scenarios which is above the applied pumping stress of 96 GL/year.

Modelling indicated that dynamic equilibrium conditions (quasi steady-state conditions) take many decades of continuous pumping to be realised. Dynamic equilibrium conditions are not attained within the 111 years of warm-up modelling prior to the start of the predictive scenarios. The regions that are heavily drawn on for groundwater production are the slowest to reach equilibrium. Dynamic equilibrium conditions are never reached in the scenarios as drawdown continues throughout the scenario runs in those areas of maximum groundwater extraction.

Groundwater extraction is expected to have a relatively low impact on flows in the Lachlan River. The interaction on the river is associated with both a reduction in groundwater baseflow feeding the rivers and an increase in leakage of river water to the groundwater system. While reductions in river flow are predicted to be relatively minor (less than 4 GL/year), over the duration of the scenarios modelled in this project, additional impacts are expected at dynamic equilibrium. These potential impacts are concluded based on the large imbalance in the model water balance in the storage and lateral groundwater flow terms.

6.8.2 Upper Lachlan groundwater model

Analysis of fluxes in the groundwater models of the Upper Lachlan region were complicated by evapotranspiration fluxes superimposed in places on river boundary cells. This has resulted in anomalous fluxes of water into the model from river cells and out of the model via evapotranspiration so evapotranspiration fluxes were subtracted from the total recharge fluxes in all mass balance analyses. This correction showed the applied groundwater extraction fluxes (65 GL/year for scenarios A and C and 120 GL/year for Scenario D) are not sustainable at dynamic equilibrium. Although Scenario D models are able to sustain average extractive fluxes of about 65 GL/year, drawdown in groundwater level (and associated release of water from storage) persists for the duration of the model runs. The long-term average level of groundwater recharge (after correction for evapotranspiration) amounts to about 50 GL/year.

Groundwater extractions of about 60 GL/year in Scenario A are supported by a reduction in river flow of about 17 GL/year. The remainder of the extracted water is derived from loss of storage and reduction in evapotranspiration. Eventually, the loss of storage will decrease as other recharge sources are intercepted. This may lead to increased river impacts in the very long term.

6.9 References

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7 Environment

This chapter presents the environmental assessments undertaken for the Lachlan region. It has four sections:

- a summary
- an overview of the assessment approach
- a presentation and description of results
- a discussion of key findings.

7.1 Summary

7.1.1 Issues and observations

- Assessment of the environmental implications of changes in water availability is largely beyond the terms of reference of this project (see Chapter 1). The exception is reporting against environmental water allocations and quantified environmental flow rules specified in water sharing plans. Otherwise, environmental assessments form a very small part of the project.
- The Lachlan River is regulated with large storages, including storages off the lower river. Flows are affected by major water extractions.
- The Lachlan wetlands on the floodplain of the lower river are of regional and national importance. The wetlands support large colonial waterbird breeding events and an appreciable assemblage of rare, endangered and vulnerable species.

7.1.2 Key messages

Booligal Wetlands

- As a result of water resource development the average period between winter–spring floods entering the Booligal wetlands has increased from 6.2 years to 8.3 years (34 percent). The maximum period between these events has increased from 18.7 to 22.2 years (9 percent). These changes are consistent with observed substantial reductions in the frequency and size of waterbird breeding events.
- Under the best estimate 2030 climate the average period between winter–spring inflows would increase by a further 24 percent. This would be likely to reduce the frequency of waterbird breeding events in these wetlands.
- Under the dry extreme 2030 climate the average period between winter–spring inflow floods would increase by 87 percent (to once in over 15 years on average). The maximum period between the events would increase by 47 percent (or by an additional ten years). These changes would be very likely to have major ecological consequences including much longer periods between waterbird breeding events and adverse effects on the status of the Lignum vegetation used as breeding habitat by some waterbirds. The wet extreme 2030 climate would cause a 21 percent decrease in the average period and a 16 percent decrease in the maximum period between winter–spring inflow events.
- Projected future catchment and groundwater development would have no additional effect on the frequency of these floods.
- Neither climate change nor future development greatly affect the volumes entering the wetlands during individual winter–spring events. The average annual flood volumes entering the wetlands would change as a result of the changes in flood frequency.

Great Cumbung Swamp

- As a result of water resource development there has been a substantial increase in the average period between winter–spring flood events from 1.2 years to 2.5 years (102 percent). The maximum period between these events has increased from 6.6 years to 16 years (143 percent). These changes are consistent with observed deterioration in the condition of vegetation in the swamp.
- Under the best estimate 2030 climate the average period between winter–spring flood events would increase by a further 24 percent and the maximum period between events would increase by a further 16 percent. These increases would be likely to further adversely affect the vegetation of the swamp and its use by waterbirds.
- Under the dry 2030 climate extreme the average period between winter–spring floods events would increase by 131 percent and the maximum period would increase by 39 percent. These changes are very likely to have substantial adverse consequences for the condition and composition of current vegetation. The wet extreme 2030 climate would cause an 11 percent decrease in the average period between events but would not affect the maximum period between events.
- Projected future catchment and groundwater development would lead to small additional increases in the average period between winter–spring flood events.
- Neither climate change nor future development greatly affect the volumes entering the swamp during individual winter–spring events. The average annual flood volumes entering the swamp would change as a result of the changes in flood frequency.

7.1.3 Uncertainty

The main uncertainties involving analysis and reporting include:

- Aquatic and wetland ecosystems are highly complex and many factors in addition to water regime can affect ecological features and processes such as water quality and land use practices.
- The indicators are based on limited hydrology parameters with no direct quantitative relationships for environmental responses. This study only makes general observations on the potential implications of changed water regimes and some related ecological responses.
- Considering only a few of the important environmental assets and using a limited number of indicators to represent overall aquatic ecosystem outcomes is a major simplification. Actual effects on these and other assets or localities are likely to vary.
- Uncertainties expressed in Chapters 3, 4 and 5 affect the hydrologic information used in the environmental assessments.

7.2 Approach

This chapter considers the specific rules that apply to the provision of environmental water in the region and assesses hydrologic indicators defined by prior studies for key environmental assets in the region. A broader description of the catchment, its water resources and important environmental assets, is provided in Chapter 2.

7.2.1 Summary of environmental flow rules

The Water Sharing Plan for the Lachlan Regulated River Water Source (DIPNR, 2004) has the following environmental water provisions:

- A limit on the total annual amount of water that can be extracted from the water source over the long-term. This limit is equal to the amount of water that could be extracted under 1999/2000 water use development and 1993/94 cropping patterns and the management rules in the water sharing plan (currently estimated to average 305 GL/year over the long-term). This rule protects an estimated 75 percent of the average annual flow over the long-term for the environment.

- Releases that are translucent (or subject to certain triggers) up to a maximum of 350 GL from Wyangala Dam between 15 May and 15 November, to achieve a flow at Lake Brewster Weir of up to 8000 ML/day. The releases are subject to dam inflows, dam storage and total flow passing Lake Brewster Weir. This water is not available until after 250 GL has entered Wyangala Dam starting on 1 January each year.
- An environmental contingency allowance of 10 GL/year held in Wyangala Dam subject to general security access licence allocation levels.
- An environmental contingency allowance of 10 GL/year held in Lake Brewster subject to general security access licence allocation levels.
- A water quality allowance of 20 GL/year.

The translucent environmental flow rules are assessed for the assets and indicators selected below.

7.2.2 Environmental assets and indicators

The Lachlan region contains several important and large wetlands. These wetlands and other assets are described in Chapter 2. The Booligal Wetlands and the Great Cumbung Swamp are amongst the most notable sites as both are wetlands of national importance (Figure 7-1 and Figure 7-2). The following descriptions are from Environment Australia (2001) unless otherwise cited. Selected indicators for the Lachlan region are described in Table 7-1.

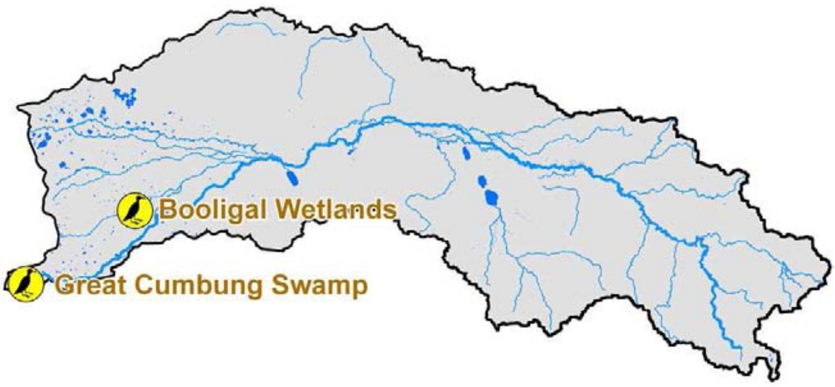

Figure 7-1. Location of assessed wetlands in the Lachlan region

Booligal Wetlands

The Booligal Wetlands (NSW043) cover some 5000 ha on the Lower Lachlan River near the township of Booligal. The wetlands are a complex including the Booligal Swamp and Little Gum Swamp and are associated with Lake Merrimajeel and Murrumbidgil Swamp (NSW049) which are downstream on the same creek system.

The wetlands are situated on the Muggabah-Merrimajeel Creek system which is a distributary system which leaves the Lachlan River. Flood flows into the system are infrequent and the area drains rapidly once floods in the river recede.

The wetlands are well known for providing habitat for a large number and species of waterbirds when the area is flooded. Breeding colonies of 80,000 pairs have been recorded, including Straw-necked Ibis (*Threskiornis spinicollis)*, White Ibis (*T. mollucca*) and Glossy Ibis (*Plegadis falcinellus*). As such, this area is considered to be one the top five breeding sites for these species in Australia. Freckled Duck (*Stictonetta naevosa*) and Blue-billed Duck (*Oxyura australis*) are vulnerable species in New South Wales that have been recorded at this site. Little Gum Swamp is notable for providing breeding habitat for several species of Egret (Magrath, 1992). Lignum (*Muehlenbeckia florulenta*) is the primary vegetation of the Booligal Swamp area, with River Red Gum (*Eucalyptus camaldulensis*) being the dominant over-storey at Little Gum Swamp (Magrath, 1992). Land in the area is used for grazing.

Driver et al. (2005) studied flow and waterbird breeding relationships at the Booligal Wetlands and established that large-scale waterbird breeding occurs when flows exceed 2500 ML/day for a period of two months at the Booligal gauge. This indicator is used for the assessment as reported below, and within the period 15 May to 15 November in accordance with the translucency rules of the Water Sharing Plan.

Great Cumbung Swamp

The Great Cumbung Swamp (NSW045) covers some 16,000 ha at the terminus of the Lachlan River and is adjacent to Murrumbidgee River and the Lowbidgee Wetlands (CSIRO, 2008). Initially a flow and groundwater connection with the Murrumbidgee River was identified (Brady et al., 1998) but subsequent work did not find these connections and the swamp is now recognised to be dependent on flood flows in the Lachlan River (Driver et al., 2002).

Contrary to its name, the core area of some 4000 ha of the swamp is dominated by Common Reed (*Phragmites australis*). Cumbungi (*Typha orientalis*) occurs along the more permanently flooded stream lines. River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*E. argiflorens*) woodland covers large areas of the swamp. Numerous species of waterbird are found at the swamp, particularly after flooding, including Freckled Duck (*Stictonetta naevosa*), and Blue-billed Duck (*Oxyura australis*). Land use is predominantly grazing with some River Red Gum forestry.

Brady et al. (1998) found that broad-scale flooding of the Great Cumbung Swamp occurs when flows exceed 3000 ML/day at the Booligal gauge. The study did not specify an optimal duration for these events. This indicator is used for the assessment as reported below and within the period 15 May to 15 November in accordance with the translucency rules of the Water Sharing Plan.

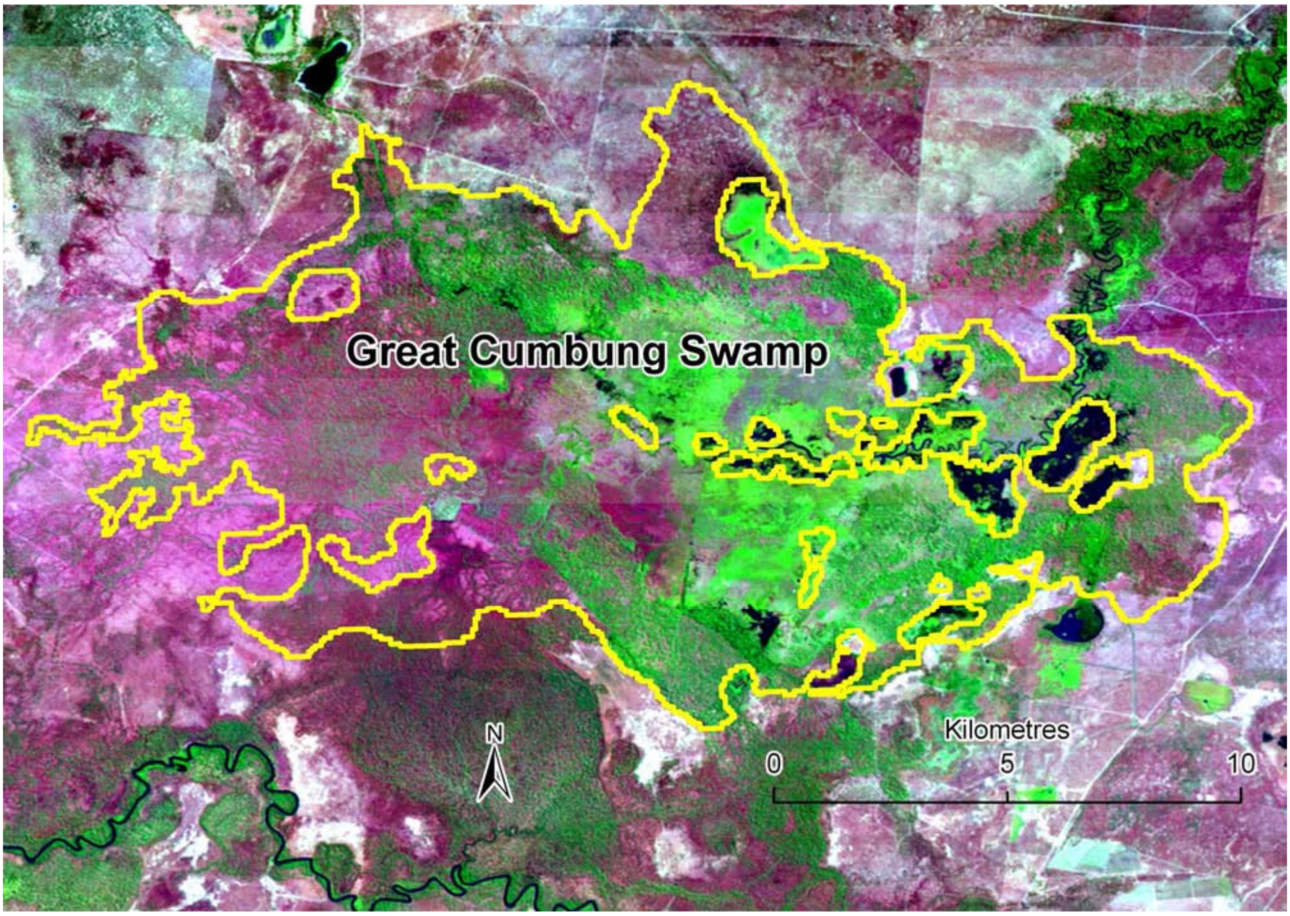

Figure 7-2. Satellite image indicating the extent of the Great Cumbung Swamp as defined by Environment Australia (2001)

Table 7-1. Definition of environmental indicators

Indicator Name	Description
Booligal Wetlands	
Average period between winter–spring floods	Average period (years) between flows in excess of 2500 ML/day at Booligal gauge for 2 months between 15 May to 15 November
Maximum period between winter–spring floods	Maximum period (years) between flows in excess of 2500 ML/day at Booligal gauge for 2 months between 15 May to 15 November
Average winter–spring flooding volume per year	Average flow volume above 2500 ML/day at Booligal gauge for 2 months between 15 May to 15 November per year
Average winter–spring flooding volume per event	Average flow volume above 2500 ML/day at Booligal gauge for 2 months between 15 May to 15 November per event
Great Cumbung Swamp	
Average period between winter–spring floods	Average period (years) between flows in excess of 3000 ML/day at Booligal gauge between 15 May to 15 November
Maximum period between winter–spring floods	Maximum period (years) between flows in excess of 3000 ML/day at Booligal gauge between 15 May to 15 November
Average winter–spring flooding volume per year	Average flow volume above 3000 ML/day at Booligal gauge between 15 May to 15 November per year
Average winter–spring flooding volume per event	Average flow volume above 3000 ML/day at Booligal gauge between 15 May to 15 November per event

7.3 Results

The projected changes in the chosen environmental indicators are listed for the various scenarios in Table 7-2. These were assessed using scenario outputs for the Booligal gauge from the Lachlan River model (see Chapter 4).

Table 7-2. Environmental indicator values under scenarios P and A, and percentage change (from Scenario A) in indicator values under scenarios C and D

	P	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	years		percent change from Scenario A					
Booligal Wetlands indicators								
Average period between floods	6.2	8.3	87%	24%	-21%	86%	24%	-22%
Maximum period between floods	18.7	22.2	47%	0%	-16%	47%	0%	-16%
	GL							
Average flood volume per year	50.9	40.7	-51%	-21%	20%	-52%	-22%	15%
Average flood volume per event	353	376	-2%	5%	-4%	-5%	4%	-2%
Great Cumbung Swamp indicators								
	years							
Average period between floods	1.2	2.5	131%	24%	-11%	158%	32%	-7%
Maximum period between floods	6.6	16	39%	16%	0%	39%	16%	0%
	GL							
Average flood volume per year	71	47	-56%	-23%	11%	-58%	-26%	7%
Average flood volume per event	94	124	3%	-4%	-1%	10%	-3%	0%

7.4 Discussion of key findings

7.4.1 Booligal Wetlands

As a result of water resource development, there has been a substantial increase in the average period between winter–spring flood events (from 6.2 years to 8.3 years, or a 34 percent change) and in the maximum period between these events (from 18.7 to 22.2 years, or a 19 percent change). This assessment reinforces the findings of Driver et al. (2005) who reported a 38 percent reduction in inundation days per year for the Lower Lachlan swamps (including the Booligal Wetlands) as a result of water resource development. Driver et al. (2005) also established substantial reductions in the frequency and size of waterbird breeding events (less than about 60 days duration) from without-development to current water resource development conditions.

Under the best estimate 2030 climate the average period between winter–spring inflows to the wetlands would increase by a further 24 percent. This would be likely to reduce the frequency of waterbird breeding events in these wetlands. The maximum period between events would not be affected.

Under the dry extreme 2030 climate the average period between winter–spring inflow events would increase by a further 87 percent (to once in over 15 years on average). The maximum period between the events would increase by a further 47 percent (or by an additional ten years). These changes would be very likely to have major ecological consequences including much longer periods between waterbird breeding events and adverse effects on the status of the Lignum vegetation used as breeding habitat by some waterbirds. The wet extreme 2030 climate would cause a 21 percent decrease in the average period and a 16 percent decrease in the maximum period between winter–spring inflow events.

Projected future catchment and groundwater development (Scenario D) would have no additional effect on the frequency of these floods.

The volumes entering the wetlands during individual winter–spring events change little between all scenarios. The differences in average annual flood volumes between the scenarios are thus largely a reflection of the changes in flood frequency.

7.4.2 Great Cumbung Swamp

As a result of water resource development there has been a substantial increase in the average period between winter–spring flood events (from 1.2 years to 2.5 years, or 102 percent) and in the maximum period between these events (from 6.6 years to 16 years, or 143 percent). In a specific study of inundation changes for the Great Cumbung Swamp, Driver et al. (2002) found a 51 percent reduction in infiltration and average inundated area due to the effects of water resources development. There were notable adverse impacts on plant communities, including River Red Gum woodland. Within swamp water manipulation and grazing impacts are also involved in the degradation (DLWC, 1997).

Under the best estimate 2030 climate the average period between winter–spring flood events would increase by a further 24 percent and the maximum period between these events would increase by a further 16 percent. These increases would be likely to further adversely affect the vegetation of the swamp and its use by waterbirds.

Under the dry 2030 climate extreme the average period between winter–spring floods events would increase by 131 percent and the maximum period would increase by 39 percent. These changes are very likely to have substantial adverse consequences for the condition and composition of current vegetation of the Great Cumbung Swamp. The wet extreme 2030 climate would cause an 11 percent decrease in the average period between events but would not affect the maximum period between events.

Projected future catchment and groundwater development (Scenario D) would lead to small additional increases in the period between winter–spring flood events.

Once again, the volumes entering the wetlands during individual winter–spring events change little between all scenarios. The differences in average annual flood volumes between the scenarios are thus largely a reflection of the changes in flood frequency.

7.5 References

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Appendix A Rainfall-runoff results for all subcatchments

Table A-1. Summary of modelling results for all subcatchments under scenarios A and C

		Scenario A					Scenario Cdry		Scenario Cmid		Scenario Cwet	
Modelling catchment	Area	Rainfall	APET	Runoff	Runoff coefficient	Runoff contribution	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff
	km^2	mm			percent		percent change from Scenario A					
4120021	1640	634	1318	34	5%	3%	-12%	-32%	-4%	-11%	6%	11%
4120041	1633	575	1374	25	4%	2%	-13%	-33%	-4%	-10%	6%	21%
4120091	1685	751	1277	74	10%	6%	-12%	-27%	-4%	-10%	5%	9%
4120100	8197	731	1228	89	12%	37%	-12%	-30%	-3%	-11%	5%	4%
4120111	18234	477	1385	16	3%	15%	-21%	-42%	-4%	-10%	7%	22%
4120261	33545	328	1432	5	2%	9%	-20%	-40%	-4%	-7%	9%	44%
4120290	1552	641	1276	51	8%	4%	-12%	-35%	-4%	-13%	5%	6%
4120300	1692	659	1333	37	6%	3%	-12%	-33%	-4%	-10%	6%	16%
4120361	2005	511	1380	19	4%	2%	-22%	-43%	-4%	-10%	6%	21%
4120430	4175	507	1403	29	6%	6%	-18%	-38%	-4%	-8%	11%	37%
4120481	8192	401	1429	16	4%	7%	-19%	-38%	-4%	-10%	11%	42%
4120551	417	609	1361	28	5%	1%	-12%	-32%	-4%	-10%	6%	21%
4120571	1309	615	1346	31	5%	2%	-12%	-33%	-4%	-11%	6%	16%
4120720	802	603	1308	32	5%	1%	-12%	-33%	-4%	-12%	5%	10%
4120800	86	873	1229	114	13%	0%	-12%	-27%	-4%	-10%	5%	8%
4120920	132	810	1199	130	16%	1%	-12%	-28%	-3%	-10%	5%	4%
4121060	235	745	1226	100	13%	1%	-12%	-28%	-3%	-10%	6%	8%
	85532	**461**	**1384**	**23**	**5%**	**100%**	**-17%**	**-34%**	**-4%**	**-10%**	**8%**	**17%**

Table A-2. Summary of modelling results for all subcatchments under scenarios A and D

Modelling catchment	A runoff	Plantations increase	Farm dam increase		Ddry runoff	Dmid runoff	Dwet runoff
	mm	ha	ML	ML/km^2	percent change from Scenario A		
4120021	34	0	870	0.5	-34%	-13%	9%
4120041	25	0	877	0.5	-35%	-12%	19%
4120091	74	0	876	0.5	-28%	-11%	8%
4120100	89	0	4364	0.5	-31%	-12%	3%
4120111	16	0	10114	0.6	-44%	-12%	20%
4120261	5	0	9694	0.3	-40%	-8%	42%
4120290	51	0	838	0.5	-36%	-14%	4%
4120300	37	0	969	0.6	-34%	-12%	14%
4120361	19	0	1060	0.5	-44%	-12%	18%
4120430	29	0	2499	0.6	-39%	-10%	35%
4120481	16	0	2646	0.3	-38%	-11%	40%
4120551	28	0	240	0.6	-34%	-12%	19%
4120571	31	0	694	0.5	-35%	-13%	14%
4120720	32	0	488	0.6	-35%	-14%	8%
4120800	114	0	44	0.5	-28%	-10%	7%
4120920	130	0	68	0.5	-28%	-11%	3%
4121060	100	0	130	0.6	-29%	-11%	7%
	23	**0**	**36471**	**0.4**	**-35%**	**-12%**	**15%**

Appendix B River water modelling reach mass balances

4120091

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Carcoar Dam	-0.1	-15%	46%	62%	-11%	50%	59%
Total change in storage	**-0.1**	**-15%**	**46%**	**62%**	**-11%**	**50%**	**59%**
Inflows							
Subcatchments							
Directly gauged	46.3	6%	-10%	-28%	5%	-11%	-28%
Indirectly gauged	155.5	9%	-10%	-27%	8%	-11%	-28%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**201.8**	**8%**	**-10%**	**-27%**	**7%**	**-11%**	**-28%**
Diversions							
Licensed private diversions							
High security irrigation	0.2	-1%	7%	19%	-1%	7%	19%
General security irrigation	0.0	0%	0%	0%	0%	0%	0%
High security diversions							
Town water supply	0.0	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**0.2**	**-1%**	**7%**	**17%**	**-1%**	**7%**	**17%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	197.0	8%	-10%	-28%	7%	-11%	-29%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**197.0**	**8%**	**-10%**	**-28%**	**7%**	**-11%**	**-29%**
Net evaporation							
Public storages	2.7	4%	-4%	-9%	3%	-5%	-10%
Unattributed fluxes							
River unattributed loss	2.0	4%	-8%	-18%	3%	-9%	-19%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120551

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	197.0	8%	-10%	-28%	7%	-11%	-29%
Indirectly gauged	20.8	21%	-10%	-32%	18%	-12%	-34%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**217.9**	**10%**	**-10%**	**-28%**	**8%**	**-11%**	**-29%**
Diversions							
Licensed private diversions							
High security irrigation	0.0	0%	0%	0%	0%	0%	0%
General security irrigation	2.4	0%	-2%	-6%	-1%	-3%	-8%
High security diversions							
Town water supply	0.0	0%	0%	0%	0%	0%	0%
Stock and domestic	0.2	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**2.5**	**0%**	**-2%**	**-6%**	**-1%**	**-3%**	**-7%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	192.8	10%	-10%	-29%	9%	-11%	-30%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**192.8**	**10%**	**-10%**	**-29%**	**9%**	**-11%**	**-30%**
Net evaporation							
Public storages	0.0	0%	0%	0%	0%	0%	0%
Unattributed fluxes							
River unattributed loss	22.5	5%	-10%	-23%	4%	-11%	-25%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120021

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Wyangala Dam	-6.2	2%	14%	29%	4%	17%	29%
Total change in storage	**-6.2**	**2%**	**14%**	**29%**	**4%**	**17%**	**29%**
Inflows							
Subcatchments							
Directly gauged	810.0	4%	-11%	-31%	3%	-13%	-32%
Indirectly gauged	101.9	11%	-11%	-32%	9%	-13%	-34%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**911.9**	**5%**	**-11%**	**-31%**	**3%**	**-13%**	**-33%**
Diversions							
Licensed private diversions							
High security irrigation	1.9	0%	7%	18%	0%	7%	18%
General security irrigation	1.1	2%	-4%	-9%	0%	-7%	-11%
High security diversions							
Town water supply	4.2	0%	0%	-1%	0%	-1%	-3%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	2.4	15%	-12%	-53%	11%	-16%	-57%
Sub-total	**9.6**	**4%**	**-2%**	**-11%**	**3%**	**-4%**	**-13%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	861.4	5%	-11%	-32%	4%	-13%	-33%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**861.4**	**5%**	**-11%**	**-32%**	**4%**	**-13%**	**-33%**
Net evaporation							
Public storages	20.0	4%	1%	-3%	2%	-2%	-7%
Unattributed fluxes							
River unattributed loss	27.2	3%	-10%	-26%	2%	-11%	-28%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120571

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	1083.0	6%	-11%	-31%	5%	-13%	-33%
Indirectly gauged	72.0	16%	-11%	-33%	14%	-13%	-35%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**1155.1**	**7%**	**-11%**	**-31%**	**5%**	**-13%**	**-33%**
Diversions							
Licensed private diversions							
High security irrigation	0.0	0%	0%	0%	0%	0%	0%
General security irrigation	7.4	3%	-6%	-19%	1%	-9%	-23%
High security diversions							
Town water supply	0.0	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**7.4**	**3%**	**-6%**	**-19%**	**1%**	**-9%**	**-23%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	1097.5	7%	-11%	-31%	5%	-13%	-33%
River groundwater loss	7.8	-4%	0%	5%	59%	59%	60%
Sub-total	**1105.3**	**7%**	**-11%**	**-31%**	**5%**	**-13%**	**-32%**
Net evaporation							
Public storages	0.0	0%	0%	0%	0%	0%	0%
Unattributed fluxes							
River unattributed loss	42.4	13%	-11%	-39%	11%	-13%	-41%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120041

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	1163.7	7%	-11%	-31%	5%	-13%	-33%
Indirectly gauged	48.0	21%	-10%	-33%	19%	-12%	-35%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**1211.8**	**8%**	**-11%**	**-31%**	**6%**	**-13%**	**-33%**
Diversions							
Licensed private diversions							
High security irrigation	0.0	0%	0%	0%	0%	0%	0%
General security irrigation	25.8	5%	-7%	-18%	2%	-10%	-22%
High security diversions							
Town water supply	4.1	0%	0%	-2%	0%	-1%	-3%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**29.9**	**4%**	**-6%**	**-16%**	**2%**	**-9%**	**-19%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	1060.4	7%	-11%	-30%	5%	-13%	-32%
River groundwater loss	3.0	5%	-11%	-24%	15%	-5%	-22%
Sub-total	**1063.4**	**7%**	**-11%**	**-30%**	**5%**	**-13%**	**-32%**
Net evaporation							
Public storages	0.0	0%	0%	0%	0%	0%	0%
Unattributed fluxes							
River unattributed loss	118.4	16%	-15%	-45%	13%	-17%	-47%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120361

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	1060.4	7%	-11%	-30%	5%	-13%	-32%
Indirectly gauged	20.6	21%	-10%	-43%	18%	-12%	-44%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**1081.0**	**7%**	**-11%**	**-31%**	**5%**	**-13%**	**-32%**
Diversions							
Licensed private diversions							
High security irrigation	3.2	4%	8%	22%	3%	7%	21%
General security irrigation	57.4	4%	-10%	-26%	2%	-13%	-30%
High security diversions							
Town water supply	0.0	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**60.5**	**4%**	**-9%**	**-24%**	**2%**	**-12%**	**-27%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	931.9	7%	-11%	-31%	5%	-13%	-32%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**931.9**	**7%**	**-11%**	**-31%**	**5%**	**-13%**	**-32%**
Net evaporation							
Public storages	0.0	0%	0%	0%	0%	0%	0%
Unattributed fluxes							
River unattributed loss	88.6	13%	-11%	-34%	10%	-12%	-36%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120111

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Lake Cargelligo	-0.1	5%	1%	-15%	-20%	3%	72%
Total change in storage	**-0.1**	**5%**	**1%**	**-15%**	**-20%**	**3%**	**72%**
Inflows							
Subcatchments							
Directly gauged	995.1	9%	-11%	-31%	7%	-13%	-33%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**995.1**	**9%**	**-11%**	**-31%**	**7%**	**-13%**	**-33%**
Diversions							
Licensed private diversions							
High security irrigation	0.0	-2%	4%	12%	-2%	4%	10%
General security irrigation	56.4	4%	-7%	-22%	2%	-10%	-26%
High security diversions							
Town water supply	1.2	0%	0%	-2%	0%	-1%	-3%
Stock and domestic	1.5	0%	-1%	-2%	0%	-1%	-3%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**59.0**	**4%**	**-7%**	**-21%**	**2%**	**-10%**	**-25%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	730.4	7%	-11%	-31%	5%	-13%	-32%
River groundwater loss	1.0	-2%	-3%	-7%	2%	-2%	-7%
Sub-total	**731.4**	**7%**	**-11%**	**-31%**	**5%**	**-13%**	**-32%**
Net evaporation							
Public storages	11.3	0%	6%	16%	-1%	6%	16%
Unattributed fluxes							
River unattributed loss	193.4	16%	-12%	-39%	14%	-14%	-41%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120481

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Natural storages	0.0	-21%	-21%	-3%	-21%	-14%	0%
Total change in storage	**0.0**	**-21%**	**-21%**	**-3%**	**-21%**	**-14%**	**0%**
Inflows							
Subcatchments							
Directly gauged	730.4	7%	-11%	-31%	5%	-13%	-32%
Indirectly gauged	48.3	24%	-11%	-35%	13%	-22%	-46%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**778.7**	**8%**	**-11%**	**-31%**	**6%**	**-14%**	**-33%**
Diversions							
Licensed private diversions							
High security irrigation	0.0	0%	0%	0%	0%	0%	0%
General security irrigation	6.0	4%	-9%	-27%	2%	-13%	-30%
High security diversions							
Town water supply	0.0	0%	0%	0%	0%	0%	0%
Stock and domestic	1.0	0%	-1%	-2%	0%	-1%	-2%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**7.0**	**4%**	**-8%**	**-23%**	**2%**	**-11%**	**-26%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	719.7	8%	-12%	-32%	6%	-14%	-34%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**719.7**	**8%**	**-12%**	**-32%**	**6%**	**-14%**	**-34%**
Net evaporation							
Public storages	52.0	9%	-4%	-18%	7%	-7%	-22%
Unattributed fluxes							
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4120261

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Lake Brewster	0.0	59%	9%	96%	41%	136%	313%
Brewster Weir	0.0	-65%	-102%	-96%	-209%	-131%	-1036%
Natural storages	0.0	49%	59%	89%	50%	62%	94%
Total change in storage	**0.0**	**72%**	**29%**	**117%**	**71%**	**156%**	**435%**
Inflows							
Subcatchments							
Directly gauged	719.7	8%	-12%	-32%	6%	-14%	-34%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**719.7**	**8%**	**-12%**	**-32%**	**6%**	**-14%**	**-34%**
Diversions							
Licensed private diversions							
High security irrigation	3.9	4%	6%	15%	4%	6%	14%
General security irrigation	101.1	3%	-11%	-31%	1%	-15%	-34%
High security diversions							
Town water supply	0.5	0%	-1%	-1%	0%	-1%	-2%
Stock and domestic	6.3	0%	-1%	-1%	-1%	-1%	-2%
Wetland replenishment	26.1	1%	-1%	-5%	0%	-2%	-6%
Environmental contingency flow	2.4	15%	-11%	-53%	11%	-16%	-57%
Sub-total	**140.4**	**3%**	**-8%**	**-24%**	**1%**	**-11%**	**-26%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	93.9	8%	-14%	-36%	5%	-17%	-38%
River groundwater loss	17.2	-4%	-7%	0%	-5%	0%	1%
Sub-total	**111.0**	**6%**	**-13%**	**-31%**	**3%**	**-14%**	**-32%**
Net evaporation							
Public storages	69.6	7%	-2%	-5%	6%	-2%	-7%
Unattributed fluxes							
River unattributed loss	398.7	11%	-14%	-40%	8%	-17%	-42%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4265326

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	0.0	0%	0%	0%	0%	0%	0%
Indirectly gauged	121.2	10%	-11%	-33%	8%	-14%	-35%
Effluent return	0.0	0%	0%	0%	0%	0%	0%
Urban returns	0.0	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**121.2**	**10%**	**-11%**	**-33%**	**8%**	**-14%**	**-35%**
Diversions							
Licensed private diversions							
High security irrigation	0.0	0%	0%	0%	0%	0%	0%
General security irrigation	6.6	5%	-6%	-22%	3%	-9%	-26%
High security diversions							
Town water supply	0.0	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%
Wetland replenishment	0.0	0%	0%	0%	0%	0%	0%
Environmental contingency flow	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**6.6**	**5%**	**-6%**	**-22%**	**3%**	**-9%**	**-26%**
Outflows							
Subcatchment effluent	0.0	0%	0%	0%	0%	0%	0%
End of catchment flows	114.6	11%	-12%	-34%	8%	-14%	-36%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**114.6**	**11%**	**-12%**	**-34%**	**8%**	**-14%**	**-36%**
Net evaporation							
Public storages	0.0	0%	0%	0%	0%	0%	0%
Unattributed fluxes							
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%
Mass balance							
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix C River system model uncertainty assessment by reach

This Appendix contains the results of river reach water accounting for this region, as well as an assessment of the magnitude of the project change under each scenario compared to the uncertainty associated with the river model. Each page provides information for a river reach that is bounded by a gauging station on the upstream and downstream side, and for which modelling results are available. Table C-1 provides a brief explanation for each component of the results page.

Table C-1. Explanation of components of the uncertainty assessments

Table	Description
Land use	Information on the extent of dryland, irrigation and wetland areas. Land use areas are based on remote sensing classification involving BRS land use mapping, water resources infrastructure and remote sensing-based estimates of actual evapotranspiration.
Gauging data	Information on how well the river reach water balance is measured or, where not measured, can be inferred from observations and modelling. The volumes of water measured at gauging stations and off-takes is compared to the grand totals of all inflows or gains, and/or all outflows or losses, respectively. The 'fraction of total' refers to calculations performed on average annual flow components over the period of analysis. The 'fraction of variance' refers to the fraction of month-to-month variation that is measured. Also listed are the same calculations but for the sum of gauged terms plus water balance terms that could be attributed to the components listed in the 'Water balance' table with some degree of confidence. The same terms are also summed to water years and shown in the diagram next to this table.
Correlation with ungauged gains/losses	Information on the likely nature of ungauged components of the reach water balance. Listed are the coefficients of correlation between ungauged apparent monthly gains or losses on one hand, and measured components of the water balance on the other hand. Both the 'normal' (parametric) and the ranked (or non-parametric) coefficient of correlation are provided. High coefficients are highlighted. Positive correlations imply that the apparent gain or loss is large when the measured water balance component is large, whereas negative correlation implies that the apparent gain or loss is largest when the measured water balance component is small. In the diagram below this table, the monthly flows measured at the gauge at the end of the reach are compared with the flows predicted by the baseline river model, and the outflows that could be accounted for (i.e., the net result of all measured or estimated water balance components other than main stem outflow – which ideally should equal main stem outflows in order to achieve mass balance).
Water balance	Information on how well the modelled and the best estimate river reach water balances agree, and what the nature of any unspecified losses in the river model is likely to be. The river reach water balance terms are provided as modelled by the baseline river model (Scenario A) over the period of water accounting. The accounted terms are based on gauging data, diversion records, and (adjusted) estimates derived from SIMHYD rainfall-runoff modelling, remote sensing of water use and simulation of temporary storage effects. Neither should be considered as absolutely correct, but large divergences point to large uncertainty in river modelling.
Model efficiency	Information on the performance of the river model in explaining historic flow patterns at the reach downstream gauge, and the scope to improve on this performance. All indicators are based on the Nash-Sutcliffe model efficiency (NSME) indicator. In addition to the conventional NSME calculated for monthly and annual outflows, it has also been calculated after log-transformation or ranking of the original data, as well as having been calculated for the 10% of months with highest and lowest observed flows, respectively. Using the same formulas, the 'model efficiency' of the water accounts in explaining observed outflows is calculated. This provides an indication of the scope for improving the model to explain more of the observed flow patterns: if NSME is much higher for the water accounts than for the model, than this suggests that the model can be improved upon and model uncertainty reduced. Conversely, if both are of similar magnitude, then it is less likely that a better model can be derived without additional observation infrastructure.

Table	Description
Change-uncertainty ratios	Information on the significance of the projected changes under different scenarios, considering the performance of the river model in explaining observed flow patterns at the end of the reach. In this table, the projected change is compared to the river model uncertainty by testing the hypothesis that the scenario model is about as good or better in explaining observed historic flows than the baseline model. The metric to test this hypothesis is the change-uncertainty ratio, which is calculated as the ratio of Nash-Sutcliffe Model Efficiency indicators for the scenario model and for the baseline (scenario A) model, respectively. A value of around 1.0 or less suggests that is likely that the projected scenario change is not significant when compared to river model uncertainty. Conversely, a ratio that is considerably greater than 1.0 implies that the scenario model is much worse in reproducing historic observations than the baseline model, which provides greater confidence that the scenario indeed leads to a significant change in flow patterns. The change-uncertainty ratio is calculated for monthly as well as annual values, to account for the possibility that the baseline model may reproduce annual patterns well but not monthly. Below this table on the left, the same information is provided in a diagram. Below the table on the right, the observed annual flows at the end of the reach is compared to those simulated by the baseline model and in the various scenarios. To the right of this table, the flow-duration curves are shown for all scenarios.

Downstream gauge	412002 Lachlan @ Cowra	Reach 1
Upstream gauge	412067 Lachlan @ Wyangala	

Reach length (km)	40.2
Area (km²)	11389
Outflow/inflow ratio	1.20
Net gaining reach	

Land use	ha	%
Dryland	1,137,002	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	1,898	0
Open water*	-	-

* averages for 1990–2006

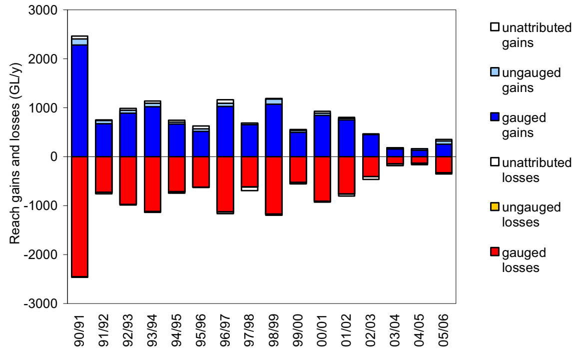
This is a gaining reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains. There are some diversions and ungauged losses are small.

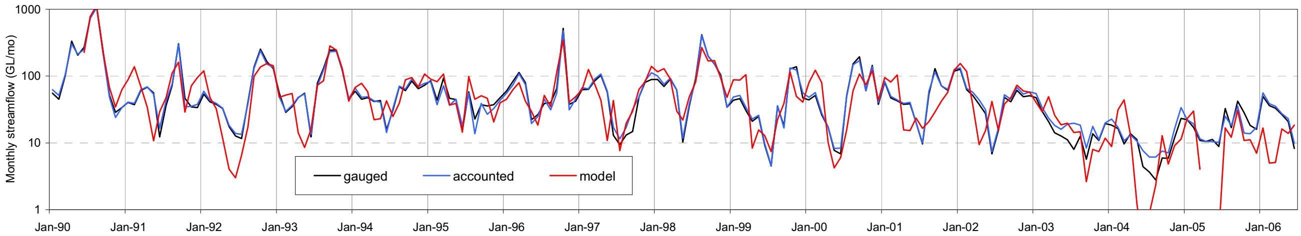
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the wet scenarios where projected changes are similar to the uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.90	0.96	0.93
Attributed	0.97	0.97	0.97
Fraction of variance			
Gauged	0.99	1.00	1.00
Attributed	1.00	1.00	1.00



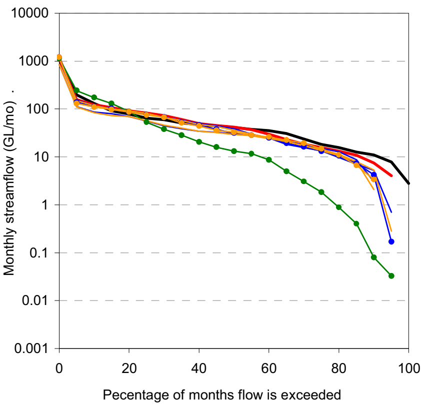
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.68**	-0.17	-0.02	-0.27	
Tributary inflows	**-0.85**	**-0.71**	-0.23	-0.45	
Main gauge outflows	**-0.79**	-0.46	-0.07	-0.10	
Distributory outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.89**	**-0.69**	-0.25	-0.49	



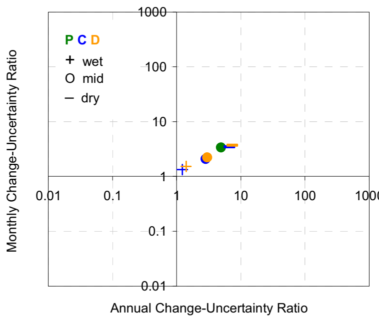
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	688	663	25
Tributary inflows	0	82	-82
Local inflows	89	54	35
Unattributed gains and noise	59	28	32
Losses	GL/y	GL/y	GL/y
Main stem outflows	782	794	-13
Distributory outflows	0	0	0
Net diversions	10	5	5
River flux to groundwater	0	-	0
River and floodplain losses	19	0	19
Unspecified losses	26	-	26
Unattributed losses and noise	-	27	-27
	0	0	0

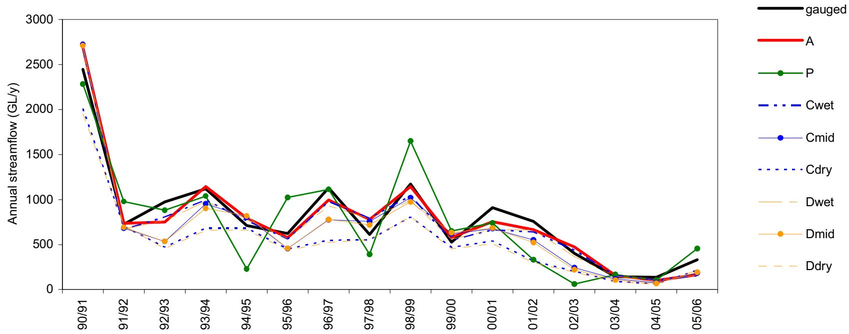
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.89	1.00
Log-normalised	-	-
Ranked	0.56	0.97
Low flows only	<0	<0
High flows only	0.92	1.00
Annual		
Normal	0.95	1.00
Log-normalised	0.90	0.99
Ranked	0.80	0.99

Definitions:
- low flows (flows<10% percentile) : 10.9 GL/mo
- high flows (flows>90% percentile) : 129.9 GL/mo



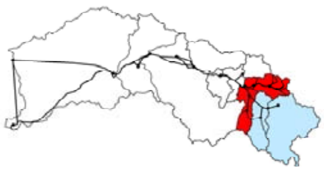
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.9		1.2	2.8	6.6	1.4	3.0	7.3
Monthly streamflow	3.4		1.3	2.1	3.5	1.5	2.2	3.7





Downstream gauge	412057 Lachlan @ Nanami	Reach 2
Upstream gauge	412002 Lachlan @ Cowra	

Reach length (km)	57.6
Area (km²)	16056
Outflow/inflow ratio	1.23
Net gaining reach	



This is a gaining reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains, but an adjustment was required. There are some diversions and ungauged losses are small.

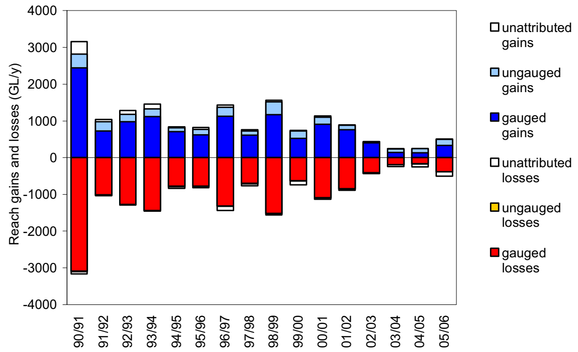
Baseline model performance is excellent. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the wet scenarios where projected changes are similar to the uncertainty.

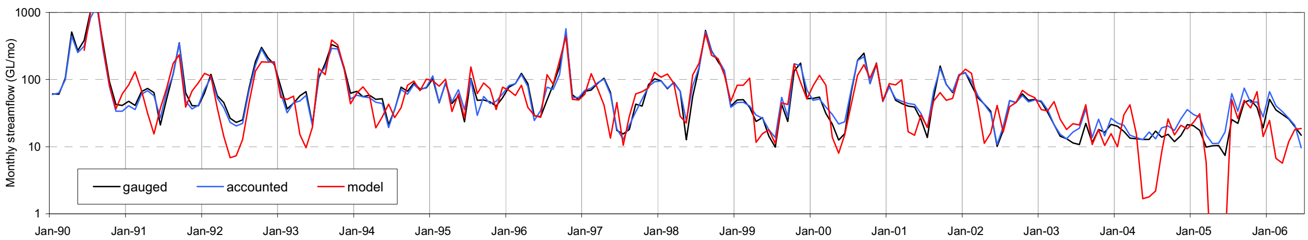
Land use	ha	%
Dryland	1,600,524	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	5,076	0
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.77	0.94	0.86
Attributed	0.94	0.95	0.95
Fraction of variance			
Gauged	0.95	1.00	0.97
Attributed	0.98	1.00	0.99



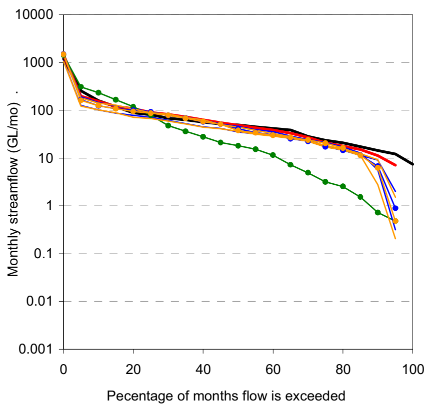
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.73	-0.38	-0.18	-0.04	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.83	-0.56	-0.12	-0.13	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.79	-0.68	-0.06	-0.16	Adjusted -33.0%



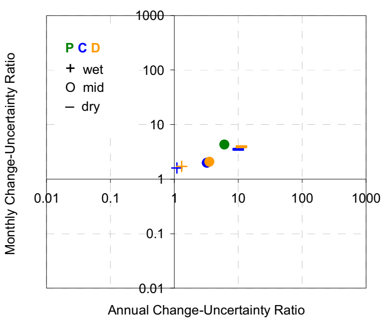
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	978	794	184
Tributary inflows	0	0	0
Local inflows	48	182	-134
Unattributed gains and noise	-	59	-59
Losses	GL/y	GL/y	GL/y
Main stem outflows	975	976	0
Distributary outflows	0	0	0
Net diversions	7	9	-2
River flux to groundwater	8	-	8
River and floodplain losses	0	0	0
Unspecified losses	38	-	38
Unattributed losses and noise	-	50	-50
	-1	0	-1

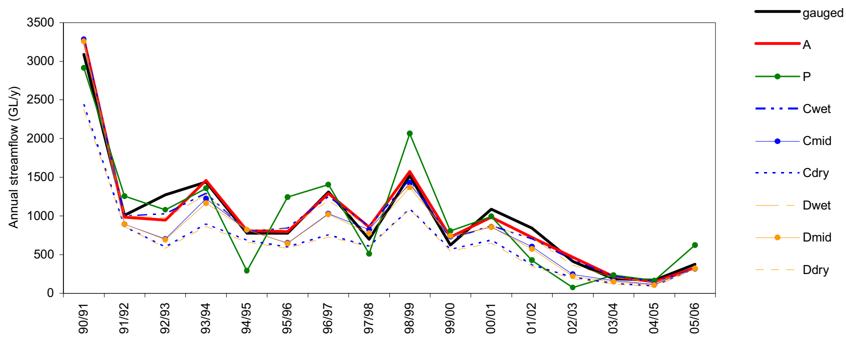
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	0.98
Log-normalised	-	-
Ranked	0.60	0.94
Low flows only	<0	<0
High flows only	0.93	0.96
Annual		
Normal	0.97	0.98
Log-normalised	0.97	0.97
Ranked	0.91	0.98

Definitions:
- low flows (flows<10% percentile) : 14.3 GL/mo
- high flows (flows>90% percentile) : 159.4 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.1		1.1	3.2	10.0	1.3	3.6	11.3
Monthly streamflow	4.3		1.6	2.0	3.5	1.7	2.1	3.9



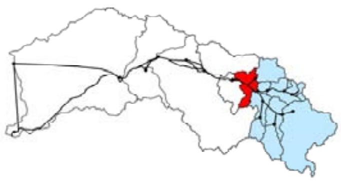


Downstream gauge	412004 Lachlan @ Forbes (Cottons Wr)	Reach 3
Upstream gauge	412057 Lachlan @ Nanami	

Reach length (km)	60.9
Area (km^2)	20584
Outflow/inflow ratio	1.00
Net losing reach	

Land use	ha	%
Dryland	2,053,040	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	5,360	0
Open water*	-	-

* averages for 1990–2006



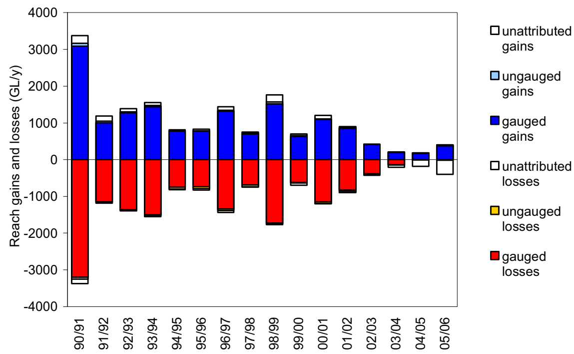
This is neither a gaining nor a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains but an adjustment was required. There are some diversions and ungauged losses are small.

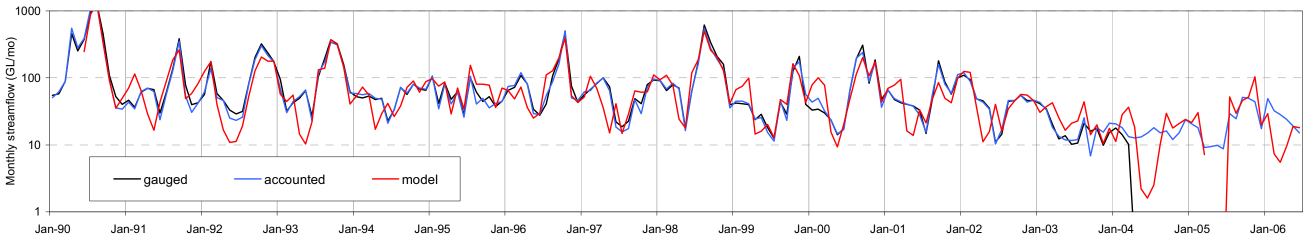
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the wet scenarios where projected changes are similar to the uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.91	0.91	0.91
Attributed	0.94	0.94	0.94
Fraction of variance			
Gauged	0.99	0.99	0.99
Attributed	0.99	0.99	0.99



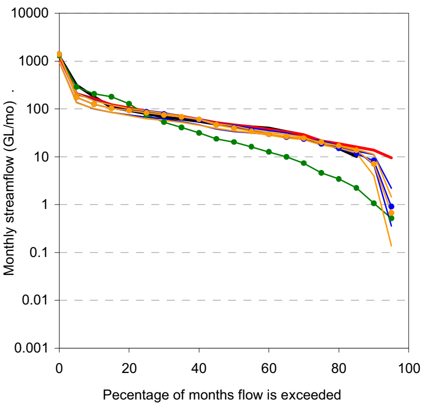
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.52**	-0.38	-0.31	-0.05	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.62**	-0.48	-0.20	-0.24	
Distributory outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.49	-0.48	-0.25	-0.24	Adjusted -35.0%



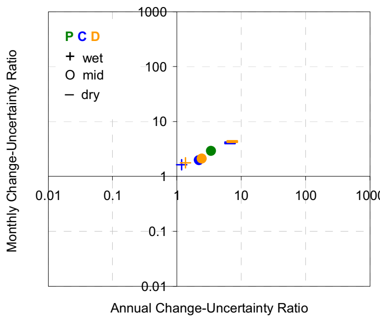
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1041	976	65
Tributary inflows	0	0	0
Local inflows	48	26	21
Unattributed gains and noise	-	68	-68
Losses	GL/y	GL/y	GL/y
Main stem outflows	960	971	-12
Distributory outflows	0	0	0
Net diversions	29	31	-2
River flux to groundwater	3	-	3
River and floodplain losses	0	3	-3
Unspecified losses	99	-	99
Unattributed losses and noise	-	65	-65
	-2	0	-2

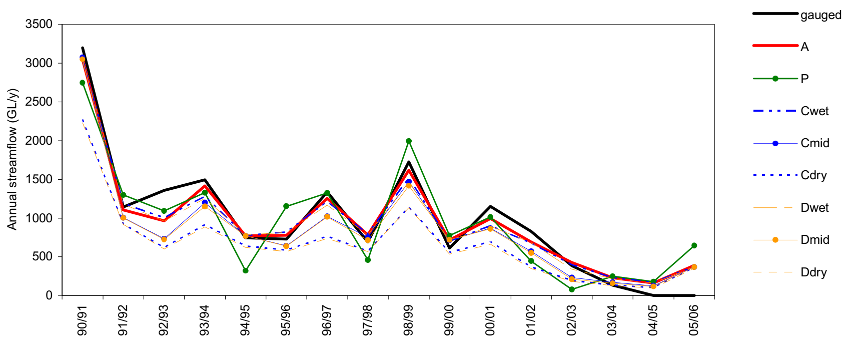
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	0.98
Log-normalised	-	-
Ranked	0.51	0.89
Low flows only	-	-
High flows only	0.94	0.97
Annual		
Normal	0.95	0.97
Log-normalised	-	-
Ranked	0.86	0.97

Definitions:
- low flows (flows<10% percentile) : 0.0 GL/mo
- high flows (flows>90% percentile) : 178.8 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.4		1.2	2.2	6.7	1.4	2.4	7.3
Monthly streamflow	2.9		1.6	2.0	4.1	1.8	2.1	4.3





Downstream gauge	412036 Lachlan @ Jemalong Weir	Reach 4
Upstream gauge	412004 Lachlan @ Forbes (Cottons Wr)	

Reach length (km)	38.7
Area (km^2)	21386
Outflow/inflow ratio	0.88
Net losing reach	

This is a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are large diversions and ungauged losses.

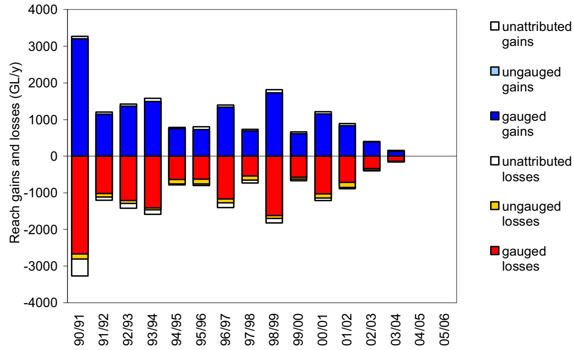
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the wet scenarios where projected changes are similar to the uncertainty.

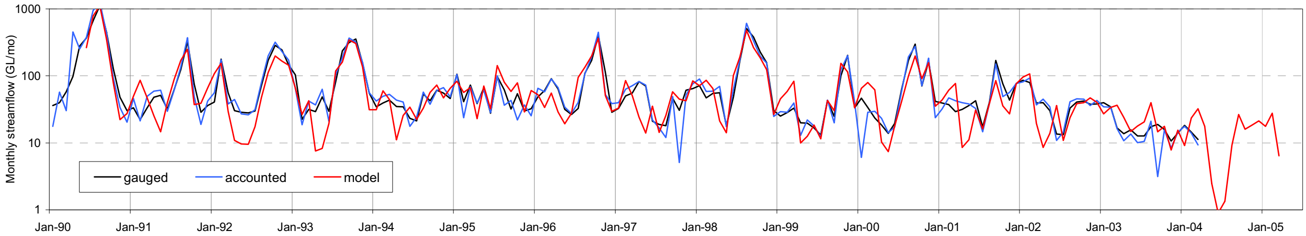
Land use	ha	%
Dryland	2,124,456	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	14,144	1
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.95	0.84	0.92
Attributed	0.95	0.93	0.95
Fraction of variance			
Gauged	1.00	0.99	0.99
Attributed	1.00	0.99	0.99



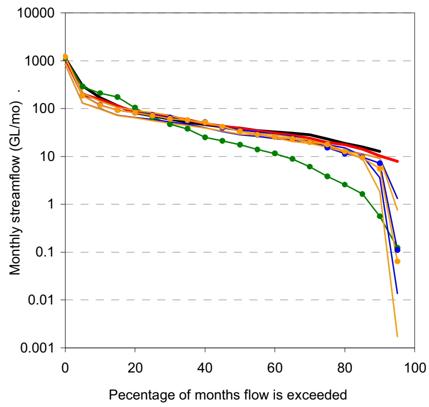
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.14	-0.00	-0.68	-0.53	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.25	-0.10	-0.49	-0.37	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.08	-0.24	-0.77	-0.14	Adjusted -100.0%



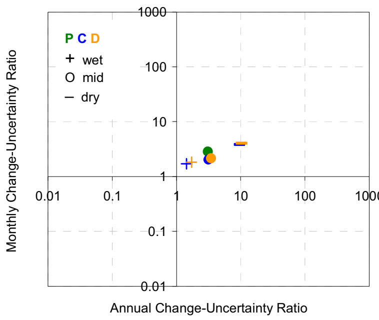
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	998	1036	-39
Tributary inflows	0	0	0
Local inflows	20	0	20
Unattributed gains and noise	-	54	-54
Losses	GL/y	GL/y	GL/y
Main stem outflows	872	912	-40
Distributary outflows	0	0	0
Net diversions	63	77	-14
River flux to groundwater	0	-	0
River and floodplain losses	0	9	-9
Unspecified losses	82	-	82
Unattributed losses and noise	-	91	-91
	-1	0	-1

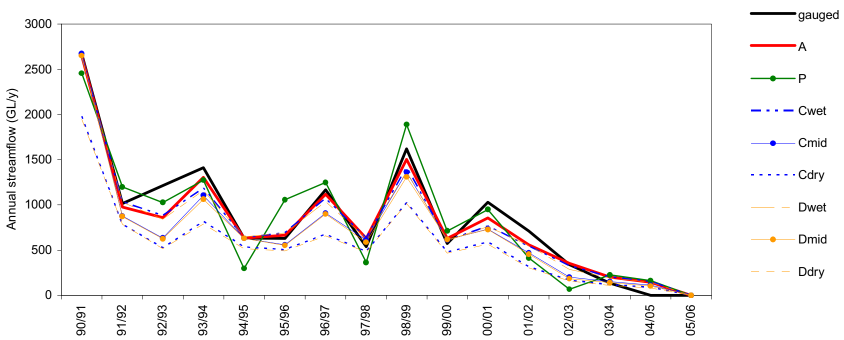
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	0.95
Log-normalised	-	-
Ranked	0.54	0.89
Low flows only	<0	0.96
High flows only	0.93	0.89
Annual		
Normal	0.96	0.98
Log-normalised	-	-
Ranked	0.89	0.99

Definitions:
- low flows (flows<10% percentile) : 12.7 GL/mo
- high flows (flows>90% percentile) : 169.9 GL/mo



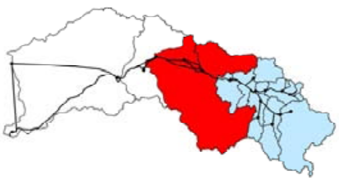
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.1		1.4	3.1	9.6	1.7	3.5	10.3
Monthly streamflow	2.9		1.7	2.0	3.8	1.8	2.1	4.0





Downstream gauge	412011 Lachlan @ Cargelligo Weir	Reach 5
Upstream gauge	412036 Lachlan @ Jemalong Weir	

Reach length (km)	225.7
Area (km^2)	43795
Outflow/inflow ratio	0.68
Net losing reach	



Land use	ha	%
Dryland	4,201,402	96
Irrigable area	-	-
Open water*	-	-
River and wetlands	178,098	4
Open water*	-	-

* averages for 1990–2006

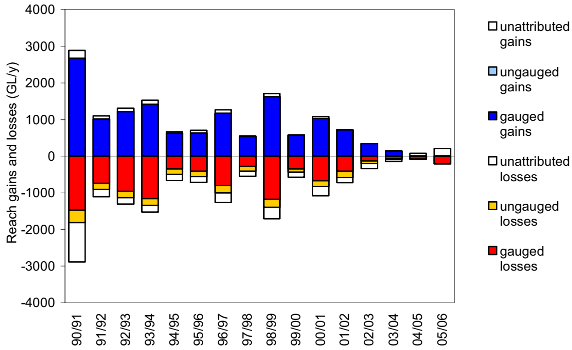
This is a strongly losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. Estimated local runoff does not explains ungauged gains. There are moderate diversions and ungauged losses are small.

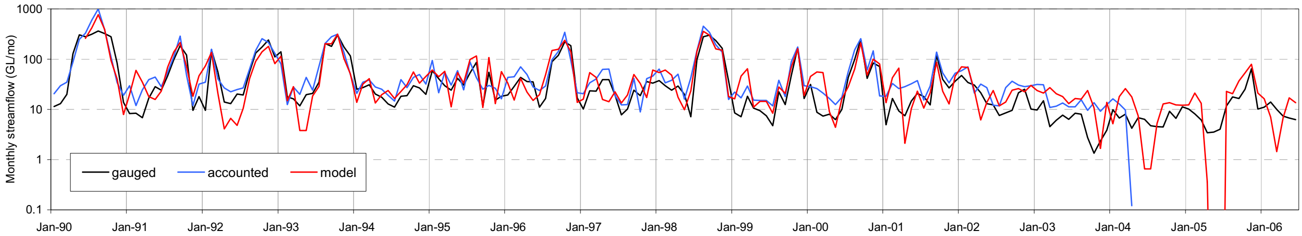
Baseline model performance is good. Accounting explains observed flows reasonably well, except towards the end of the period when accounting performs poorly.

The projected changes are generally similar to river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.92	0.62	0.77
Attributed	0.92	0.77	0.85
Fraction of variance			
Gauged	0.98	0.72	0.85
Attributed	0.98	0.81	0.90



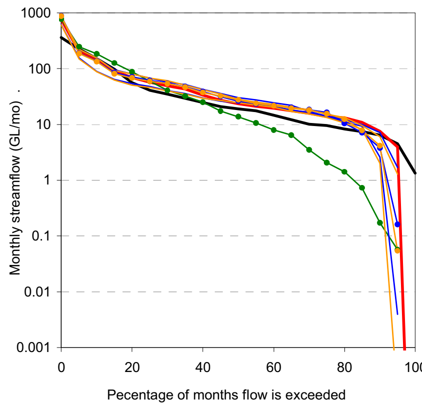
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.01	-0.14	-0.88	-0.70	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.28	-0.11	-0.55	-0.41	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.07	-0.05	-0.44	-0.13	Adjusted -100.0%



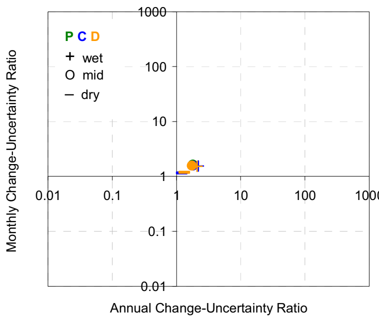
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	894	855	38
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	74	-74
Losses	GL/y	GL/y	GL/y
Main stem outflows	658	579	79
Distributary outflows	104	0	104
Net diversions	58	43	14
River flux to groundwater	1	-	1
River and floodplain losses	11	94	-83
Unspecified losses	63	-	63
Unattributed losses and noise	-	213	-213
	-1	0	-1

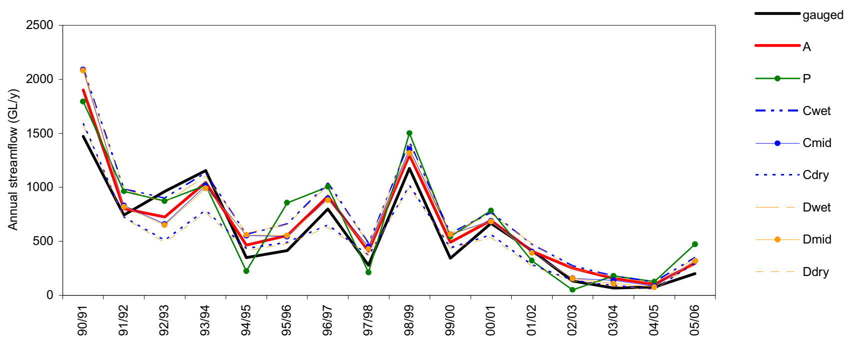
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.68	0.32
Log-normalised	<0	-
Ranked	0.45	0.67
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	0.86	0.64
Log-normalised	0.85	-
Ranked	0.91	0.95

Definitions:
- low flows (flows<10% percentile) : 6.4 GL/mo
- high flows (flows>90% percentile) : 151.7 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.8		2.2	1.8	1.2	2.1	1.7	1.3
Monthly streamflow	1.6		1.5	1.6	1.2	1.5	1.6	1.2





Erratum: Lachlan

This is an erratum sheet, issued May 2009, for the following report:

CSIRO (2008) Water availability in the Lachlan. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 133pp

List of erratum

Erratum #	Chapter	Section	Page	Errata
1	6 Groundwater assessment	6.6.3	103	Replacement Table 6-19 – connectivity units changed to percents (from fractions)
2	6 Groundwater assessment	6.6.3	104	Para 1, Line 5 – replace 16 GL/year with 26 GL/year

1

Table 6-19. Surface-groundwater connectivity showing an estimate of the volumetric impact extraction has on streamflow in groundwater management units under Scenario D

Code	Name	Current Entitlements	Future Extraction	Difference	Connectivity	Stream Impact
			GL/y		percent	
N21	Belubula Valley Alluvium	6.29	6.29	0.00	15%	0.00
N801	Orange Basalt	6.23	6.44	0.21	30%	0.06
N802	Young Granite	7.75	7.75	0.00	25%	0.00
N811	Lachlan Fold Belt	33.46	119.19	85.73	30%	25.72
	Total	**53.73**	**139.67**	**85.94**		**25.78**

2

[Replacement paragraph]

The impacts of groundwater extraction on streamflow listed in Table 6-19 are distributed to the relevant surface water subcatchments or stretches of river. Streamflow losses of less than 2 GL/year in a subcatchment (Table 6-20) would be difficult to observe and thus only subcatchments where the estimated impact from groundwater extraction exceeds a 2 GL/year reduction in streamflow are considered further. Calculation using original future extraction data showed this cut-off discounts about 15 GL/year of impacts reducing the total estimated impact from about 26 GL/year (Table 6-19) to about 11 GL/year.

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Enquiries

More information about the project can be found at www.csiro.au/mdbsy. This information includes the full terms of reference for the project, an overview of the project methods and the project reports that have been released to-date.