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Water Availability in the Murrumbidgee

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

June 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: The Murrumbidgee River near Jugiong, NSW. Courtesy of 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

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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 Murrumbidgee 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 Murrumbidgee region is in southern New South Wales and represents 8.2 percent of the total area of the MDB. The region is based around the Murrumbidgee River. The population is 500,000 or 27 percent of the MDB total, concentrated in the centres of Canberra, Wagga Wagga, Griffith, Leeton and Hay. The major land use is dryland pasture used for livestock grazing. Dryland cropping is a major enterprise and around 17 percent of the region is covered with native vegetation. Approximately 426,400 ha were irrigated in 2000 for cereals including rice, pasture and hay production. Citrus and grapes are grown within the central areas of the Murrumbidgee Irrigation Area near Griffith and Leeton. The existing area of commercial forestry plantations is 136,700 ha (less than 2 percent of the region). The region includes the Fivebough and Tuckerbil Swamps Ramsar site, the nationally significant Mid Murrumbidgee Wetlands and Lowbidgee Floodplain, and numerous smaller important wetlands.

The region uses over 22 percent of surface water diverted for irrigation and urban use in the MDB and over 24 percent of the groundwater used in the MDB. The rivers of the region are regulated by multiple storages including those of the Snowy Mountains Hydro-electric Scheme, those of the Australian Capital Territory Water Supply System and the major New South Wales irrigation dams of Blowering (on the Tumut River) and Burrinjuck (on the Murrumbidgee River). Most of the groundwater extracted is from the alluvial aquifers in the Mid-Murrumbidgee and Lower Murrumbidgee.

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. Scenario A is the baseline for comparison with all other scenarios.

Historical climate and current development (Scenario A)

The annual rainfall and modelled runoff averaged over the Murrumbidgee region are 530 mm and 54 mm, respectively. Rainfall is fairly uniform throughout the year and runoff is highest in winter and early spring. The region generates about 15.7 percent of MDB total runoff.

Current average surface water availability is 4270 GL/year with approximately one tenth of this being an inter-basin transfer from the Snowy Mountains Hydro-electric Scheme. On average, 2257 GL/year (or 53 percent) of the available water diverted for use. This is an extremely high level of development. Currently in New South Wales, 60 percent of allocated general security water is used.

Streamflows in the Murrumbidgee region are highly regulated. Tantangara Dam on the upper Murrumbidgee regulates nearly all inflows and further downstream Burrinjuck Dam regulates 77 percent of all inflows. Blowering Dam on the Tumut River regulates 87 percent of all inflows, in addition to the effects of the upstream storages of the Snowy Mountains Hydro-electric Scheme.

Total groundwater extraction in the region for 2004/05 was 407 GL. This represents 17 percent of total water use in the region on average and 26 percent of total water use in years of lowest surface water diversion. The majority (90 percent) was from the Mid-Murrumbidgee and Lower Murrumbidgee alluvium groundwater management units (GMUs).

Extraction from the Lower Murrumbidgee Alluvium GMU in 2004/05 was 324 GL or 67 percent of recharge on average. This is a medium level of development. Entitlements in the Lower Murrumbidgee Alluvium GMU are being reduced to the long-term average extraction limit of 280 GL/year. Extraction at this limit would eventually lower the groundwater levels by up to 8 m adjacent to extraction zones. Water levels however, are expected to rise slowly in areas away from extraction zones. Total recharge exceeds extraction in all years. A large fraction of the total recharge (almost equivalent to the extraction volume) is recharge from surface water irrigation. However, this recharge transits the saline Shepparton Formation prior to extraction from lower layers, thus potentially degrading the quality of the water. Extraction can be maintained at this level and will eventually impact on Murrumbidgee River streamflow by 53 GL/year.

Extraction from the Mid-Murrumbidgee Alluvium GMU in 2004/05 was 48 GL/year or 54 percent of recharge on average. This is a medium level of development. Total recharge nearly always exceeds groundwater extraction. Dynamic equilibrium with stable groundwater levels would be attained at an extraction level of about 40 GL/year. At this level of extraction groundwater levels would fall by up to 10 m adjacent to extraction zones of the lower aquifer. Extraction has impacted on flows in the Murrumbidgee River. The eventual net streamflow loss due to groundwater extraction at 40 GL/year would be 31 GL/year. This represents a potential 'double accounting' error in the separate surface and groundwater assessments supporting water sharing plans.

The total 2004/05 extraction for the remaining GMUs was 35 GL/year. Extraction is less than half of rainfall recharge in all cases, representing low to moderate levels of development.

Water resource development has nearly doubled the average period between high flow events which inundate a large proportion of the Mid Murrumbidgee Wetlands (from 0.4 to nearly 0.8 years), and has more than tripled the maximum period between events (from less than three to nearly ten years). The flooding volume per event has been slightly reduced, however, the change in period between high flow events means that the average annual flooding volume has been nearly halved. These changes are likely to have had serious adverse ecological consequences for these wetlands.

Water resource development more than tripled the average period between high flow events at Maude Weir that flood the Lowbidgee Floodplain (from 0.4 to 1.5 years) and has more than doubled the maximum period between high flow events (from 4 to 10.5 years). Although flood events are now larger on average, the increased period between these events means the average annual flooding volume has been more than halved. It is likely these changes have adversely affected the wetlands of the Lowbidgee Floodplain but the effects are complicated by the high level of artificial manipulation of the water regime to and within this area.

Recent climate and current development (Scenario B)

The average annual rainfall and runoff over the ten-year period 1997 to 2006 are 11 percent and 31 percent lower respectively than the long-term (1895 to 2006) average values.

Under a long-term continuation of the drier recent climate (1997 to 2006) average surface water availability would reduce by 30 percent, diversions would reduce by 18 percent and end-of-system flows would reduce by 46 percent. The relative level of use would increase to 62 percent and 81 percent of general security water would be used.

Under a long-term continuation of the recent climate recharge to the Lower Murrumbidgee Alluvium GMU would be reduced by 6 percent but total recharge would still exceed extraction and water levels would rise. Total recharge to the Mid-Murrumbidgee Alluvium GMU would fall by 20 percent due mainly to longer periods between floods. Net streamflow loss to groundwater would increase to 42 GL/year. The level of development would remain moderate to low for all remaining GMUs.

Under a long-term continuation of the recent climate the average period between high flows to the Mid Murrumbidgee Wetlands would more than double to be nearly two years and the average flooding volume per year would reduce by a further 69 percent to be only 16 percent of the without-development value.

Under a long-term continuation of the recent climate the average period between high flows to the Lowbidgee Floodplain would more than double to be 3.5 years and the maximum period between these events would increase by over 50 percent to be more than 16 years. The average flooding volume per year would reduce by 74 percent to be just 11 percent of the without-development value.

Future climate and current development (Scenario C)

Rainfall-runoff modelling with climate change projections from global climate models indicate that future runoff in the 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. Under the best estimate 2030 climate average annual runoff would be reduced by 9 percent. The extreme estimates (which come from the high global warming scenario) range from a 31 percent reduction to a 13 percent increase in average annual runoff. The result from the low global warming scenario ranges from a 10 percent reduction to a 4 percent increase in average annual runoff.

Under the best estimate 2030 climate average surface water availability would reduce by 9 percent, diversions would reduce by 2 percent and end-of-system flows would reduce by 17 percent. The impacts would differ between water products. General security water use for irrigation would decrease by 7 percent in the Lowbidgee Flood Control and Irrigation District, by 4 percent along the main river and by 2 percent in the Coleambally Irrigation Area. However, irrigation use in the Murrumbidgee Irrigation Area would increase by 1 percent, as would use in the Australian Capital Territory water supply system. New South Wales and Australian Capital Territory urban water demand would be met under this, and the dry or wet extreme 2030 climates.

Under the wet extreme 2030 climate average surface water availability would increase by 13 percent, diversions would increase by 5 percent and end-of-system flows would increase by 20 percent. Under the dry extreme 2030 climate, average surface water availability would reduce by 28 percent, diversions would reduce by 16 percent and end-of-system flows would reduce by 44 percent.

Under the best estimate 2030 climate conditions in the Lower Murrumbidgee Alluvium GMU would lead to a further 7 GL/year impact on streamflow. In the Mid-Murrumbidgee Alluvium GMU, total recharge would fall by 7 percent and net streamflow loss to groundwater would increase to 42 GL/year; however, extraction could be maintained at 40 GL/year with the existing bore distribution. The level of development would remain moderate to low for all remaining GMUs.

Under the best estimate 2030 climate the average period between high flows to the Mid Murrumbidgee Wetlands would be increased by a further 29 percent and the average annual flooding volume would reduce 32 percent. Further degradation of the wetlands would be likely. Under the dry extreme 2030 climate, the average period between high flows would more than double and the average annual flooding volume would reduce by 65 percent. These changes would have serious ecological consequences. Under the wet extreme 2030 climate, the average period between high flows would decrease by 17 percent and the average annual flooding volume would increase by 43 percent. This represents a return towards without-development flow conditions.

Under the best estimate 2030 climate the average period between high flows to the Lowbidgee Floodplain would increase by 16 percent and the average annual flooding volume would reduce by 33 percent. Under the dry extreme 2030 climate, the average period between high flows would nearly double and the average annual flooding volume would reduce by 71 percent. Under the wet extreme 2030 climate, the average period between flood events would decrease by 23 percent and the average annual flooding volume would increase by 41 percent. This would represent a return towards without-development flow conditions.

Future climate and future development (Scenario D)

The area of commercial forestry plantations is projected to increase by 17,000 ha (12 percent) by 2030. This increase would be expected to be concentrated in a small number of subcatchments, and in these subcatchments the impact on runoff would be significant. However, the impact of the projected plantation development on average annual runoff for the entire region would be negligible. Total farm dam storage capacity is projected to increase by 47.6 GL (13 percent) by 2030. The projected increase in farm dams would reduce average annual runoff by about 1 percent. The best estimate of the combined impact of climate change, additional commercial plantation forestry and additional farm dams is a 10 percent reduction in average annual runoff, with extreme estimates (due to the climate change uncertainty) ranging from -32 to +12 percent.

Projected 2030 farm dam development and commercial forestry plantation expansion would reduce inflows by a total of 26 GL/year – 20 GL/year due to additional farm dams and 6 GL/year due to commercial forestry plantation expansion. Additional groundwater extraction in the mid-Murrumbidgee would increase the eventual streamflow leakage induced by groundwater extraction from 31 to 67 GL/year. In total, these future developments would represent an increase in surface water use of 4 percent. This increase in use would reduce surface water diversions and end-of-system flows by 2 percent.

By 2030 total groundwater extraction for the region is projected to reach 496 GL/year, representing 21 percent of total water use on average and 33 percent of total water use in years of lowest surface water diversion. The projected increases are primarily for the Lachlan Fold Belt GMU, with moderate increases in the Mid-Murrumbidgee Alluvium GMU (extraction of 69 GL/year by 2030). These projected increases in groundwater extraction represent what could happen under the current plans and the impacts of such extraction on the resource. This enables appropriate management responses to be implemented. For the Mid-Murrumbidgee Alluvium GMU, this future extraction level could be supported with the existing bore distribution and could reach dynamic equilibrium assuming current streamflow leakage rates continue and assuming flood recharge occurs rapidly post-flooding. However, large groundwater drawdowns across the GMU would result from this level of extraction.

The level of development of all remaining GMUs would remain low to moderate under best estimate climate change conditions. Billabong Creek GMU would move to a high level of development under the dry extreme 2030 climate at either the current or future extraction level; unassessed streamflow recharge could help support extraction from this GMU and effectively reduce the development level to moderate.

The total eventual impact of future groundwater extraction across the region would be a net streamflow loss of 161 GL/year, including nearly 57 GL/year in the Mid-Murrumbidgee Alluvium GMU and nearly 45 GL/year in the lower priority GMUs. These impacts could be higher depending on how the 'cone of depression' associated with groundwater extraction expands and intercepts other recharge sources.

Future additional farm dams, expansion of commercial plantation forestry and growth in groundwater extraction would cause small additional hydrologic impacts on the Mid Murrumbidgee Wetlands and the Lowbidgee Floodplain to those described for the climate change scenarios.

Uncertainty

The runoff estimates for the eastern half of the region, where most of the runoff comes from, are relatively good because there are many gauged catchments from which to estimate the model parameter values. The largest sources 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 in the upstream regions which impact on future flows in the region. Future developments could differ considerably from these projections if governments were to impose different policy controls.

The river modelling reproduces observed streamflow patterns very well and produces estimates that agree well with water balance accounts. The projected changes in flows due to climate change were greater than model noise under the dry scenarios and within model noise for the wet and median scenarios in some cases. River modelling provided strong evidence of changes in flow pattern due to prior development and some evidence that projected impacts of future development may be significant towards the end of the Murrumbidgee River.

The current form of the groundwater model for the Lower Murrumbidgee Alluvium GMU produces results that have a low level of uncertainty. The Mid-Murrumbidgee Alluvium GMU modelling results in a moderate level of uncertainty. Further work on the Lower Murrumbidgee Alluvium model may be needed to include flood recharge and to simulate the without-development scenario with a more realistic recharge estimate. The Mid-Murrumbidgee Alluvium model has been developed for this project and while it has been peer reviewed, further scrutiny and testing will increase confidence in the model. More specifically, the model outputs are dependent on a particular conceptual model of river leakage and a process of flood recharge that needs further investigation.

Both models are unsuitable for use as water allocation tools. This is because local aquifer use rules are not currently implemented and the redistribution of groundwater extraction resulting as pumping bores dry out is not incorporated realistically. The level of analysis of the Lower Murrumbidgee Alluvium GMU matches its priority ranking in the project context. The level of analysis for the Mid-Murrumbidgee Alluvium GMU does not match its priority ranking as the groundwater model would require further testing and development to be appropriate for this level of priority. The two models could have been configured to model an increased level of sustainable extraction but it was not intended to demonstrate upper bounds to possible groundwater extractions in any of the models that have been developed and used. The models that were developed represent the prevailing hydrogeological setting including the existing bore distribution and pumping levels. All groundwater model predictions have a level of uncertainty associated with non-unique calibration.

There is considerable uncertainty in the groundwater development projections in other GMUs but the estimates do show the importance of the GMUs. The projected extractions generally represent upper limits and can be constrained by pumping rules, groundwater quality and land suitability. However, the analysis is conservative because: current entitlements are used to determine stream impacts, subcatchments where streamflow impacts are less than 2 GL/year are ignored, and connectivity estimates are 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).

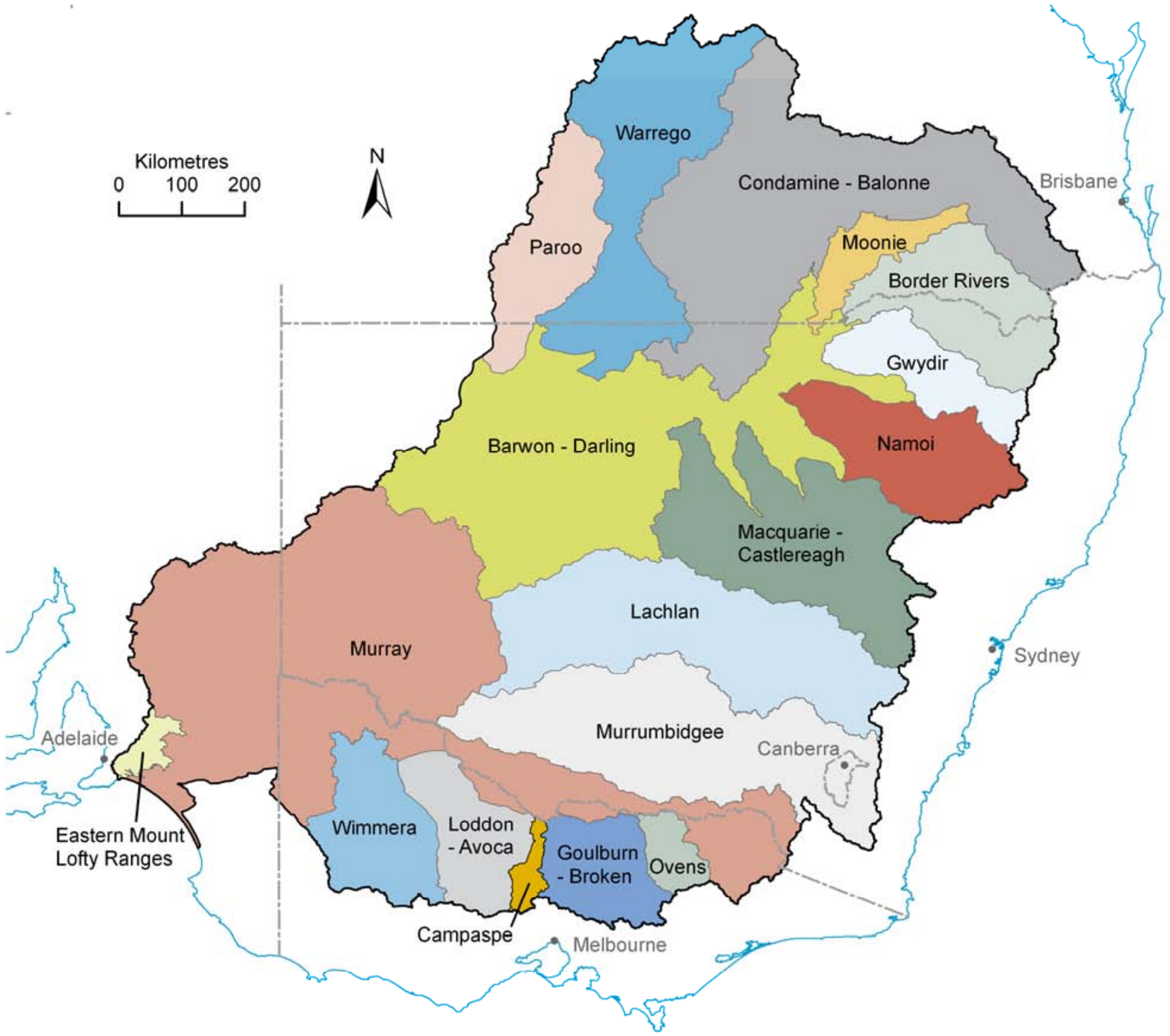

Figure 1-1. Region by region map of the Murray-Darling Basin

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.

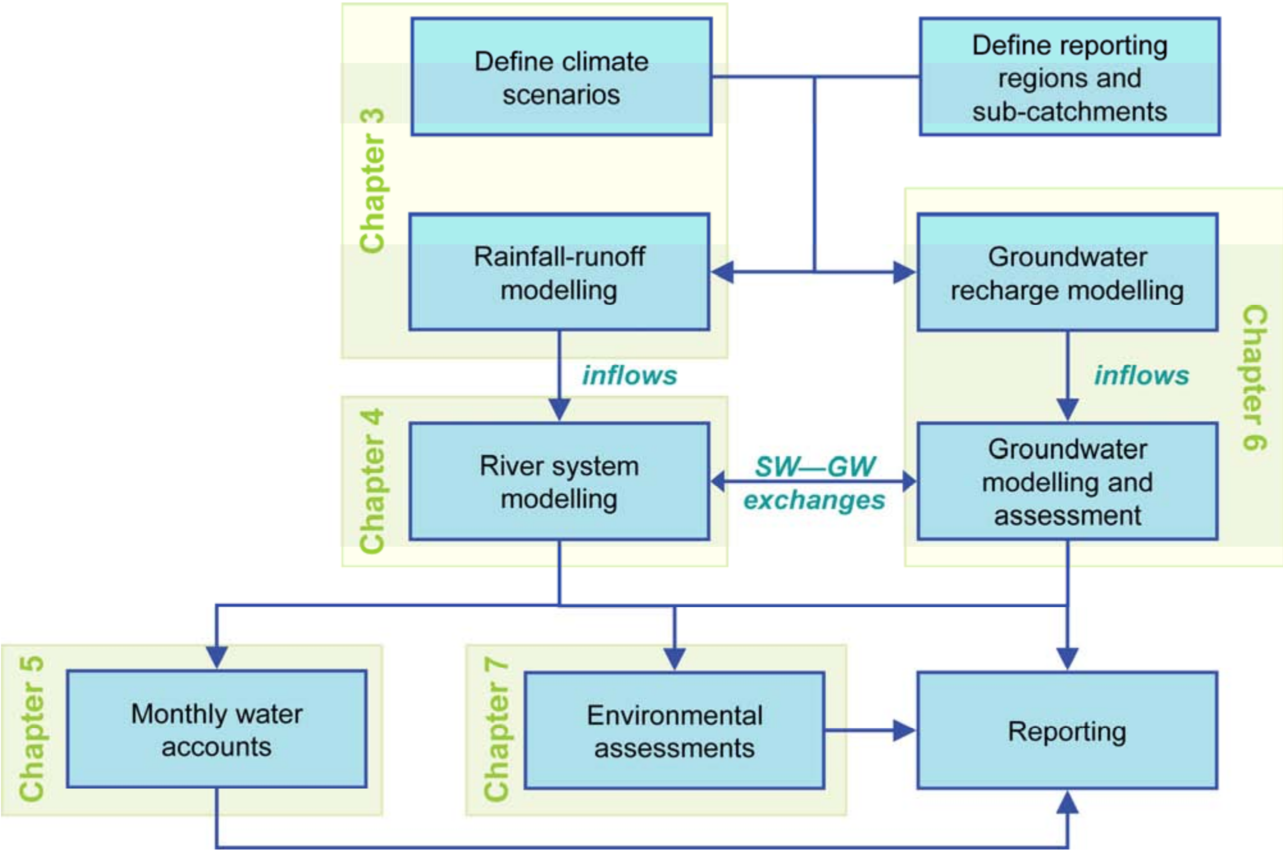

Figure 1-2. Methodological framework for the Murray-Darling Basin Sustainable Yields Project

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 DSE, 2004) and current policy controls (Queensland Government, 2000; NSW Government, 2000; Victorian Government, 1989; South Australian Government, 2004). Data on the current extent of farm dams is taken from the 2007 Geosciences Australia ‘Man-made Hydrology’ GIS coverage (Geosciences Australia, 2007) and from the 2006 VicMap 1:25,000 topographic GIS coverage (VicMap, 2007). The former covers the eastern region of the MDB that falls within Queensland and the northeastern and southern regions of the New South Wales part of the MDB. The latter data covers the entire Victorian portion of the 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.

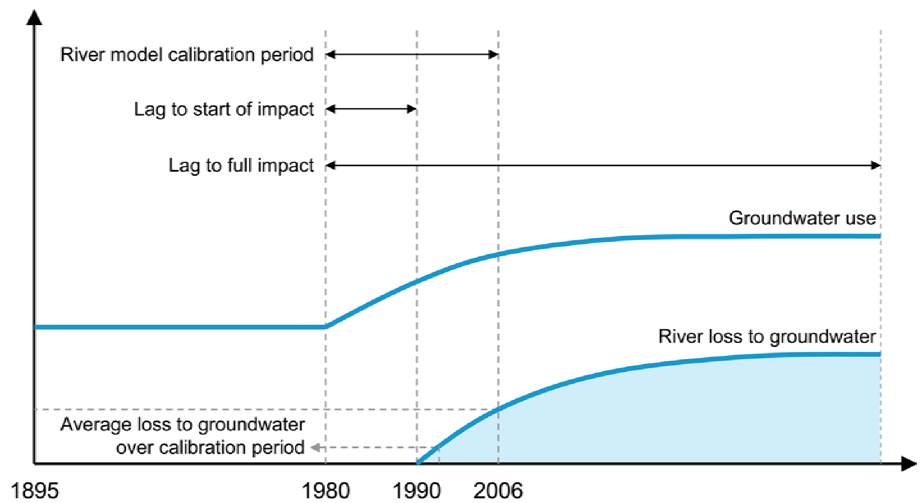

Figure 1-3. Timeline of groundwater use and resultant impact on river

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 (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 Murrumbidgee region is in southern New South Wales and represents 8.2 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the Murrumbidgee River. The population is 500,000 or 27 percent of the MDB total, concentrated in the centres of Canberra, Wagga Wagga, Griffith, Leeton and Hay. The major land use is dryland pasture used for livestock grazing. Dryland cropping is a major enterprise and around 17 percent of the region is covered with native vegetation. Approximately 426,400 ha were irrigated in 2000 for cereals including rice, pasture and hay production. Citrus and grapes are grown within the central areas of the Murrumbidgee Irrigation Area near Griffith and Leeton. The existing area of commercial forestry plantations is 136,000 ha (less than 2 percent of the region). The region includes the Tuckerbil and Fivebough Swamps Ramsar site, the nationally significant Mid Murrumbidgee Wetlands and Lowbidgee Floodplain, and numerous smaller important wetlands.

The region uses over 22 percent of surface water diverted for irrigation and urban use in the MDB and over 24 percent of the groundwater used in the MDB. The rivers of the region are regulated by multiple storages including those of the Snowy Mountains Hydro-electric Scheme, those of the ACT Water Supply System and the major New South Wales irrigation dams of Blowering (on the Tumut River) and Burrinjuck (on the Murrumbidgee River). Most of the groundwater extracted is from the alluvial aquifers in the Mid-Murrumbidgee and Lower Murrumbidgee groundwater management units.

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

2.1 The region

The Murrumbidgee region is located within southern New South Wales and covers 87,348 km^2 or 8.2 percent of the MDB. It is bounded to the east by the Great Dividing Range, to the north by the Lachlan region and to the south and west by the Murray region. The region terminates on the Murrumbidgee River at Balranald Weir, 73 km upstream of the junction with the Murray River. The topography varies from the alpine regions of the Kosciuszko National Park and the Monaro High Plains, through the south-west slopes, to the low-lying plains of the western Riverina.

Major water resources in the region include the Murrumbidgee River and its tributaries; the Snowy Mountains Hydro-electric Scheme and its associated storages; alluvial aquifers; wetlands and water storages. Both private and public infrastructure is associated with the water resources including the storages of the Snowy Mountains Hydro-electric Scheme, the storages of the ACT Water Supply System, the major New South Wales irrigation dams of Blowering (on the Tumut River) and Burrinjuck (on the Murrumbidgee River) and on-farm water storages.

The average annual rainfall for the region is 530 mm varying from around 1500 mm in the east to 300 mm in the west. Rainfall varies considerably between years and is generally fairly uniform throughout the year. 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 is around 11 percent lower than the long-term (1895 to 2006) mean (Figure 2-1).

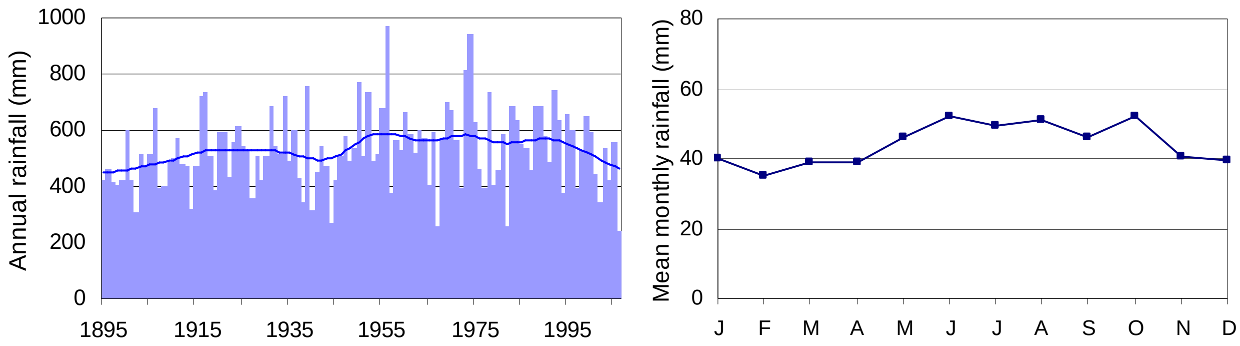

Figure 2-1. 1895–2006 annual and monthly rainfall averaged over the region. The curve on the annual graph shows the low frequency variability

The region contributes 15.7 percent of the total runoff in the MDB, nearly all from the eastern half of the region. The mean annual modelled runoff over the region for the 111-year period is 54 mm and is highest in the winter and early spring. The mean annual modelled runoff over the ten-year period 1997 to 2006 has been 31 percent lower than the long-term mean. The runoff estimates for the eastern half of the region are relatively good because there are many gauged catchments from which to estimate the model parameter values.

The regional population is approximately 500,000 or 27 percent of the MDB total. The larger urban centres include Canberra, Wagga Wagga, Griffith and Leeton. The predominant land use is dryland pasture used for broadacre grazing. Dryland cropping is also a major enterprise and around 17 percent of the region is covered with native vegetation. Approximately 426,400 ha of land were irrigated in 2000. The major enterprises were cereals, including rice, and pastures and hay production. Citrus and grapes are grown within the Murrumbidgee Irrigation Area around Griffith and Leeton. The land use area information (Table 2-1) and land use map (Figure 2-2) are based on the '2000 land use of the MDB grid', derived from 2001 Bureau of Rural Sciences AgCensus data (BRS, 2005). 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 Murrumbidgee region

Land use	Area		
	percent		ha
Dryland crops	15.7%		1,365,000
Dryland pasture	59.7%		5,213,100
Irrigated crops	4.9%		426,400
Cereals		*60.1%*	*256,100*
Cotton		*3.6%*	*15,800*
Horticulture		*3.2%*	*13,600*
Orchards		*3.4%*	*14,400*
Pasture and hay		*26.4%*	*112,400*
Vine fruits		*3.3%*	*14,100*
Native vegetation	16.8%		1,465,200
Plantation forests	1.6%		136,700
Urban	0.7%		65,300
Water	0.6%		56,600
Total	**100.0%**		**8,728,300**

Source: BRS, 2005.

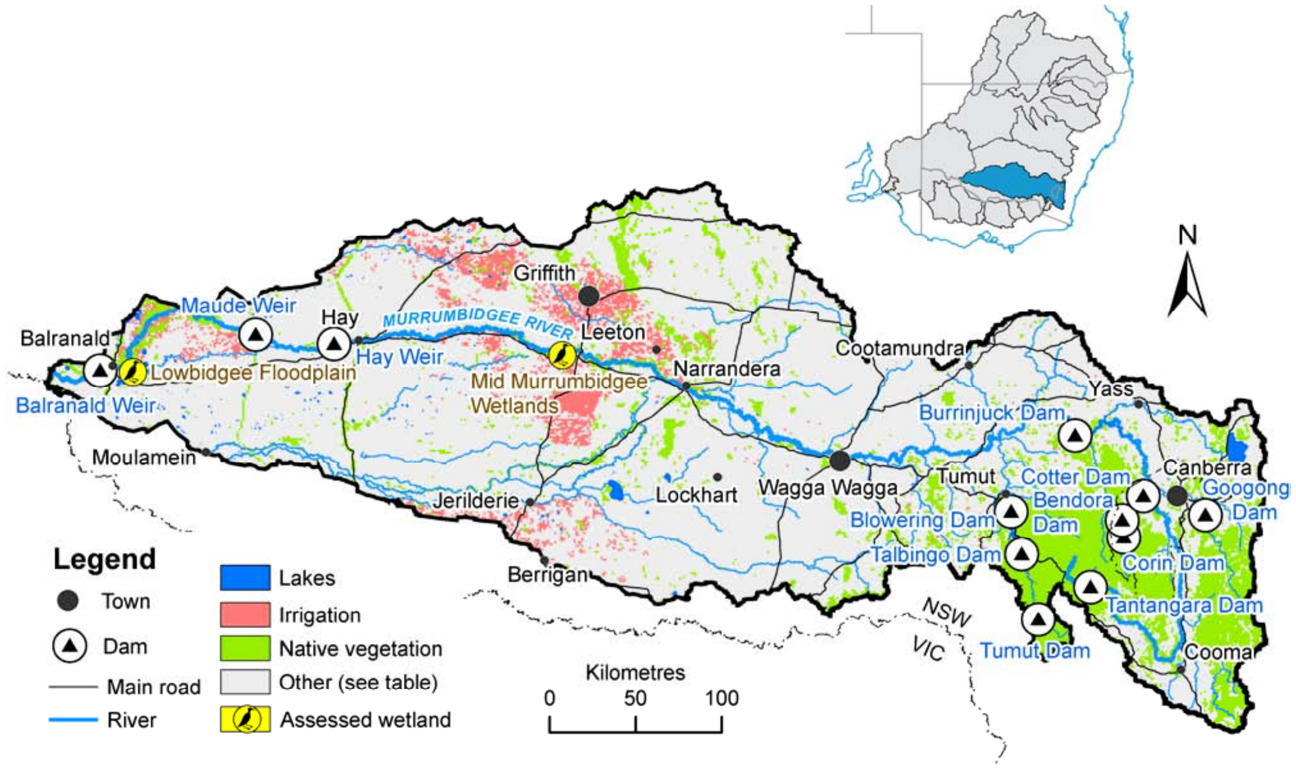

Figure 2-2. Map of dominant land uses of the Murrumbidgee region with inset showing the region's location within the Murray-Darling Basin. The map only shows the environmental assets that are assessed in the project (see Chapter 7) and that fall within the region. A full list of key assets associated with the region is in Table 2-2

The Murrumbidgee Catchment Action Plan (CAP; Murrumbidgee CMA, 2007) is a statutory document prepared under the Catchment Management Authorities Act 2003 (NSW Government, 2003), approved in January 2007 for a term of ten years and administered by the Murrumbidgee Catchment Management Authority (CMA). The CAP directs investment in regional natural resource management (NRM). The Murrumbidgee CMA has identified community, biodiversity, water and land assets as the CAP's focus and assigned targets, actions and ways to monitor progress toward improvement. The CAP encompasses NRM education, planning and partnership development and builds on pre-existing activity including the Murrumbidgee Catchment Blueprint (DLWC, 2003), vegetation management plans and water sharing plans (Murrumbidgee CMA, 2007).

The CAP's water theme covers groundwater and river ecosystems. Its vision is to improve water quality and environmental condition in surface and groundwater systems and wetlands and maintain the economic and social values derived from water use. The theme includes four resource condition targets:

- by 2016 predicted annual average suspended sediment levels within the Murrumbidgee River will be reduced by 15 percent
- by 2016 river salinity at Balranald will be less than: 245 EC for 50 percent of the time and 320 EC for 80 percent of the time
- by 2016 extractions from aquifers are within identified sustainable yields, namely 270 GL for Lower Murrumbidgee Murray Basin and Lachlan Fold Belt groundwater systems to be defined through the macro planning process
- by 2016 the extent, diversity, condition and connectivity of inland aquatic ecosystems is increased.

Catchment management targets are established for each of the resource condition targets (Murrumbidgee CMA, 2007).

The irrigation communities of the Murrumbidgee Irrigation Area and the Coleambally Irrigation Area developed detailed Land and Water Management Plans in the late 1990s (Murrumbidgee CMA, 2006). The initial focus was to undertake works and measures, including landholder education and research and development, to improve water use efficiency and reduce the risk of future watertable rise and salinity. The plans were subsequently expanded to include a stronger focus on the protection and enhancement of the native biodiversity including downstream riparian environments.

Both Murrumbidgee Irrigation Limited and Coleambally Irrigation Cooperative Limited were issued with Environment Protection Licences by the New South Wales Government as part of the corporatisation process undertaken in the late 1990s. Requirements of these licences include the development and implementation of detailed water quality monitoring programs, achievement of implementation targets for on-farm works associated with reuse of farm drainage water, and annual reporting. Each authority produces an annual compliance report and an annual report detailing progress and outcomes related to licence conditions (Murrumbidgee Irrigation, 2007; Coleambally Irrigation, 2008a).

2.2 Environmental description

The region is divided into six bioregions based on the geology, landform, altitude and climate. They are the Australian Alps, the New South Wales South Western Slopes, the South Eastern Highlands, the Cobar Peneplain, the Murray-Darling Depression and the Riverina (NPWS, 2003). The status of the bioregions is shown below. It includes the cleared and conserved percentages for the entire bioregion:

- Australian Alps (3.3 percent cleared, 82.5 percent conserved)
- New South Wales South Western Slopes (85.0 percent cleared, 1.2 percent conserved)
- South Eastern Highlands (58.4 percent cleared, 9.8 percent conserved)
- Cobar Peneplain (32.5 percent cleared, 1.7 percent conserved)
- Murray-Darling Depression (7.7 percent cleared, 3.6 percent conserved)
- Riverina (31.0 percent cleared, 0.4 percent conserved).

It is estimated that over half of the region is cleared completely of native vegetation. The native vegetation classes vary from alpine herb fields, native grasslands, wet forests and woodlands to semi-arid chenopod ‘saltbush’ shrublands and River Red Gum forests. The most widely distributed native vegetation classes are the Box-Gum Woodlands and Grey Box Woodlands. These native vegetation classes were cleared extensively (Murrumbidgee CMA, 2007).

The wetlands within the region that have international and/or national importance are detailed in Table 2-2. The large Mid Murrumbidgee Wetlands and the Lowbidgee Floodplain are both nationally important and the non-riparian Fivebough and Tuckerbil Swamps near Leeton are listed as a Ramsar site. Fivebough Swamp is a permanent, but fluctuating, fresh-brackish, shallow wetland and Tuckerbil Swamp is a seasonal, shallow, brackish-saline wetland. Both swamps are known for the presence, abundance and diversity of recorded waterbirds, including migratory shorebirds and threatened species (Ramsar Convention Secretariat, 2002).

The Mid Murrumbidgee Wetlands are an assemblage of lagoons and billabongs along the Murrumbidgee River from near Narrandera to Carrathool. These wetlands include Bulgari Lagoon, Currawananna Lagoon, McKennas Lagoon and Sunshower Lagoon. The wetlands are on the floodplain and receive flows from the river mostly during winter and spring floods. River Red Gum (*Eucalyptus camaldulensis*) forest and woodlands dominate the vegetation of the Mid Murrumbidgee Wetlands. Black Box (*E. largiflorens*) woodland is more marginal on the floodplain. The lagoons and billabongs have open-water habitat and aquatic plants such as Spike Rush (*Juncus* spp and/or *Eleocharis* spp), Garland Lily (*Calostemma purpureum*) and Blanket Fern (*Pleuosorus rutiflolius*). Many species of waterbird are recorded on the lagoons and billabongs (Briggs et al., 1994). Resident species which are listed as endangered at the state level include the Bush Stone-curlew (*Burhinus grallarius*). There are several species listed as vulnerable including the Freckled Duck *(Stictonetta naevosa)*, Blue-billed Duck *(Oxyura australis)* and Brolga *(Grus rubicundus).* Other notable resident fauna includes the Koala *(Phascolarctus cinereus).*

The Lowbidgee Floodplain is located on the lower Murrumbidgee River downstream of Maude and covers some 200,000 ha. The area contains some of the largest lignum wetlands in New South Wales. The broader Lowbidgee is generally sub-divided into the Nimmie-Pollen-Caira system near Maude Weir and the Redbank-Yanga system further downstream (Kingsford and Thomas, 2001). The floodplain receives floodwaters from the river either from overbank flooding or via controlled diversions from Maude and Redbank weirs (Kingsford and Thomas, 2001). The controlled diversions are surplus to regulated river requirements and tend to occur during the winter and spring months. The Nimmie-Pollen-Caira system also has a large number of water control structures. The vegetation of the Nimmie-Pollen-Caira system includes extensive areas of Lignum (*Muelhlenbeckia florulenta*). The Redbank-Yanga portion is covered River Red Gum (*E. camaldulensis*) forest and woodlands with Black Box (*E. largiflorens*) woodland being more marginal on the floodplain. A wide range of fauna inhabits the wetlands and both portions are used for waterbird breeding.

Kingsford and Thomas (2001) cite major reductions in the incidence and numbers of waterbirds breeding between 1983 and 1999 and give Lignum clearing as the main cause.

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

Site code	Directory of Important Wetlands in Australia name	Area[1]	Ramsar sites
		ha	
ACT001	Cotter Flats	41	none
ACT002	Ginini and Cheyenne Flats	125	yes*
ACT003	Rock Flats	12	none
ACT004	Rotten Swamp	30	none
ACT005	Scabby Range Lake	5	none
ACT006	Snowy Flats	35	none
ACT007	Upper Cotter River	15	none
ACT008	Upper Naas Creek	56	none
ACT009	Bendora Reservoir	81	none
ACT010	Horse Park Wetland	40	none
ACT011	Jerrabomberra Wetlands	174	none
ACT012	Nursery Swamp	53	none
ACT013	Cotter Source Bog	5	none
NSW021	Lowbidgee Floodplain	200,000	none
NSW041	Tomneys Plain	90	none
NSW042	Black Swamp and Coopers Swamp	350	none
NSW047	Lachlan Swamp (part of Mid-Lachlan Wetlands)	6,600	none
NSW050	Lower Mirrool Creek Floodplain	highly variable	none
NSW052	Mid Murrumbidgee Wetlands	varies with flooding	none
NSW054	Tuckerbil Swamp	280	yes**
NSW063	Big Badja Swamp	106	none
NSW064	Coopers Swamp	20	none
NSW067	Lake George	15,000	none
NSW068	Micalong Swamp	526	none
NSW069	Monaro Lakes	up to 215	none
NSW070	Yaouk Swamp	258	none
NSW112	Bethungra Dam Reserve	385	none
NSW113	Doodle Corner Swamp	1,700	none
NSW114	Walla Walla Swamp (Gum Swamp)	200	none
NSW115	Fivebough Swamp	400	yes**
NSW128	Coree Flats	40	none
NSW131	Tomneys Plain	90	none
NSW169	Yarran Swamp	89	none

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

* Ginini Flats Wetland Complex Ramsar site, 343.1 ha.

** Fivebough and Tuckerbil Swamps Ramsar site, 689 ha.

Source: A Directory of Important Wetlands in Australia (Environment Australia, 2001).

2.3 Surface water resources

2.3.1 Rivers and storages

The Murrumbidgee River flows south-eastwards to Cooma from its headwaters in the Snowy Mountains south-west of Canberra. From there, it flows northwards to Yass and then westwards until it joins the Murray River upstream of Euston in south-western New South Wales. The Tumut River is a major tributary that rises in the Snowy Mountains near Cabramurra.

The rivers of the region are greatly affected by the dams of the Snowy Mountains Hydro-electric Scheme, including Tantangara on the Upper Murrumbidgee River, Talbingo and several other storages (Tumut Pond, Tumut 2, Happy Jacks and Jounama) on the Tumut River. The Scheme is required to release 1026 GL into the Murrumbidgee River system annually, subject to its water storage levels and water savings diverted to the Snowy River. The upper Murrumbidgee River flows are reduced due to the presence of Tantangara Dam, but flows in the Tumut River are greatly augmented by releases from the Snowy Mountains Hydro-electric Scheme. The net flow increase to the Murrumbidgee region from the Scheme is 485 GL/year on average (measured at Wagga Wagga; see Chapter 4), with the remainder of the Scheme releases to the region essentially representing natural Murrumbidgee inflows captured and rereleased by the Scheme.

The major irrigation dams are Burrinjuck on the Murrumbidgee River near Yass (constructed in 1928 and enlarged in 1957) with a storage capacity of 1026 GL and Blowering on the Tumut River upstream of Tumut (constructed in 1968) with a storage capacity of 1631 GL. Other tributary streams within the region include the Goodradigbee, Yass and Queanbeyan rivers that flow into the upper Murrumbidgee River and Tarcutta and Adelong creeks that flow into the mid-Murrumbidgee River downstream of Blowering and Burrinjuck dams.

The Australian Capital Territory draws its water from two separate catchment systems. The Cotter River catchment was the first to be developed and involved the construction of three dams on the Cotter River: Cotter, Bendora and Corin dams. Cotter Dam was built in 1912 and increased in height in 1951 and has a storage capacity of 3.9 GL. Bendora Dam was constructed in 1961 (upstream of Cotter Dam) and has a storage capacity of 11.5 GL. Corin Dam was completed in 1968, with a storage capacity of 70.9 GL, and is used to control the level of storage in Bendora Dam. Googong Dam was constructed in 1979 on the Queanbeyan River after population projections indicated that the Cotter River system would not meet the future water requirements of Canberra Googong Dam has a total storage capacity of 121 GL. The volume of farm dam storage within the region is estimated to be 351 GL (Geosciences Australia, 2007).

2.3.2 Surface water management institutional arrangements

The Water Management Act 2000 (NSW Government, 2000) stipulates implementation of ten-year water sharing plans (WSPs) that define 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 are not gazetted.

The water sharing arrangements are contained in the Murrumbidgee Regulated River WSP (DIPNR, 2004a) and the Tarcutta Creek Water Source WSP (DIPNR, 2004c). The Murrumbidgee Regulated River WSP applies to the banks of all rivers from the upper limit of Burrinjuck Dam water storage and Blowering Dam water storage downstream to the junction of the Murrumbidgee River and the Murray River. The plan also covers the Yanco/Billabong Creek system from the off-take of Yanco Creek from the Murrumbidgee to the junction of the Billabong Creek with the Edward River. The Lowbidgee Flood Control and Irrigation District is not included but the plan includes rules regarding when flows may be diverted from the Murrumbidgee into the district (DIPNR, 2004a).

The long-term modelled Murray-Darling Basin Ministerial Council Cap on surface water diversions is 2341 GL for the Murrumbidgee River in New South Wales. There is no Cap in the Australian Capital Territory but there is a notional limit on diversions of 38 GL/year. The average annual net diversions for the period 1989 to 2006 is 31 GL (MDBC, 2007c).

The Adelong Creek Water Source is an unregulated stream and one of the tributaries of the Murrumbidgee River. A WSP applies to Adelong Creek and its tributaries excluding Hindmarsh Creek, to the junction with the Murrumbidgee River, including all lakes and wetlands within the water source (DIPNR, 2004b). The Tarcutta Creek Water Source is an unregulated stream and one of the major tributaries of the Murrumbidgee River. A WSP applies to Tarcutta Creek and its tributary, the Umbango Creek to the junction with the Murrumbidgee River (DIPNR, 2004c). The water sharing arrangements for the region are detailed in Table 2-3.

Table 2-3. Summary of surface water sharing arrangements

Water Source Plan		Murrumbidgee Water Sharing Plan	Adelong Creek Water Source	Tarcutta Creek Water Source
Water products	Priority of access	Allocated entitlement		
		ML/y		
Basic rights				
Stock and domestic rights		4,560	3.63 ML/day	4.4 ML/day
Native title		none	0	0
Extraction shares				
Total licensed (long-term) extraction limit		1,925,000	Not specified	Not specified
Local water utilities	high	23,403		
High security access	high	298,021 unit shares		
General security access	medium	2,043,432 unit shares	4060	4945
Supplementary access	low	220,000 unit shares		
Conveyance - Murrumbidgee irrigation	high	243,000 unit shares		
Conveyance - Coleambally irrigation	high	130,000 unit shares		
Stock and domestic	high	35,572	1.13	[3]0.85
Environmental provisions			[5]	[4]
Total environmental share		[1]1,078,000		
Environmental allocation	high	[2]up to 50,000**		

Source: assorted water sharing plans (DIPNR, 2004a–c).

[1] At the time of gazettal, by limiting long-term average annual extractions to an estimated 1,925,000 ML/year this plan ensures that approximately 56 percent of the long-term average annual flow in this water source (estimated to be 4,360,000 ML/year) will be preserved and will contribute to the maintenance of basic ecosystem health. At the time of gazettal, it is estimated that long-term extractions after the 5^{th} year of this plan will be limited to around 1,890,000 ML/year. By doing this, this plan will ensure that approximately 57 percent of the long-term average annual flow in this water source will be preserved and contribute to the maintenance of basic ecosystem health.

[2] The total environmental provisions include reserving all water above the annual extraction limit for the environment, protecting low flows in the upper reaches including a release of 560 ML/day from Blowering Dam and transparent and translucent releases from Burrinjuck Dam, providing winter flow variability, provision of environmental water allowances and protecting end-of-system flows with a release of between 200 and 300 ML/day from Balranald weir for the first four years of the plan and increased flows thereafter.

[3] This includes licensed stock and domestic, local water utility and Aboriginal cultural access.

[4] The environmental flow provision for Tarcutta Creek WSP 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. A cease to pump provision also exists during periods of low flow.

[5] The environmental flow provision for Adelong Creek WSP 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. A cease to pump provision also exists during periods of low flow.

Water is managed under different arrangements in the Australian Capital Territory. Australian Capital Territory controlled water resources amount to approximately 490 GL in terms of average annual flows. This includes water that runs off catchments within the Australian Capital Territory and the waters of the Queanbeyan River which enter the Googong Dam in New South Wales. The Water Resources Act 2007 (ACT Government, 2007) requires provision for the environment prior to the consideration of extractive use. Through the Australian Capital Territory Environmental Flow Guidelines, about 270 GL is dedicated to environmental flows, leaving a potential harvestable resource of about 220 GL.

Water sharing arrangements are set out in the Australian Capital Territory strategy for sustainable water resource management. The strategy aims to improve water use efficiency, reduce water quality impacts, enhance ecological values in waterways and protect recreational and amenity value. The strategy takes a catchment perspective, and focuses on the integration of stormwater, water supply and wastewater elements to address the challenges, objectives and targets. (Environment ACT, 2004).

2.3.3 Water products and use

A range of crops are grown under irrigation including rice, winter cereal grains, grapes, citrus, pasture, lucerne and cotton. Major irrigation development dates from the early 1900s around Yanco and Mirrool. The construction of Burrinjuck Dam in 1928 and its subsequent expansion in 1957 and construction of Blowering Dam in 1968 led to further irrigation development. The main irrigation areas are the Murrumbidgee, Coleambally and Lowbidgee irrigation areas.

The Murrumbidgee Irrigation Area, located between Leeton and Griffith, covers around 160,000 ha of intensive irrigation and 3320 landholdings (Murrumbidgee Irrigation, 2007). Water is diverted from the Murrumbidgee River at Berembed Weir upstream of Narrandera and Gogeldrie Weir near Leeton. Flows continue through a network of supply channels to each farm where it is measured onto the property. Runoff water from the irrigated area is drained to the Mirrool Creek and Barren Box storage then diverted to the Wah Wah irrigation district for use as irrigation water.

The Coleambally Irrigation Area was established between 1958 and 1970 when the then Water Conservation and Irrigation Commission resumed a number of large pastoral holdings to make use of water from the Snowy Mountains Hydro-electric Scheme. Water is supplied via the Murrumbidgee River from the Gogeldrie Weir through the 41 km main canal and 477 km of supply channels. There is a further 734 km of drainage channels into Billabong and Yanco creeks where the drainage and system losses are used for stock and domestic and irrigation purposes on an ‘opportunistic basis’.

The Coleambally Irrigation Area covers some 79,000 ha of intensive irrigation and 42,000 ha of larger less intensively irrigated farms. There is an area of 297,000 ha referred to as the Outfall District that accesses water from the Coleambally drainage channels. Coleambally Irrigation delivers water to 473 farms owned by 364 businesses. Coleambally Irrigation has a number of access licences with a total volume of 629 GL of water. Irrigation water is used for crops such as rice, wheat, barley, oats, canola, soybeans, maize, sunflowers, lucerne, grapes, prunes and pastures for sheep and cattle (Coleambally Irrigation, 2008b).

Along the length of the Murrumbidgee River and its tributaries there are many individual irrigation farms that pump river water directly and up to 100,000 ha is irrigated producing a range of winter and summer fodder, grain and horticultural products. This includes irrigation along the Yanco, Columbo and Billabong creeks using water supplies from the Murrumbidgee River and from the Coleambally Irrigation Area (NSW Agriculture, 2003).

Surface water diversions within the region, including the Lowbidgee, have declined substantially from a peak of around 3000 GL in the mid-1990s to around 1600 GL in 2004/05 (Figure 2-3). This decline is a result of the drought. The majority of the water entitlements held within the Murrumbidgee valley are general security entitlements. Priority is given to high security entitlements primarily used for horticultural and grape production. Annual water availability has a significant influence on the volume of water used for annual summer and winter crop production. Water is actively traded both within the region and with the Murray region, particularly in years when the Murray River allocations are relatively low.

There is 200 GL diverted annually from the upper Murrumbidgee at Tantangara. The net diversions to Canberra rose steadily to a peak of about 44 GL in 1997/98. Currently, average demand on the urban water supply network is 63 GL and total use outside of the urban water supply network, including groundwater, is estimated to be 5 GL per annum. This does not include use under Commonwealth control such as pumping from Lake Burley Griffin. An average of about 35 GL is returned to the Molonglo River as treated effluent from the Lower Molonglo Water Quality Control Centre and Queanbeyan Sewage Treatment Works.

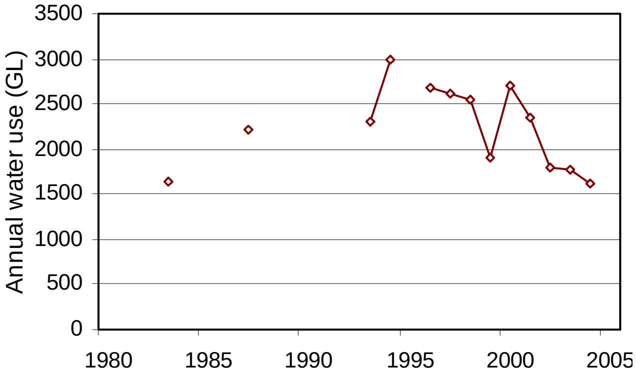

Figure 2-3. Historical surface water diversions

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: 1983/84, 1987/88 (AWRC 1987); 1993/94 (MDBMC, 1995); 1994/95–2004/05 (MDBC, 2007a).

2.4 Groundwater

2.4.1 Groundwater management units – the hydrogeology and connectivity

The region is subdivided into seven groundwater management units (GMUs) for management purposes (Figure 2-4). Three out of the seven GMUs are completely contained in the region and four GMUs overlap from surrounding regions. Also shown on the map are the Upper Murray Alluvium GMU (N15) and the Lower Murray Alluvium (Calivil/Renmark) GMU (N16) which are assessed in the Murray region, and the Lower Lachlan Alluvium GMU (N12) which is assessed in the Lachlan region.

Current groundwater extraction, entitlement and recharge is itemised for each GMU in Table 2-4. All data is sourced from a summary of macro groundwater plans provided by New South Wales Department of Water and Energy unless otherwise cited.

The Lower Murrumbidgee Alluvium and the Mid-Murrumbidgee Alluvium GMUs are categorised as very high and high priority, respectively. They are subject to detailed analysis using numerical groundwater modelling techniques (Chapter 6). The remaining GMUs are categorised as low or very low priority. All 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.

The basal aquifer under the Riverine Plains is the Renmark Group that comprises alluvial sands, gravels, black clay and peat. It is connected to the overlying Calivil Formation and is highly productive in this area if the groundwater salinity is suitable for irrigation. Renmark Group groundwater levels in the Lower Murrumbidgee Alluvium GMU steadily declined between 1979 and 1995. Since 1996 groundwater levels declined more rapidly falling 12 m over ten years. Outside the main pumping and irrigation areas, groundwater levels in the Renmark Group rose until 1995 and have since stabilised. This is likely due to the effects of pumping in nearby areas.

The Calivil Formation was deposited within an ancient drainage system during the Late Miocene and Pliocene eras. It is composed of coarse alluvial channel sands and gravels. The Calivil Formation, especially in the eastern portions of the Lower Murrumbidgee Alluvium GMU, is an extremely productive aquifer containing low salinity groundwater that can be extracted from high yielding bores. Groundwater levels in the pumped areas of the Calivil Formation have declined with seasonal fluctuations of between 5 to 20 m. Groundwater levels are rising (probably as a result of river regulation) beyond the pumping areas.

The Shepparton Formation is composed of river and lake deposits of variegated clay and lenses of yellow and brown shoestring sands deposited across the Riverine Plains. It displays low yields, generally high salinity levels and contains the watertable. All streams run across the top of the Shepparton Formation in the west on the Riverine Plain. The streams hydraulically connect to the watertable at the eastern margin of the plain. The watertable falls well below the streams towards the west where an unsaturated zone develops and causes constant leakage from flowing stream to the underlying aquifer. Other recharge mechanisms here include overbank flooding and infiltration from rainfall. The watertable is close to ground level in the far west and groundwater may discharge. There are no coordinated surface drainage systems in this area so most discharging groundwater would be lost via evapotranspiration. Shepparton Formation groundwater levels have risen by 2 m over 20 years in response to irrigation development. Groundwater level declines are evident in areas where groundwater is extracted from the Shepparton Formation.

In the middle of the region, the basal Lachlan Formation is overlain by the Cowra Formation. The Lachlan Formation contains the major groundwater resource in the area 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 supply water to urban communities including Wagga and irrigators. The Lachlan Formation is covered by the Mid-Murrumbidgee Alluvium (N13), Billabong Creek Alluvium (N14), and Upper Murray Alluvium (N15) GMUs. Groundwater salinity in the Lachlan Formation is very low. Cowra Formation groundwater salinity is higher than the underlying Lachlan Formation. Groundwater levels declined by 3 m over ten years as a result of pumping in the Lachlan Formation of the Mid-Murrumbidgee Alluvium (N13). Groundwater levels have risen in the order of 5 to 10 m over a ten-year period within the Lachlan Formation in the broad alluvial valleys of the highlands. This is caused by surface water application in irrigated areas and river regulation. Groundwater levels in the highland Cowra Formation rise in response to flood generated recharge. The Murrumbidgee River and the Cowra Formation are highly connected in the middle sections of the valley, between Cowra and Hillston.

There is a smaller level of groundwater development within the highland areas of the catchment. Recharge to the fractured rock systems 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 hydrogeology In the upland reaches is dominated by fractured rock aquifers in a range of different geologies including Palaeozoic granites, volcanics and consolidated sediments (Lachlan Fold Belt (N811) and Australian Capital Territory (A1) GMUs). Groundwater in the fractured rock aquifers is relatively fresh in the higher rainfall eastern areas and more saline further west in the lower rainfall areas. Groundwater yields are about 1 to 2 L/sec. The Young Granites GMU (N802) has a deep layer of crumbly granite that will transmit water whereas its unweathered granites are fractured. The weathered granites generally contain more saline water and the unweathered granites hold relatively fresher water but both vary in salinity according to rainfall.

Groundwater levels in the fractured rock aquifers of the 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.

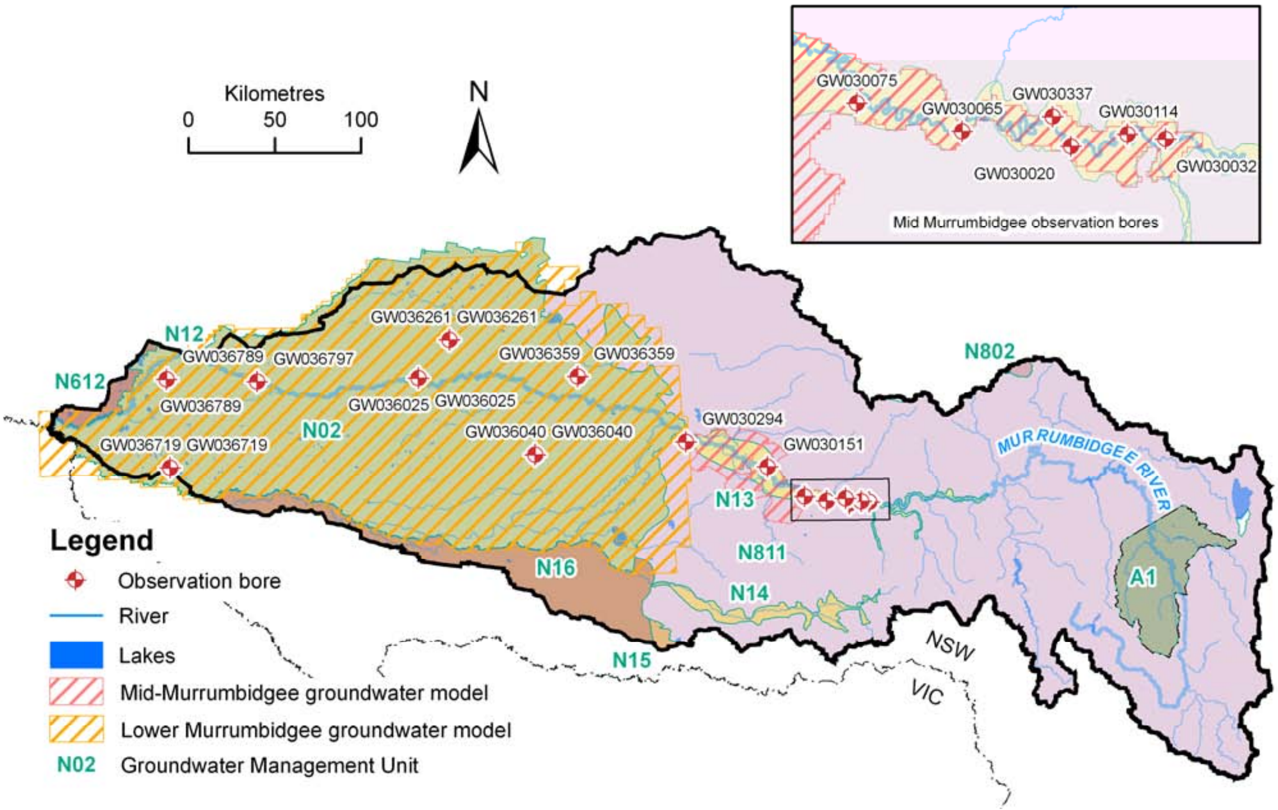

Figure 2-4. Map of groundwater management units within the Murrumbidgee region showing key observation bores, with inset showing the observation bores within the Mid-Murrumbidgee Alluvium GMU

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

Code	Name	Priority	Assessment	Entitlement	Current extraction[1] (2004/05)	Long-term average extraction limit	Recharge[2]
					GL/y		
N02	Lower Murrumbidgee Alluvium (d/s of Narrandera)	very high	thorough	280.0	323.8	[3]280.0	[3]400.0 (plus basic landholder rights)
N13	Mid-Murrumbidgee Alluvium (u/s of Narrandera)	high	thorough	80.1	48.2	8.5	12.1
N14	Billabong Creek Alluvium (u/s of Mahonga)	low	simple	7.2	5.7	7.4	12.3
N612	Western Murray Porous Rock	very low	minimal	0.1	0.1	5.6	7.9
N802	Young Granite	low	simple	1.1	0.7	1.4	2.3
N811	Lachlan Fold Belt	low	simple	37.8	27.5	541.9	1086.7
A1	ACT	very low	minimal	1.0	0.5	7.0	78.9

(1) 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.
(2) This value incorporates all sources of recharge in water sharing plan areas but represents only rainfall recharge in macro plan areas. Where indicated the recharge volume does not include the amount of groundwater available for basic rights, which is an additional volume. The volume of recharge does not include recharge to national park areas, which has generally been allocated to environmental purposes and is not available for consumptive use.
(3) Source: DIPNR, 2006.

2.4.2 Water management institutional arrangements

The New South Wales Water Management Act 2000 (NSW Government, 2000) stipulates implementation of ten-year plans that define water sharing arrangements in a similar way to that required for surface water diversions. Water sharing plans (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.

A supplementary access licence covers areas where current extraction levels exceed the long-term average extraction limit (LTAEL). This licence will decrease to zero within ten years of commencement of the WSP. Groundwater extraction is controlled by macro water sharing plans (Macro WSPs) away from areas covered by WSPs. These provide a groundwater extraction limit and environmental provisions. Groundwater extraction records for the Macro WSP regions are generally poor. The Macro WSPs are planned to commence in 2009.

The WSP for the Lower Murrumbidgee Groundwater Sources was first gazetted in 2003. The current amended version of the plan was enacted in 2006 (DIPNR, 2006). It applies to all water contained in the unconsolidated alluvial aquifers of the Shepparton and Calivil formations and the Renmark Group. The estimated volume of recharge to these aquifers is 65 GL/year (plus the allowance for basic landholder rights) for the Shepparton Formation and 335 GL/year (plus the allowance for basic landholder rights) for the Calivil Formation and the Renmark Group combined. The Shepparton Formation recharge is the net recharge resulting from inflow of 400 GL/year minus 335 GL/year that passes through to the underlying Calivil Formation and the Renmark Group. The WSP allows for access licences consisting of 3332 unit shares (equivalent to 3.33 GL/year) for the Shepparton Formation and 267,500 unit shares (equivalent to 267.50 GL/year) for the combined Calivil Formation and Renmark Group. The WSP will reduce groundwater extraction to the LTAEL of 280 GL/year. Annual water use exceeded the WSP limit at the commencement of the plan. The volume of the supplementary access licences was set at a total of 39,800 unit shares (equivalent to 39.80 GL/year) at the commencement of the plan and is being reduced annually to a final share of zero GL/year by 2015. An environmental provision equal to 55 GL/year for the Shepparton Formation and 65 GL/year for the combined Calivil Formation and Renmark Group is provided. A domestic and stock entitlement of 4.33 GL/year has been set composed of an estimated 3 GL/year for the Shepparton Formation, an estimated 1 GL/year of licensed extraction and a licensed stock and domestic volume of 0.3 GL/year for the Calivil Formation and Renmark Group combined.

Groundwater extraction in the Australian Capital Territory is controlled by the Water Resources Act (ACT Government, 2007) and is limited within the Act to ensure that extraction does not impact on aquatic ecosystems via changes to the baseflow character of streamflow. The Australian Capital Territory (and some surrounding parts of New South Wales) is subdivided into 14 water management areas and each area has a groundwater extraction limit equal to 10 percent of recharge. The groundwater sharing arrangements for the region are detailed in Table 2-5.

Table 2-5. Summary of groundwater management plans

Description	Lower Murrumbidgee Alluvium	Remaining GMUs
Name of plan	Water Sharing Plan for the Lower Murrumbidgee Groundwater Sources 2003	Groundwater Macro Sharing Plans
Year of plan	2003	*
Environmental provisions		
Planned share	120 GL/y for the environment	30–50% of rainfall recharge
Adaptive provisions	Left or taken as required on an access licence	None as yet
Basic rights		
Domestic and stock rights	4.33 GL/y	28.3 GL/y
Native title	0 GL/y	None identified
Access licences		
Urban	2.21 GL/y	27.97 GL/y
Planned share	270.83 GL/y	73.00 GL/y
Supplementary	39.8 GL/y (reducing to 0 GL/y by year ten of the plan)	-
Announced allocation	Planned share + supplementary	none

*New South Wales DWE advise that the macro groundwater sharing plans are proposed to commence in 2009.

2.4.3 Water products and use

Groundwater extraction within the region accounts for 24.4 percent (406.9 GL/year) of the total groundwater use throughout the MDB. There are 9041 users but the vast majority of licences are for stock and domestic purposes. Groundwater extraction is largely confined to alluvial deposits and to fractured granites and sedimentary rocks. A high proportion of the use occurs in the Lower and Mid-Murrumbidgee alluvia. Groundwater extraction bores are distributed relatively widely outside of these areas. These are largely constructed in consolidated and fractured rock aquifers with poorer water quality and yields.

Significant groundwater development in the Lower Murrumbidgee Alluvium GMU began in the late 1970s. Records indicate that groundwater extraction grew strongly from the 1970s and that a rapid increase in the mid- to late 1990s followed the early 1990s drought. Current (2004/05) extraction is 324 GL/year (MDBC, 2007b). Groundwater extraction in the Mid-Murrumbidgee in 2004/05 was estimated at 48 GL/year to supply irrigation, stock, domestic and town water supplies. The Lower Murrumbidgee Alluvium GMU is the most developed GMU in the region and has been studied and managed over a long period. The Mid-Murrumbidgee Alluvium GMU developed to a lower degree. Historical annual groundwater extraction is shown in Figure 2-5. Very little information exists for the region's other GMUs. The major use of groundwater in low priority areas is for stock and domestic supplies.

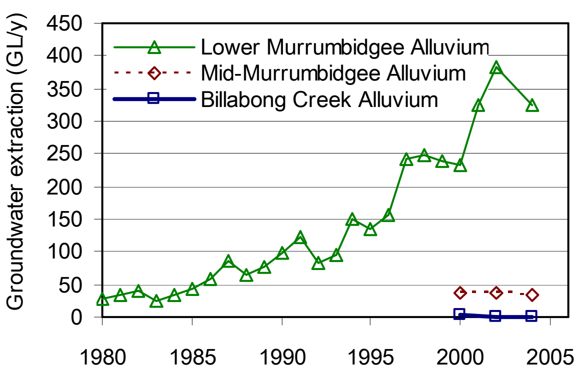

Figure 2-5. Historical groundwater extractions

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3 Rainfall-runoff modelling

This chapter includes information on the climate and rainfall-runoff modelling for the Murrumbidgee 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 Murrumbidgee region.

3.1.2 Key messages

- The annual rainfall and modelled runoff averaged over the Murrumbidgee region are 530 mm and 54 mm, respectively. Rainfall is fairly uniform throughout the year and runoff is highest in winter and early spring. The region covers 8.2 percent of the MDB and contributes 15.7 percent of the total runoff.
- The average annual rainfall and runoff over the ten-year period 1997 to 2006 are lower than the long-term (1895 to 2006) average values by 11 percent and 31 percent respectively. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 mean values at a significance level of $\alpha = 0.2$. The 1997 to 2006 runoff is statistically different to the 1895 to 1996 mean values at a significance level of $\alpha = 0.1$.
- Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the region is more likely to decrease than increase – two-thirds of the modelling results show a decrease in runoff. Under the best estimate (median) 2030 climate, average annual runoff would be reduced by 9 percent. The extreme estimates (which come from the high global warming scenario) range from a 31 percent reduction to a 13 percent increase in average annual runoff. The results from the low global warming scenario range from a 10 percent reduction to a 4 percent increase in average annual runoff.
- The area of commercial forestry plantations is projected to increase by 17,000 ha (12 percent) by 2030. This increase would be expected to be concentrated in a small number of subcatchments, and in these subcatchments the impact on runoff would be significant. However, the impact of this development on average annual runoff for the entire region would be negligible. Farm dam storage capacity is projected to increase by 47.6 GL (13 percent) by 2030. This increase in farm dams would reduce average annual runoff by about 1 percent. The best estimate of the combined impact of climate change, additional commercial plantation forestry and additional farm dams is a 10 percent reduction in average annual runoff, with extreme estimates (due to the climate change uncertainty) ranging from -32 to +12 percent.

3.1.3 Uncertainty

- Scenario A – historical climate and current development
  The runoff estimates for the eastern half of the region, where most of the runoff comes from, are relatively good because there are many gauged catchments 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 B – recent climate and current development
  Scenario B was modelled because the 1997 to 2006 rainfall and runoff are significantly different to the (1895 to 2006) long-term averages. There is large uncertainty in the Scenario B results because it is based on only ten years of data. The rainfall-runoff modelling uses 100 stochastic replicates of climate inputs based on 1997 to 2006 climate. Scenario B is defined as the replicate that produced the 1997 to 2006 mean annual runoff. This is used to obtain the catchment inflows for the river system modelling.
- 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 developments and the impact of these developments on runoff. The Bureau of Rural Sciences projections (BRS, 2005) of plantations growth are used here. There is uncertainty in the actual location of future commercial forestry plantations and only a simple method has been used in this project to assign future plantations to individual subcatchments. The increase in farm dams is estimated by considering trends in historical farm dam growth and current policy controls in New South Wales. There is uncertainty both as to how landholders will respond to existing and new 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, has relatively few parameters and provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire MDB and assessing the potential impacts of climate change and development on future runoff. Specific calibration of SIMHYD or more complex rainfall-runoff models in data-rich areas based on expert judgement and local knowledge (as done 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 Murrumbidgee region

The rainfall-runoff modelling estimates runoff in 0.05° grid cells in 59 subcatchments as defined for the river system modelling in Chapter 4 (Figure 3-1).

Fifty-eight of these subcatchments are in the eastern half of the Murrumbidgee. One subcatchment represents the entire western half of the region. Optimised parameter values from 29 calibration catchments are used to model runoff in the Murrumbidgee. All of the calibration catchments are in the eastern half of the region.

The Bureau of Rural Sciences (Parsons, pers. comm., 2007) projections that take into account industry information were used for the commercial forestry plantations impact modelling. The projections estimate an increase in commercial forestry plantations of 17,000 ha in the region by ~2030 relative to ~2005. This represents a 12 percent increase in the area of plantation forestry based on the 2000 land use data reported in Chapter 2. The projected or virtual plantation area (17,000 ha) was assigned to particular 0.05° modelling grid cells. The grid cells were sorted by the mean biomass productivity (estimated using the PROMOD model (Battaglia and Sands, 1997)). The plantations were added then to the non-woody area of successive cells until the total virtual plantation area was reached (Appendix A). Plantations were not assigned to areas where the land use was classified as 'natural forest'.

The farm dam projection is dependent on three factors: current farm dam storage volume, growth rate of farm dams, and maximum harvestable right volumes in New South Wales (NSW Government, 2000). The current farm dam storage volume is estimated from the 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. A growth rate of 0.6 percent per year is used for New South Wales. The maximum harvestable right volume is estimated by multiplying the area of each land parcel by the 'dam capacity per unit area multiplier' for that property (NSW Government, 2006) and then aggregating the values for all of the individual properties. The maximum harvestable right volume across rural land in the region is about 375 GL. The estimate of current farm dam storage volume is about 350 GL utilising about 135 GL of the harvestable right volume. Farm dams capture more than the maximum harvestable right volume as defined by the Water Management Act. The available harvestable right volume is therefore about 240 GL.

The projected increases for each subcatchment are given in Appendix A. The total increase in farm dam storage volume by ~2030 is 47.6 GL or 13 percent of the existing total volume.

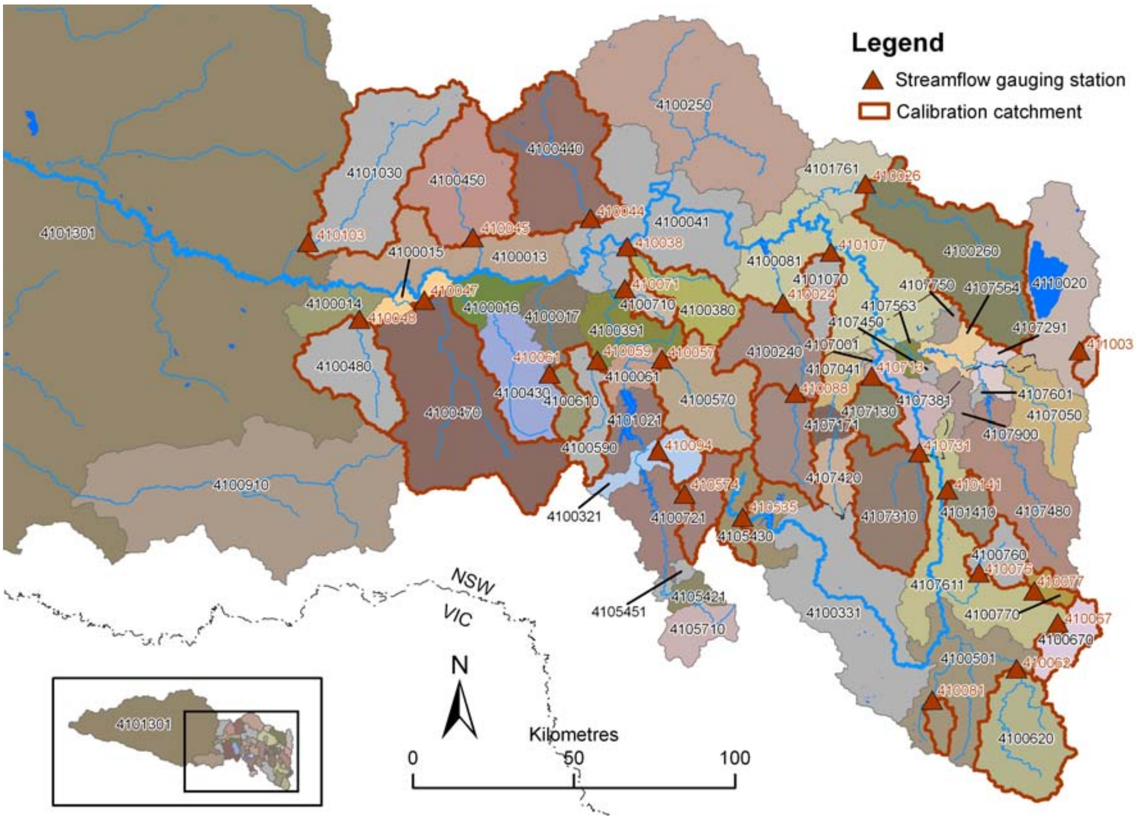

Figure 3-1. Map of the modelling subcatchments and calibration catchments

3.2.3 Model calibration

Figure 3-2 compares the modelled and observed monthly runoff and daily flow duration curves for the 29 calibration catchments. The SIMHYD calibration can satisfactorily reproduce the observed monthly runoff series (Nash-Sutcliffe efficiency values generally greater than 0.75) and the daily flow duration characteristic (Nash-Sutcliffe efficiency values generally greater than 0.85). 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 efficiency means that more importance is placed on the simulation of high runoff. Therefore SIMHYD modelling of medium and high runoff is 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 as shown in the scatter plots comparing the modelled and observed monthly runoff and the daily flow duration curves (Figure 3-2). The disagreement between the modelled and observed daily runoff characteristics is only 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 half of the region, where most of the runoff occurs, 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.

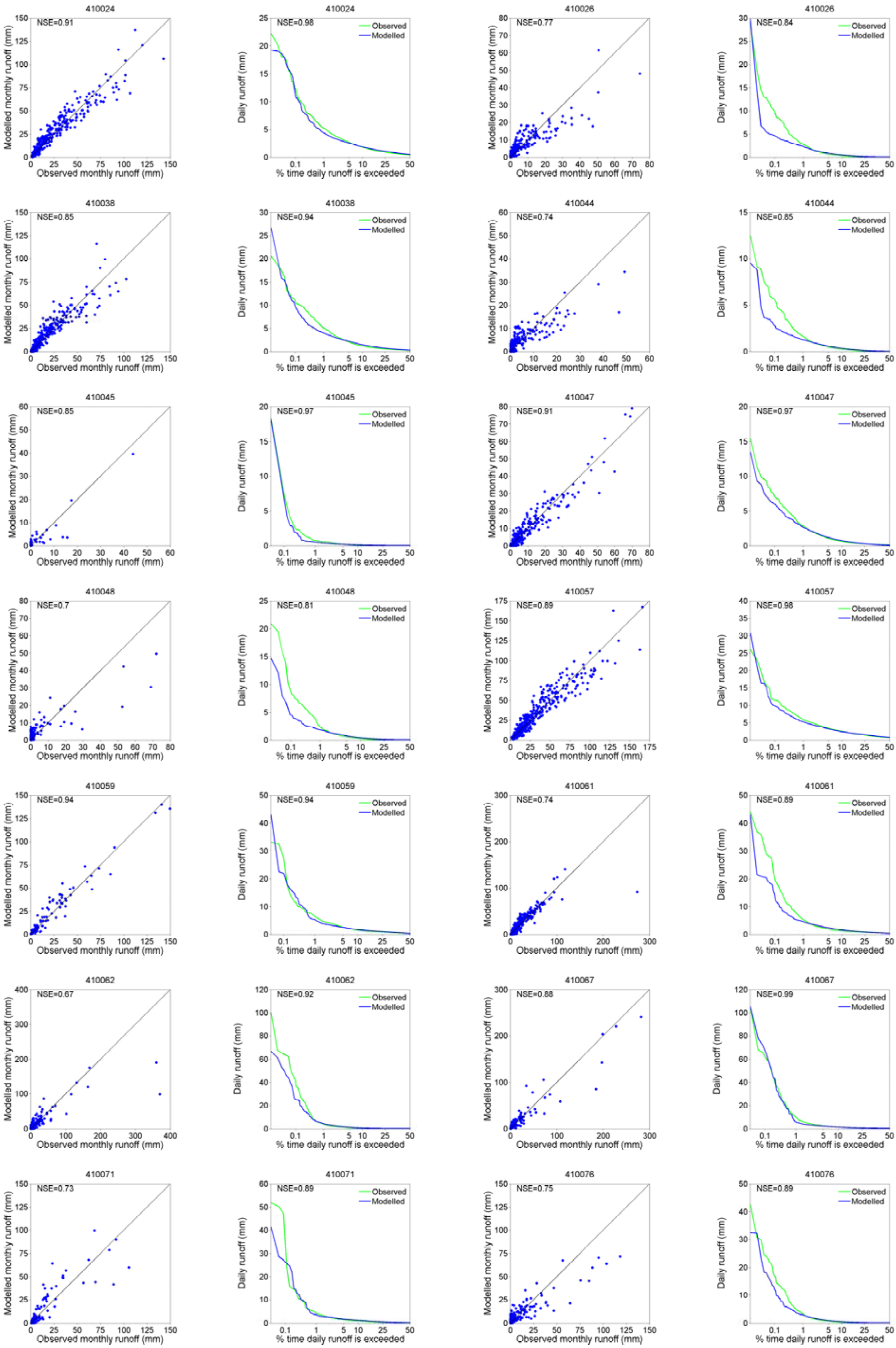

Figure 3-2. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

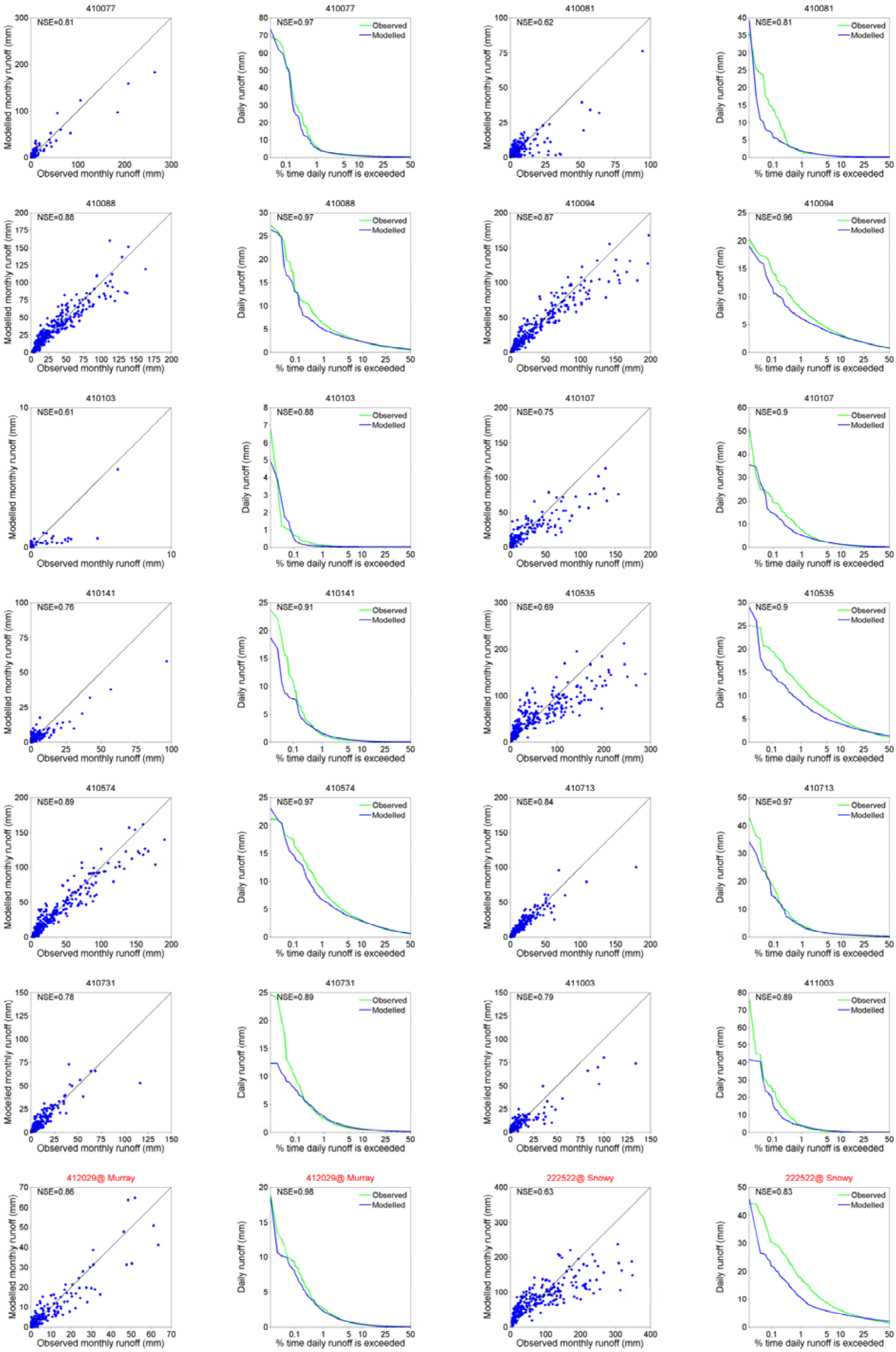

Figure 3-2 continued. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

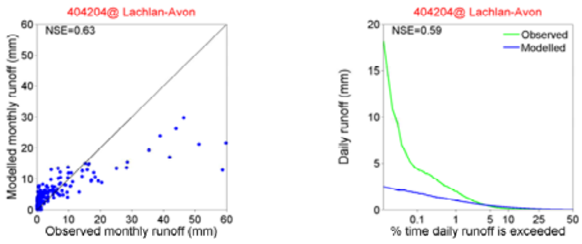

Figure 3-2 continued. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

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 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 region are 530 mm and 54 mm respectively. The mean annual rainfall varies from more than 1500 mm in the high elevations areas in the east to 300 mm in the west. The modelled mean annual runoff varies from more than 400 mm in the high elevation areas in the east to less than 10 mm in the west. Rainfall is fairly uniform throughout the year and runoff is highest in winter and early spring. The region covers 8.2 percent of the MDB and contributes about 15.7 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 region are 0.26 and 0.60 respectively, close to the median values in the 18 MDB regions. The 10^{th} percentile, median and 90^{th} 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 11 percent and 31 percent lower respectively than the long-term (1895 to 2006) mean values. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 rainfall at a significance level of $\alpha = 0.2$ and the 1997 to 2006 runoff is statistically different to the 1895 to 1996 runoff at a significance level of $\alpha = 0.1$ (with the Student-t and Rank-Sum tests). Because the 1997 to 2006 rainfall and runoff are statistically different to the 1895 to 1996 mean values, Scenario B modelling is undertaken. The Scenario B is a stochastic replicate selected such that its 1895 to 1996 mean annual runoff matches the 1997 to 2006 mean annual runoff. Potter et al. (2008) present a more detailed analysis of recent rainfall and runoff across the MDB.

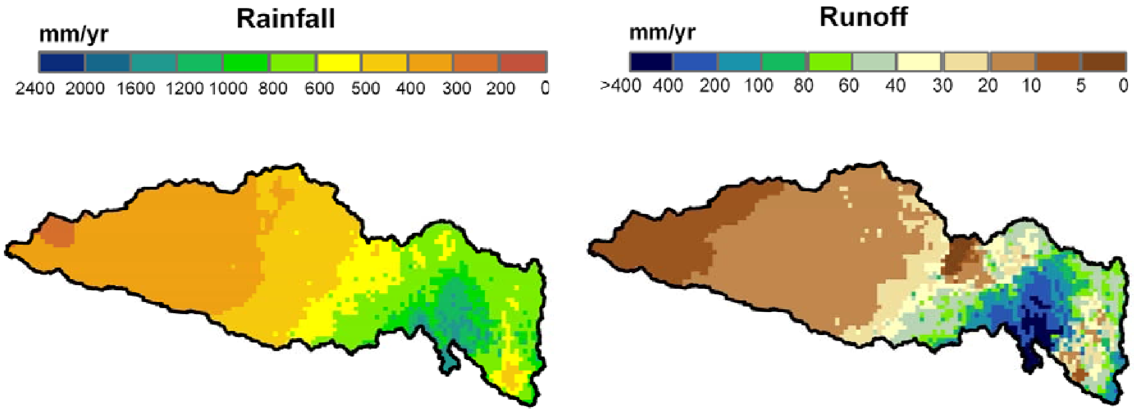

Figure 3-3. Spatial distribution of mean annual rainfall and modelled runoff averaged over 1895 to 2006

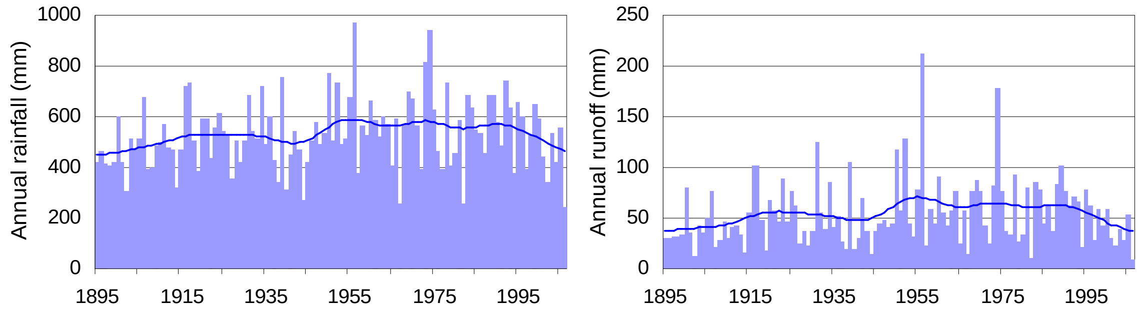

Figure 3-4. 1895 to 2006 annual rainfall and modelled runoff averaged over the region (the curve shows the low frequency variability)

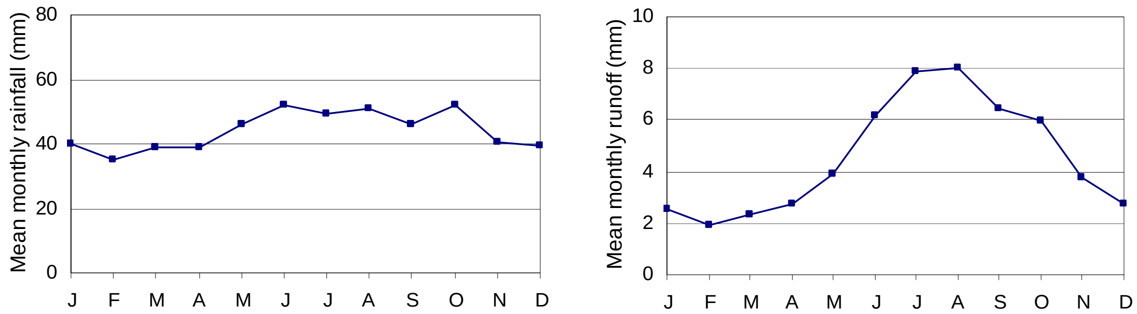

Figure 3-5. Mean monthly rainfall and modelled runoff (averaged over 1895 to 2006 for the region)

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 region under 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 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 come 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 13 percent of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting, only results from extreme 'dry', 'mid' and extreme 'wet' variants 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 best estimate 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 -31, -9 and +13 percent change in mean annual runoff. By comparison, the range based on the low global warming scenario is -10 to +4 percent change in mean annual runoff. Figure 3-7 shows the mean annual runoff across the region under Scenario A and scenarios Cdry, Cmid and Cwet.

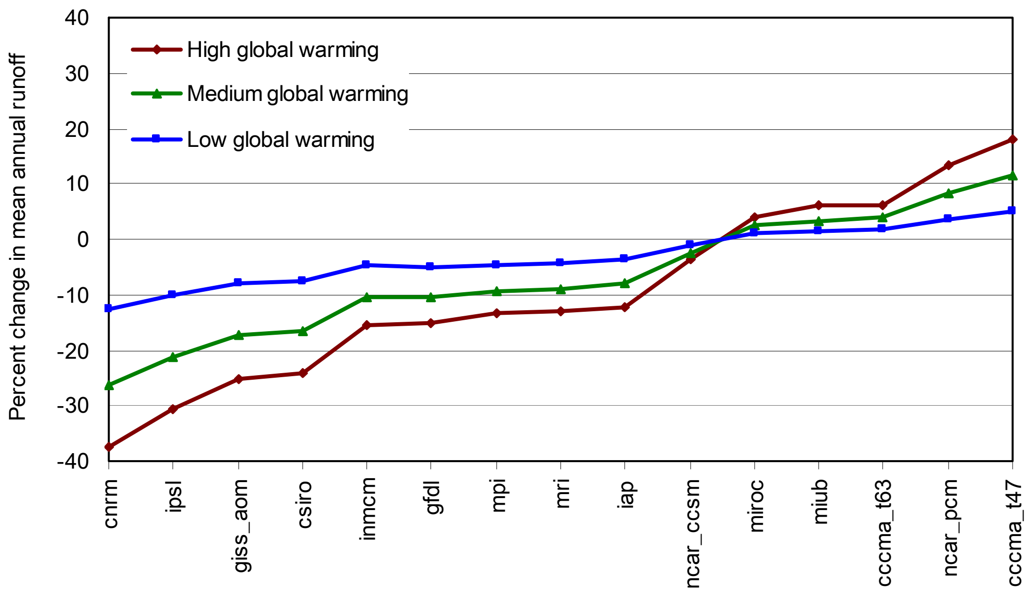

Figure 3-6. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A runoff

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	-15	-38	cnrm	-10	-26	cnrm	-4	-12
ipsl	**-18**	**-31**	ipsl	-12	-21	ipsl	-5	-10
giss_aom	-15	-25	giss_aom	-9	-17	giss_aom	-4	-8
csiro	-10	-24	csiro	-7	-16	csiro	-3	-8
inmcm	-5	-16	gfdl	-4	-11	gfdl	-2	-5
gfdl	-6	-15	inmcm	-3	-10	inmcm	-1	-5
mpi	-6	-13	mpi	-4	-10	mpi	-2	-5
mri	-4	-13	**mri**	**-2**	**-9**	mri	-1	-4
iap	-4	-12	iap	-2	-8	iap	-1	-4
ncar_ccsm	2	-4	ncar_ccsm	1	-3	ncar_ccsm	1	-1
miroc	4	4	miroc	3	2	miroc	1	1
miub	5	6	miub	3	3	miub	1	1
cccma_t63	4	6	cccma_t63	3	4	cccma_t63	1	2
ncar_pcm	**6**	**13**	ncar_pcm	4	8	ncar_pcm	2	4
cccma_t47	5	18	cccma_t47	3	11	cccma_t47	1	5

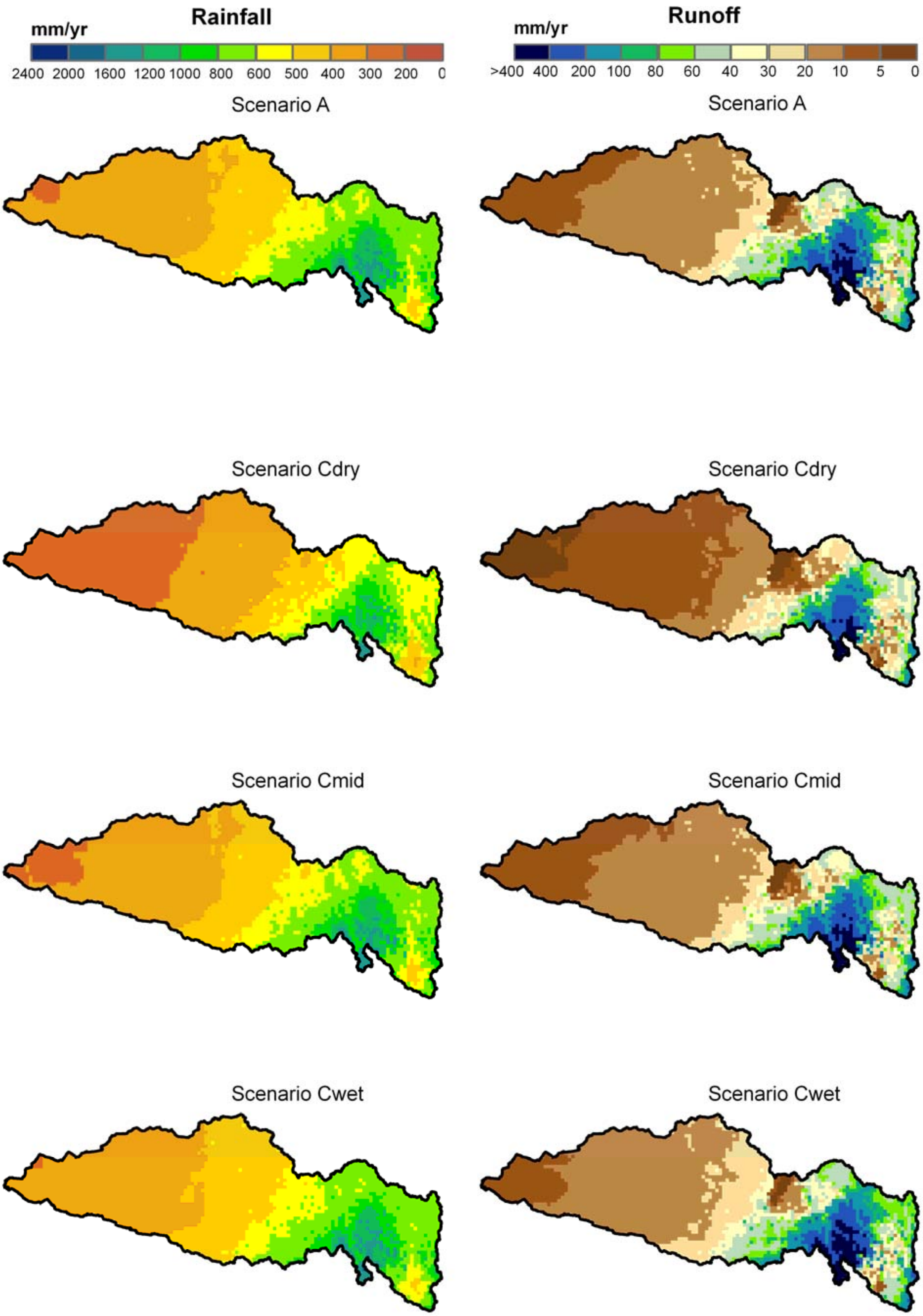

Figure 3-7. Mean annual rainfall and modelled runoff under scenarios A, Cdry, Cmid and Cwet

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 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 under scenarios A, C and D averaged over 1895 to 2006 for the region. Figure 3-9 shows the daily rainfall and flow duration curves under scenarios A, C and D averaged over the region. The modelling results for all the subcatchments in the 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, about 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).

The mean annual runoff over the ten-year period 1997 to 2006 is 31 percent lower than the long-term (1895 to 2006) mean values. For Scenario B modelling, 100 replicates of 112-year daily climate sequences are generated using the mean annual rainfall characteristics over 1997 to 2006. The replicate that reproduced the 1997 to 2006 mean annual runoff is used to obtain the catchment inflows for the river system modelling in Chapter 4. Because the replicate is chosen based on mean annual runoff, the change in rainfall has little meaning and is therefore not shown in Table 3-2.

The modelling results indicate that mean annual runoff would be reduced by 9 percent under a best estimate 2030 climate. However, there is considerable uncertainty and extreme estimates range from -31 to +13 percent.

The commercial forestry plantations in the region are projected to increase by 17,000 ha by ~2030 and modelling results indicated that there would be a negligible impact on mean annual runoff. The total farm dam storage volume over the entire region is projected to increase by 47.6 GL by ~2030. The best estimate of the combined impact of climate change and new farm dams would be a 10 percent reduction in mean annual runoff. Extreme estimates range from -32 to +12 percent.

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

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	530	54	476
		percent change from Scenario A	
B	–	-31%	–
Cdry	-18%	-31%	-17%
Cmid	-2%	-9%	-2%
Cwet	6%	13%	5%
Ddry	-18%	-32%	-17%
Dmid	-2%	-10%	-2%
Dwet	6%	12%	6%

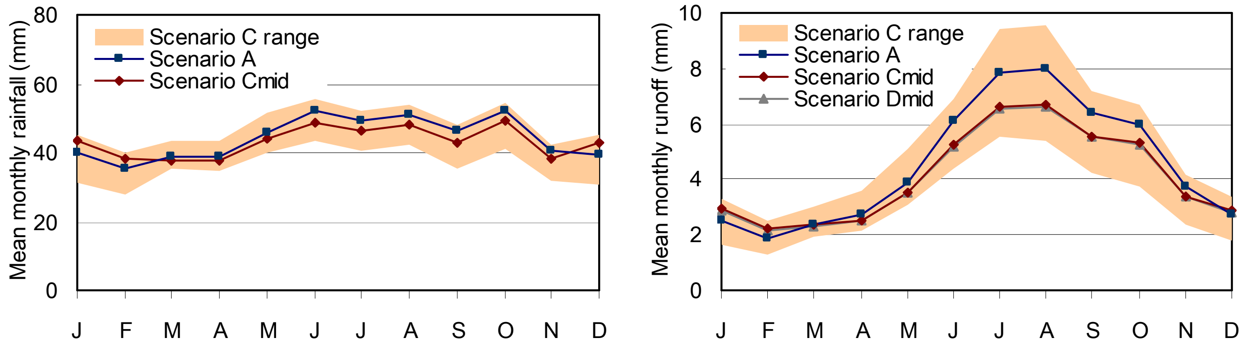

Figure 3-8. Mean monthly rainfall and modelled runoff under scenarios A, C and D averaged over 1895–2006 across the region (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

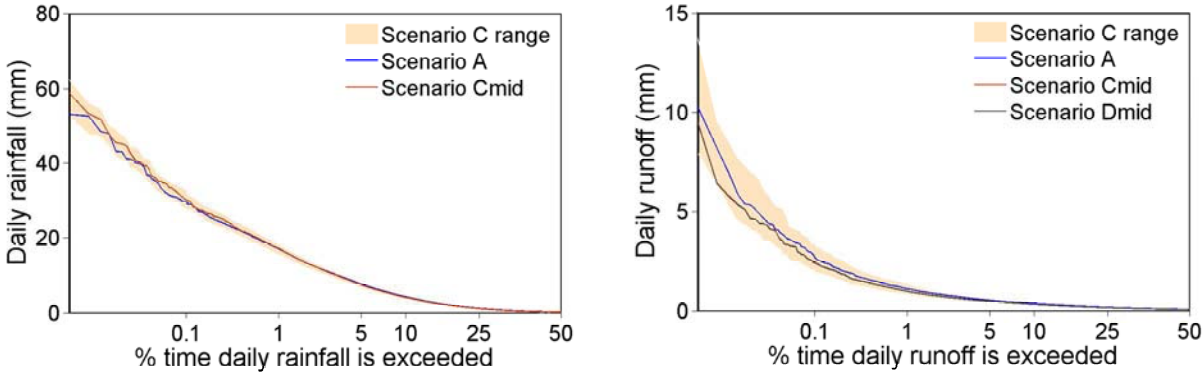

Figure 3-9. Daily flow duration curves under scenarios A, C and D averaged over the region (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

3.4 Discussion of key findings

The annual rainfall and modelled runoff averaged over the region are 530 mm and 54 mm, respectively. The average annual rainfall varies from more than 1500 mm in the high elevation areas in the east to 300 mm in the west. The modelled average annual runoff varies from more than 400 mm in the east to less than 10 mm in the west. Rainfall is fairly uniform throughout the year and runoff is highest in winter and early spring. The region covers 8.2 percent of the MDB and contributes about 15.7 percent of the total runoff.

The average annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 11 percent and 31 percent lower respectively than the long-term (1895 to 2006) average values. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 rainfall at a significance level of $\alpha = 0.2$ and the 1997 to 2006 runoff is statistically different to the 1895 to 1996 runoff at a significance level of $\alpha = 0.1$ (with the Student-t and Rank-Sum tests).

The runoff estimates for the eastern half of the region, where most of the runoff occurs, are relatively good because there are many calibration catchments 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 region is more likely to decrease than increase. Two-thirds of the modelling results show a decrease in average annual runoff and one-third shows an increase in average annual runoff.

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

Under the best estimate 2030 climate, average annual runoff would be reduced by 9 percent. However, there is considerable uncertainty in the modelling results with the extreme estimates ranging from -31 to +13 percent. These extreme estimates come from the high global warming scenario. The range from the low global warming scenario is -10 to +4 percent change in average 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 increase in commercial forestry plantations is 17,000 ha by ~2030 and the impact on average annual runoff would be negligible. The total farm dam storage volume over the entire region is projected to increase by 47,000 ML (13 percent) by ~2030. The best estimate of the combined impact of climate change and new farm dams would be a 10 percent reduction in average annual runoff. Extreme estimates range from -32 to +12 percent. The modelled reduction in average annual runoff from the projected increase in farm dams alone is about 1 percent and is relatively small compared to the runoff reduction under the best estimate 2030 climate of 9 percent.

There is considerable uncertainty in the commercial forestry plantation and farm dam development projections and the impact of these developments on runoff. The Bureau of Rural Sciences projections of plantation area growth are used here. The increase in farm dams is estimated by considering trends in historical farm dam growth and current policy controls. 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 Murrumbidgee 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 sources specific to the four models used for the river modelling:

- the Upper Murrumbidgee model with information from the CSIRO IQQM of the Upper Murrumbidgee River system between Tantangara Dam and Burrinjuck Dam (CSIRO, 2008a)
- the Murrumbidgee model with information from the New South Wales Department of Water and Energy (DWE) IQQM of the Murrumbidgee River downstream of Burrinjuck Dam (DLWC, 2001; Salbe et al., 2007)
- the Snowy Hydro model with information from the Snowy Mountains Hydro-electric Authority model of the Snowy Mountains Hydro-electric Scheme
- the Australian Capital Territory Water Supply model with information from the ActewAGL REALM model of the Australian Capital Territory water supply (ActewAGL, 2004).

4.1 Summary

4.1.1 Issues and observations

River system modelling for the Murrumbidgee region considers eleven modelling scenarios:

- Scenario O
  This scenario represents the latest version of the water sharing plan (WSP) river system model supplied by DWE. It covers the original planning period 1 July 1892 to 30 June 2000 used by DWE to develop the Murrumbidgee Water Sharing Plan (DIPNR, 2004).
- Scenario A0
  This scenario incorporates the Scenario O model but connects the inflows from the Snowy Hydro, Upper Murrumbidgee and Australian Capital Territory Water Supply models and operates over the longer common historical climate period (1 July 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 against which scenarios B, C and D are compared.
- Scenario P – without-development
  This scenario incorporates a specific set of without-development models for the upper Murrumbidgee, Tumut River, Murrumbidgee River (with a without-development Yanco-Colombo-Billabong creek offtake) and Billabong Creek and covers the common historical climate period. Current levels of development such as public storages and demand nodes are not included in these models. Natural water bodies, fixed diversion structures and existing catchment runoff characteristics are not adjusted. Contributions from the Snowy Mountains Hydro-electric Scheme from outside of the region are not included.
- Scenario B – recent climate and current development
  This scenario represents a future climate condition if the climate observed in the region from 1997 to 2006 persisted. The level of development is the same as Scenario A. For Scenario B, a without-development model run is also undertaken; this uses Scenario B climate and Scenario P development conditions.
- Scenario C – future climate and current development
  Scenarios Cwet, Cmid and Cdry represent a range of future climate conditions 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. For each Scenario Cwet, Cmid and Cdry, without-development model runs are also undertaken; these use Scenario C climate and Scenario P development conditions.

- Scenario 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.

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. In particular, the scenarios do not consider how WSP rules may change in the future.

The differences in inflows between scenarios in this chapter and changes in runoff in Chapter 3 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 only a subset of the region is considered in this chapter.

The Murrumbidgee model covers the Murrumbidgee Regulated River WSP area. The model is based on that used by the New South Wales Government to develop the WSP, but differs in its historical simulation periods, representation of some tributary inflows, use of flow inputs directly from the upstream Upper Murrumbidgee and Snowy Hydro models, and the incorporation of feedback effects between the Murray region models (CSIRO, 2008b) and Murrumbidgee model and between the Murrumbidgee model and the Snowy Hydro model. The Murrumbidgee model represents the 1999/2000 level of water resource development, including farm infrastructure, irrigated areas and crop mix. It does not reproduce the actual irrigation demand changes caused by historical changes in farm development as it considers development at a fixed point in time. It represents 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 high security demands are not met is when supply storages reach dead storage capacity.

4.1.2 Key messages

- Current average surface water availability is 4270 GL/year with approximately one-tenth of this being an inter-basin transfer from the Snowy Mountains Hydro-electric Scheme. On average, 2257 GL/year (or 53 percent) of the available water is diverted for use. This is an extremely high level of development. Currently in New South Wales, 60 percent of allocated general security water is used.
- Streamflows in the Murrumbidgee region are highly regulated. Tantangara Dam on the upper Murrumbidgee River regulates nearly all inflows and further downstream Burrinjuck Dam regulates 77 percent of all inflows. Blowering Dam on the Tumut River regulates 87 percent of all inflows, in addition to the effects of the upstream storages of the Snowy Mountains Hydro-electric Scheme.
- Under a long-term continuation of the drier recent climate (1997 to 2006), average surface water availability would reduce by 30 percent, diversions would reduce by 18 percent and end-of-system flows would reduce by 46 percent. The relative level of use would increase to 62 percent and 81 percent of general security water would be used.
- Under the best estimate 2030 climate average surface water availability would reduce by 9 percent, diversions would reduce by 2 percent and end-of-system flows would reduce by 17 percent. The impacts would differ between water products. General security water use for irrigation would decrease by 7 percent in the Lowbidgee Flood Control and Irrigation District, by 4 percent along the main river and by 2 percent in the Coleambally Irrigation Area. However, irrigation use in the Murrumbidgee Irrigation Area would increase by 1 percent, as would use in the Australian Capital Territory water supply system. New South Wales and Australian Capital Territory urban water demand would be met under this, and the dry or wet extreme 2030 climates.
- Under the wet extreme 2030 climate average surface water availability would increase by 13 percent, diversions would increase by 5 percent and end-of-system flows would increase by 20 percent. Under the dry extreme 2030 climate, average surface water availability would reduce by 28 percent, diversions would reduce by 16 percent and end-of-system flows would reduce by 44 percent.
- Projected 2030 farm dam development and commercial forestry plantation expansion would reduce inflows by a total of 26 GL/year – 20 GL/year due to additional farm dams and 6 GL/year due to commercial forestry

plantation expansion. Additional groundwater extraction in the mid-Murrumbidgee would increase the eventual streamflow leakage induced by groundwater extraction from 31 to 67 GL/year. In total, these future developments would represent an increase in surface water use of less than 3 percent. This increase in use would reduce surface water diversions and end-of-system flows by 2 percent.

4.1.3 Robustness

The Murrumbidgee 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 tied closely 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. So the model was checked with allocations and storages at or close to empty to ensure a reasonable performance. Allocations during this test scenario reached zero percent in the Murrumbidgee regulated system. Blowering and Burrinjuck reservoirs were drawn down below active storage capacity. The model behaved robustly. The model's response to increases and decreases in inflow was reasonable and the change in diversions and end-of-systems flows consistent. 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 four river system models and how these were developed. Chapter 1 provides 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 were used to assess the implications of the changes in inflows on the reliability of water supply to users. The river system models currently employed by state agencies and the Murray-Darling Basin Commission were used because of project time constraints and the need to link the assessments to state water planning processes. The main models are IQQM, REALM, MSM-BigMod, WaterCress and a model of the Snowy Mountains Hydro-electric Scheme. The Murrumbidgee IQQM incorporates Murrumbidgee Regulated River Water Sharing Plan rules. The rules underpin the climate change and future development impact assessment. Plan rules may change in the future to accommodate environmental needs, as a response to drought, bushfire and climate change impacts.

4.2.2 Model description

The Murrumbidgee region is described by four river models (Figure 4-1): the Upper Murrumbidgee model, the Snowy Hydro model, the Australian Capital Territory water supply model and the Murrumbidgee model. The Upper Murrumbidgee and Snowy Hydro models connect to the Murrumbidgee model at Burrinjuck and Blowering dam headwater inflows, respectively. The Australian Capital Territory Water Supply model connects to the Upper Murrumbidgee model; it diverts flows into the Australian Capital Territory water supply system, and returns local catchment and treated effluent flows. The net contribution from the Snowy Mountains Hydro-electric Scheme varies from year to year according to the amount of water harvested from the Murrumbidgee River and hydropower generated. The scheme produces a net inflow gain via release to the Murrumbidgee River. This adds to the natural river inflow that would occur without the scheme. The net gain in the Scenario A model is an average of 417 GL/year above the natural catchment inflow. The 417 GL/year should include an additional 66.4 GL/year of residual Blowering Dam inflow that was omitted from all of the developed scenarios. The minimum total release into the Murrumbidgee River in any year is 1026 GL including natural catchment inflow.

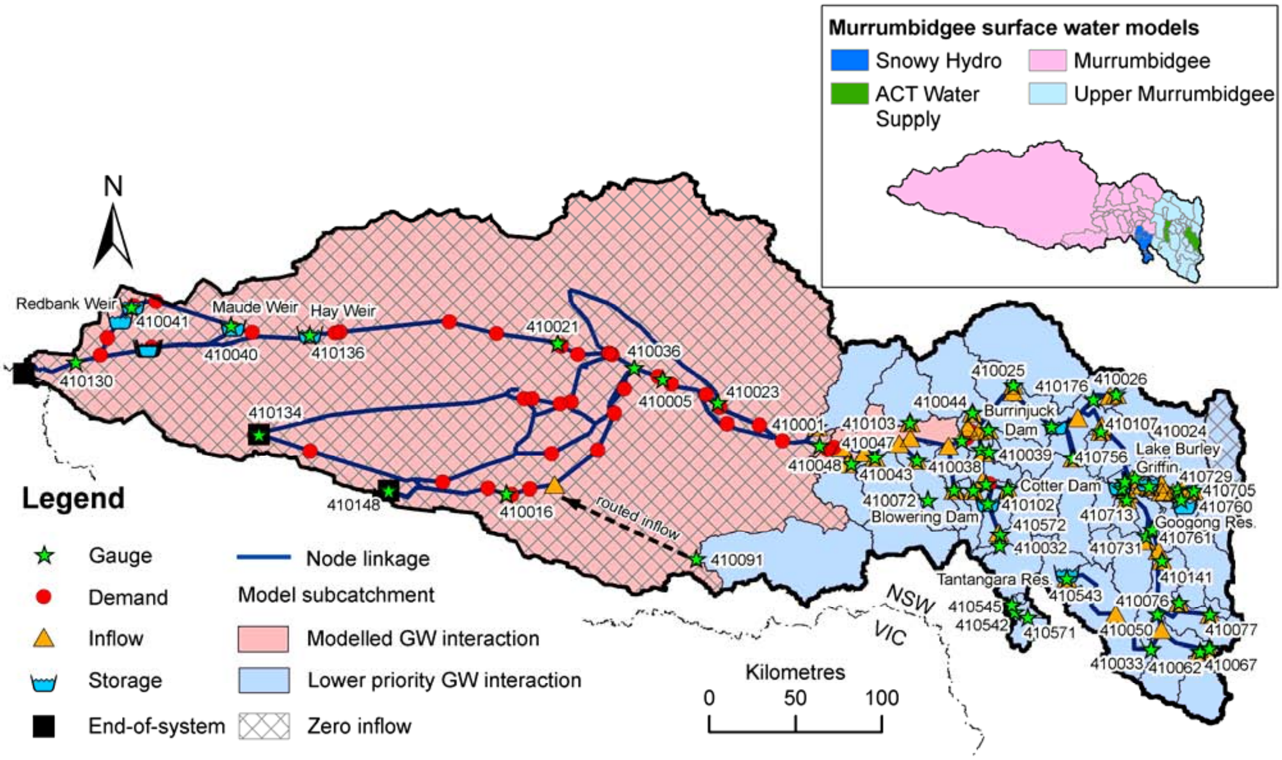

Figure 4-1. River system map showing subcatchments, inflow and demand nodes, links and gauge locations with inset showing the extent of the four Murrumbidgee surface water models

Upper Murrumbidgee model

The Upper Murrumbidgee model is a daily IQQM V7.61.2 representation of the upper Murrumbidgee system built for the project. Prior to this project, inflows into Burrinjuck Dam were estimated by gauges prior to commissioning Burrinjuck Dam and thereafter by back calculating inflows based on Burrinjuck Dam mass balance. The model commences at Tantangara Dam, ends at the headwaters of Burrinjuck Dam, and represents all tributary inflows into the reservoir including the Goodradigbee River. The model output is a time series of the total flow into Burrinjuck Dam that is a direct input to the Burrinjuck Dam storage node in the separate Murrumbidgee model of the river between Burrinjuck Dam and Balranald. Diversions in this part of the Murrumbidgee River and the associated tributaries are implicit in the model calibration. These diversions will be covered by the Murrumbidgee macro WSP.

The Upper Murrumbidgee model represents the system with 137 links and 138 nodes arranged into 13 river sections. There are no storages in the model. The Australian Capital Territory water supply is the only diversion considered and this is covered by the Australian Capital Territory Water Supply model. The monthly demand from this model is divided equally for each day of the month as a demand input to the Upper Murrumbidgee model.

The Australian Capital Territory water use, Googong and Cotter dam spills and effluent returns are modelled by the Australian Capital Territory Water Supply model. The Upper Murrumbidgee model was divided into two at the Australian Capital Territory water supply extraction point on the Murrumbidgee River to connect the Australian Capital Territory Water Supply model. This allows the Upper Murrumbidgee model to provide flow sequences to the Australian Capital Territory Water Supply model, which is then run to provide inputs to the lower half of the Upper Murrumbidgee model.

Snowy Hydro model

The Snowy Mountains Hydro-electric Scheme is modelled by a monthly model (SIM V9) developed by the Water Section of the Snowy Mountains Hydro-electric Authority. SIM V9 (used for the Snowy corporatisation studies undertaken by the Murray-Darling Basin Commission and DWE) was modified and renamed the Snowy Hydro model for this assessment. The pre-corporatisation version did not consider required reductions in annual releases and the provision of environmental releases according to Snowy Water Licence 2002 rules (WAMC, 2002).

The Snowy Hydro model simulates the hydraulic operation of the Snowy-Murray and Snowy-Tumut developments according to the Target Rule principle. Scheduled releases are set to 1062 GL/year for the Snowy-Murray Development and 1026 GL/year for the Snowy-Tumut Development. Deficits in scheduled releases are satisfied as soon as possible in later periods. Water ('above target water') is accrued when effective storages exceed the relevant monthly target storage and target releases are made as soon as possible subject to downstream channel capacity and diversion constraints. The model does not report changes in hydro-power generation.

Water operations, various constraints and operating guidelines are modelled by water balances involving reservoir storage, inflows, evaporation at the major storages, diversions and spills to meet scheduled and target releases. The model consists of seven Snowy Hydro reservoirs and Blowering Dam, six tunnels, five power stations, and one pumping station. There are also a number of additional water accounts that have to be maintained. These relate to development shares of water, effective and target storages, notional spills and accountable releases. The Snowy Hydro model does not account for any consumptive water use.

The model ends at four locations: Murrumbidgee River at Tantangara Dam, Tumut River at Blowering Dam, and Murray 1 power station releases to the Murray River and to the Snowy River. Blowering Dam operation is modelled using irrigation release requirements supplied by the Murrumbidgee model. Jounama Creek releases into Blowering Reservoir are constrained by Tumut River channel capacity and pre-Snowy natural flows. The Tantangara connection with the Upper Murrumbidgee model is not considered as the dam only spills once in 100 years.

Australian Capital Territory Water Supply model

The Australian Capital Territory Water Supply model is a monthly time step REALM (V5.0) representation of the Canberra water supply system (ActewAGL, 2004). The model commences with inflows into Googong, Corin, Bendora, and Cotter storages. The model ends with spills and releases from Googong and Cotter dams. The model is comprised of 15 nodes and 27 links, arranged into two river systems. There are four public storages. The dams are used to supply water to Canberra. Water is also extracted from the Murrumbidgee River to supplement Canberra's water supply.

Management of Canberra's water supply uses a per capita regression relationship between historical demand, rainfall and evaporation at Canberra Airport. The demands are based on current population which is not modified for the future development scenarios. The demands are modelled using monthly patterns constrained by restriction levels. There are no irrigation demands in the model. The model includes:

- Cotter Dam as part of Canberra's water supply system. Four pumps have been included at Cotter pump station to enable supply of Cotter Dam and Murrumbidgee River water
- a pump station has been included to pump water from the Murrumbidgee to Cotter pump station and then on to Mount Stromlo water treatment plant
- water transfer rules from Corin Dam to Bendora Dam
- water transfer rules from Bendora Dam to Cotter Dam
- water transfer rules from Bendora Dam, Cotter Dam and/or the Murrumbidgee River to Googong Dam via a pipeline that allows treated water from the Cotter system to be delivered to Googong Dam via the bulk supply network. This pipeline allows water from the Cotter River or Murrumbidgee River to be supplied to Googong Dam (as well as directly to town) in order to minimise the amount of water spilling from Cotter River dams
- there are environmental release rules for Corin, Bendora, Googong, and Cotter dams (Table 4-3)
- the return of treated effluent from the water supply is modelled as a fixed annual pattern of 33.3 GL/year. This is represented as an inflow into the Upper Murrumbidgee model.

Murrumbidgee model

The Murrumbidgee region below the major irrigation dams is modelled by a custom version of IQQM based on IQQM V6.104.1. It is known as the Murrumbidgee model and commences with inflows from the Upper Murrumbidgee and Snowy models into the headwaters of Burrinjuck and Blowering dams, respectively.

The model ends at three locations: Murrumbidgee River at Balranald gauge (410130), Billabong Creek at Darlot gauge (410134) and Forest Creek downstream of Warriston Weir (410148). These three outflows are inflows to the Murray region. The model represents the Murrumbidgee system with 566 links and 567 nodes arranged into 67 river sections. The model covers the extent of the Murrumbidgee Regulated River System WSP applying to the regulated reaches of the Murrumbidgee River (Chapter 2). The Lowbidgee Flood Control and Irrigation District is not in the plan area. However, the plan specifies rules for diversion timing and volume into the District (DIPNR, 2004).

The model represents:

- eight public storages - Burrinjuck Dam, Blowering Dam, Berembed Weir, Gogeldrie Weir, Hay Weir, Maude Weir, Redbank Weir and Tombullen storage (Table 4-1). Tombullen storage is an off-river storage
- irrigation diversions to the Nimmie-Caira and Redbank Forest Floodplain systems between Hay and Balranald weirs. These diversions also provide some environmental benefit to the Lowbidgee Floodplain
- the 1999/2000 level of development by water users including farm infrastructure, irrigated areas and crop mix. Model calibration also represents farm management practices during this period
- town water supplies and stock and domestic demands with a fixed demand pattern (does not vary with water availability or climatic conditions). These high security demands are not met when supply storages reach dead storage capacity.

The WSP specifies access licences for stock and domestic and native access rights, local water utility access (town water supply), high security regulated river supply, general security regulated river supply, conveyance licences for the Murrumbidgee and Coleambally irrigation corporations, and supplementary access licences. General security users operate under an annual accounting scheme and carryover is limited to 15 percent of entitlement. Surplus flow events are shared according to supplementary access entitlements that allocate water in excess of other higher priority licence requirements and specific environmental requirements. These are available when determinations exceed 0.7 ML per unit share in the Murrumbidgee River system and exceed 0.6 ML per unit share in the Murray and Lower Darling (including carryover) river systems. They are also available when determinations exceed 0.7 ML per unit share in the Murrumbidgee River system and less than 0.6 ML per unit share in the Murray and Lower Darling river systems (including carryover) when water cannot be re-regulated within the Murray River system (Table 4-2).

General security, high security, conveyance and supplementary access licences are allocated as unit shares rather than entitlement volumes. The WSP outlines the priority for water sharing, how determinations are made to allocate ML per share annually by the DWE, and maximum ML per share determinations that can be made. However stock and domestic and town water supply licences are still allocated as entitlement volumes. Irrigation water use is modelled directly with irrigation nodes or by ‘resource’ nodes that supply irrigation nodes. The irrigation corporations have the most prominent ‘resource’ nodes. Resource nodes are also used in the model to pool general security, high security, stock and domestic allocations to provide resources for cropping outside the irrigation corporation areas. Several licence categories were combined because historical data was lumped. Altogether there are 67 irrigation nodes, 10 nodes representing town water supplies and 14 resource nodes (included in the general security). High security, stock and domestic and town water supply licences are used first in reporting under licence categories.

The model 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. Note that the model represents the 1999/2000 level of development so modelled irrigation demands may not match history of use as farm development is not static.

The model includes a number of WSP release requirements and the associated operational rules. Operations include a range of minimum flow, transparency and translucency requirements, maximum flow constraints and environmental water allocations. Minimum flow requirements, maximum flow constraints and environmental flow allowances are summarised in Table 4-3.

Transparency and translucency requirements for operation of storages include:

- transparent releases are made from Blowering Dam of 560 ML/day, in addition to provision for usage along the Tumut River to the Murrumbidgee River confluence
- translucent releases from Burrinjuck Dam between 22 April and 21 October to meet flow conditions at Gundagai. The releases are between 300 and 615 ML/day and are based on storage inflow, Goodradigbee flows at Wee Jasper, Burrinjuck storage volume and expected usage on the Murrumbidgee River to the Tumut River confluence
- a minimum release of 300 ML/day is required from Burrinjuck Dam in addition to provision for water use between the dam and the Tumut confluence.

Inter-valley transfer of water from the Murrumbidgee to the Murray is also represented in the model (Table 4-3). The transfer of water into the Murray is simply represented as a constant 25 GL/year transfer. The Murrumbidgee model has feedbacks with the Snowy and Murray models. The Murrumbidgee model requests water from the Snowy Mountains Hydro-electric Scheme affecting inflows into Blowering Dam. Supplementary access and Lowbidgee District access in the Murrumbidgee is modified by Murray River New South Wales allocations and 75 percent exceedance forecast (to May) of South Australian surplus flows provided by the Murray models. The Snowy, Murrumbidgee and Murray models are run five times to converge and account for these feedbacks.

Table 4-1. Storages in the Australian Capital Territory water supply and Murrumbidgee river system models

	Active storage	Average annual inflow[1]	Average annual release and abstraction[2]	Average annual net evaporation	Degree of regulation
	GL	GL/y			
Major supply reservoirs					
Blowering Dam	1607.0	1612.0	1397.0	5.6	0.87
Burrinjuck Dam	1025.0	1309.0	1010.0	-2.2	0.77
Corin Dam	70.9	58.8	27.7	-0.2	0.47
Bendora Dam	11.5	97.7	61.2	-0.1	0.62
Googong Dam	121.1	89.8	21.4	3.4	0.28
Cotter Dam	3.9	98.3	6.7	0.1	0.07
Minor supply reservoirs					
Berembed weir	2.0			0.0	
Gogeldrie Weir	1.0			4.0	
Hay Weir	13.3			7.9	
Maude Weir	4.6			5.0	
Redbank Weir	5.1			4.8	
Off-river supply reservoirs					
Tombullen storage	11.2			3.8	
Region totals	**2877.1**	**3265.0**	**2524.0**	**32.1**	**0.78**

[1] Inflows: the total inflows to a reservoir may include releases and spills from upstream storages.
[2] Release and abstraction: includes all water released or abstracted for consumptive uses, environmental flows or urban supply. Excludes spills from the dam.

Table 4-2. Modelled water use configuration

	Number of nodes	Medium security water product	Licence (unit shares)	Pump constraints	Model notes
		GL/y		ML/day	
Upper Murrumbidgee					
No water use					Implicit in model calibration
Australian Capital Territory water supply					
Canberra water supply					Per capita regression relationship based on historical demand and rainfall and evaporation at Canberra airport
Murrumbidgee pump	1			80	
Return flows	1				Fixed pattern of 33.3 GL/year
Murrumbidgee					
Irrigation					Soil moisture accounting separate store for each crop type within an irrigation node
General security	56		2,043,432		
High security	11		298,021		
Conveyance			373,000		Applies to irrigation company areas to meet diversion losses
Supplementary access	*		220,000		Modelled at river extraction point rather than at irrigation node, not distinguished at individual node level in all cases
Sub-total	**67**		**2,934,453**	**66,033**	Pump constraints for separate licence types cannot be distinguished due to pooling of types together into "resource nodes"
Stock and domestic	0		25,572		Lumped representation with irrigation demand
Town water supply	10		23,403		Fixed demand

4.2.3 Model setup

The customized Murrumbidgee River model was based on IQQM V6.104.1 executable code obtained from DWE (DLWC, 2001, Salbe et al., 2007). The model was run for the period of 1 June 1892 to 30 June 2000 and validated against previous results. The time series rainfall, evaporation and flow inputs (except for the Snowy Hydro model component) did not require extension. The Snowy Hydro model commenced on 1 April 1906 and rainfall, evaporation and flow inputs were extended back to 1 January 1895. The flow inputs were derived using the rainfall-runoff models developed for the Snowy Hydro model (Chapter 3). These flow inputs were scaled based on the overlapping period of the existing flow inputs into the Snowy Hydro model.

The without-development scenarios are described by a different set of four daily IQQM models: Upper Murrumbidgee, Tumut, Murrumbidgee, and Yanco and Billabong Creek.

The without-development Upper Murrumbidgee model is identical to the developed Upper Murrumbidgee model but receives without-development inflows rather than spills from Tantangara, Googong and Cotter dams. The effluent return is set to zero. The without-development Tumut model was built for this project to represent the natural inflow from the Tumut River. This model combines the inflows of several subcatchments to generate a Tumut River flow at the Tumut gauge (410006). The Upper Murrumbidgee and Tumut without-development models connect to the without-development Murrumbidgee model. The without-development Murrumbidgee model does not include public storages or water use diversions. Irrigation schemes and associated supply networks were removed. Regulated distributaries in the model were modified to match without-development characteristics. Natural floodplains were not removed from the model. Without-development outflows from it are inputs into a separate without-development Yanco and Billabong Creek model that ends at Darlot where it provides inflows into the Murray region model (CSIRO, 2008b).

The Murrumbidgee system contains a large amount of public storage. The initial state of these storages can influence the results. The initial state of all public storages needs to be determined as both Murrumbidgee models start with a warm-up period from 1 June 1895 to 30 June 1895. So the models were started from 1 January 1890 with empty storages, run up to 31 May 1895 and the final storage volumes recorded. This was repeated starting with full storages. The results are presented in Table 4-4 and show that the storages converged to a similar result in both cases. Each storage was configured with these volumes for the commencement of all model runs. The initial volume of Snowy Hydro model storages was not determined as there were no outputs for the model. These storages remained at an unknown fixed initial state.

The Australian Capital Territory Water Supply model also contains a large amount of public storage. The initial state of these storages was set by a warm-up period from January 1871 to June 1895. The Upper Murrumbidgee model does not contain any storage and consequently has a 1 month warm-up period.

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

The Australian Capital Territory Water Supply model had already been used by ActewAGL in climates change studies and consequently a robustness test was not required. The Upper Murrumbidgee model does not contain any storages or regulation and consequently a robustness test was not required.

Table 4-3. Water management in Australian Capital Territory Water Supply and Murrumbidgee models

Water Management	
Minimum flow requirements	
ACT water supply	
Corin Reservoir to Bendora Reservoir	
Base flow	**No restrictions:** Base flows equal 75% of the 80th percentile monthly natural flow or the calculated natural flow below Corin Dam whichever is less. Percentile flows range between 81 to 3551 ML/month **Stage 1 restrictions:** The lesser of 1120 to 1240 ML/month and above **Stage 2 or greater restrictions:** The lesser of 560 to 640 ML/month or natural inflow whichever is smaller
Riffle maintenance	**Stage 1 or less restrictions:** Riffle maintenance flows of 450 ML/month in January, March, May, July, September, November **Stage 2 or greater restrictions:** Reviewed under adaptive management process
Pool maintenance	Pool maintenance flows of 550 ML/d for 2 days between July and October
Bendora Reservoir to Cotter Reservoir	
Base flow	**No restrictions:** Base flows equal 75% of the 80th percentile monthly natural flow or the calculated natural flow below Bendora Dam whichever is less. Percentile flows range between 269 to 5115 ML/month **Stage 1 restrictions:** The lesser of 1120 to 1240 ML/month (40 ML/day) and above **Stage 2 or greater restrictions:** The lesser of 560 to 640 ML/month (20 ML/day) or natural inflow whichever is smaller
Riffle maintenance	**Stage 1 or less restrictions:** Riffle maintenance flows of 450 ML/month in January, March, May, July, September, November **Stage 2 or greater restrictions:** Reviewed under adaptive management process
Pool maintenance	Pool maintenance flows of 550 ML/day for 2 days between July and October
Below Cotter Reservoir	
Base flow	**Stage 1 or less restrictions:** Base flows of 420 to 465 ML/month **Stage 2 or greater restrictions:** Base flows of 136 ML/month (2 ML/day for 27 days followed by 20 ML/day for four days)
Riffle maintenance	**No restrictions:** Riffle maintenance flows of 100 ML/month in January, March, May, July, September, November **Stage 1 or greater**: Not required
Below Googong Reservoir	
Base flow	**Stage 1 or less restrictions:** Base flows of 280 to 310 ML/month or inflow whichever is less **Stage 2 or greater restrictions:** Base flows of 112 to 124 ML/month or inflow whichever is less
Riffle maintenance	**No restrictions:** Riffle maintenance flows of 100 ML/month in January, March, May, July, September, November **Stage 1 or greater restrictions** 100 ML/month in a month (100 ML/day for one day once per year)
Murrumbidgee River at Cotter pumping station	
Base flow	**No restrictions:** Maintain a base flow from April to November of 560 to 620 ML/month (20 ML/day) or 67% of natural flow whichever is greater. Measured at Mt Macdonald gauging station (410738) **Stage 1 restrictions or greater:** Maintain a base flow of 560 to 620 ML/month (20 ML/day) or natural flow whichever is greater. Measured at Mt Macdonald gauging station (410738)

Table 4-3 (cont.). Water management in Australian Capital Territory Water Supply and Murrumbidgee models

Minimum flow requirements	
Murrumbidgee	
Murrumbidgee at Balranald	Minimum daily flow of 200 ML/day when allocations and carryover are below 80% of share components else 300 ML/day
Blowering Dam	Transparent releases of natural inflows up to 560 ML/day, in addition to provisions for usage along the Tumut to the Murrumbidgee confluence
Burrinjuck Dam	Minimum release of between 300 and 615 ML/day depending on inflows into storage; seasonal translucent and transparent release requirements dependent on dam inflows, Goodradigbee at Wee Jasper River Flows, Burrinjuck Dam storage, expected water use along the Murrumbidgee to the Tumut confluence; minimum release of 300 ML/day in any condition.
Tantangara Dam outflow into Murrumbidgee River	Minimum daily flow of 32 ML/day
Billabong Creek at Warriston Weir	Minimum daily flow of 100 ML/day
Billabong Creek at Darlot	Minimum daily flow of 50 ML/day
Maximum flow constraints	
Tumut River at Oddy's Bridge	9000 ML/d in Water Sharing Plan; currently 9100 ML/day in model to represent actual physical river conditions
Murrumbidgee at Gundagai	32,000 ML/d in Water Sharing Plan; currently 30,000 ML/day in model to represent actual operational margins
Yanco Creek offtake	Maximum daily flow of 1400 ML/day
Main Canal (Murrumbidgee Irrigation Area) offtake	Maximum daily flow of 6700 ML/day
Sturt Canal (Murrumbidgee Irrigation Area) offtake	Maximum daily flow of 1800 ML/day
Barren Box Swamp inflow	Maximum daily flow of 1030 ML/day
Warburn Escape flow	Maximum daily flow of 790 ML/day
Environmental Water Allocation (EWA)	
EWA1	When general security licence determinations and carryover from the previous year exceed 0.6 ML for every General Security unit share, water above this volume up to a total of 50,000 ML is credited to EWA1; an additional 50,000 ML may also be credited to EWA1 under certain conditions
EWA2	When transparent or translucent releases are made from Burrinjuck Dam, a volume up to 315 ML/day is credited to the account depending on the size of the transparent/translucent release
EWA3	When general security licence determinations and carryover from the previous year exceed 0.8 ML for every General Security unit share, a proportion of the water above this volume can be credited to EWA3 between 1 July and 1 January
Murrumbidgee water accounting	
Murrumbidgee Regulated River	Annual accounting with maximum allocation of 100% and maximum carryover of 15%
Surplus flow sharing	
Supplementary (off-allocation) diversion volumes	Restricted by licence share. Sum of general security, carryover and supplementary access diversion is restricted to 100% of licence share.
Supplementary (off-allocation) diversion announcement and diversion to Lowbidgee system	Announcement of off-allocation flows and diversions into the Lowbidgee system is dependent on the Effective Allocation in the Murray system, and the 75% exceedance forecast of South Australia surplus flow to May
Lowbidgee system representation	Model represents overall net flow into the Nimmie-Caira and Redbank Forest systems, rather than representing detailed usage of water within these
Inter-valley transfer	
Transfer into the Murray system	Represented as a constant 25 GL/y in the model
Additional information	
Irrigation corporation licensing	Volumes debited against corporation licence shares at the point of diversion from the Murrumbidgee River, and then allocated internally by the corporation
Murray River inflow through Finley's Escape	Inflow series generated by Murray model

Table 4-4. Model setup information

Model setup information		Version	Start date	End date
Upper Murrumbidgee	IQQM	7.61.2	1/01/1895	30/06/2006
ACT	REALM	5.0	01/1871	09/2006
Murrumbidgee	IQQM	6.73.4	1/07/1892	30/06/2000
Connection				
Tumut River upstream of Blowering Dam	Snowy model to Murrumbidgee model			
Extraction Murrumbidgee River	Connections between ACT model and Upper Murrumbidgee model			
Cotter Dam spills				
Googong Dam spills				
Sewerage treatment plant outflows				
Burrinjuck Dam inflows including Goodradigbee River	Connection between Upper Murrumbidgee and Murrumbidgee models			
Edward River through Forest Creek	Outflow through Forest Creek			
Edward River through Billabong Creek	Outflow through Billabong Creek through Moulamein			
Murray River	Outflow to Murray downstream of Balranald			
Murray River NSW allocation	Feedback from Murray model to Murrumbidgee model			
75% exceedance forecast SA surplus flow to May	Feedback from Murray model to Murrumbidgee model			
Surface and groundwater interactions (4 gain nodes and 21 loss nodes)	Murrumbidgee model to Mid- and Lower Murrumbidgee groundwater models			
Baseline models				
Warm-up period				
Upper Murrumbidgee	IQQM	7.61.2	01/06/1895	30/06/1895
ACT Model	REALM	5.0	01/1871	06/1895
Murrumbidgee	IQQM	6.104.1	01/06/1895	30/06/1895
Upper Murrumbidgee modifications				
Inflows	Observed data extended by Sacramento models			
Rainfall and evaporation	Obtained from Silo			
ACT water supply modifications				
No modifications required				
Murrumbidgee modifications				
Data	Extend to 30/06/2006			
Inflows	No adjustment required			
Groundwater loss nodes	Groundwater loss and gain nodes added on all reaches in Murrumbidgee model downstream of Gundagai			
Murrumbidgee warm-up test results				
Setting initial storage volumes	Storages commence empty	Storages commence full	Difference	Percent of full volume
		GL		percent
Blowering storage volume 31/05/1895	1080	1080	0	0%
Burrinjuck storage volume 31/05/1895	846.6	846.6	0	0%
Storage volume 30 May (1895-2006)	Mean	Median		
	GL			
Blowering	736.7	764.8		
Burrinjuck	515.4	496.3		
Murrumbidgee robustness test results				
Minimum allocation				
Percent of time allocation less than 0.5%	24			
Minimum storage volume during simulation (GL)				
Blowering (DSV 23.99)	12.4			
Burrinjuck (DSV 3.25)	0.7			

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

Season	Rainfall	Evaporation	Flow
DJF	0.99	1.06	0.93
MAM	0.96	1.06	0.85
JJA	0.77	1.05	0.29
SON	0.81	1.06	0.39

4.3 Modelling results

4.3.1 River system water balance

The mass balance table (Table 4-6) shows the net fluxes for the Murrumbidgee region. Scenario O fluxes, Scenario A0 and Scenario A fluxes are displayed as GL/year, while all other scenarios are presented as a percentage change from Scenario A. Note the assemblage of models and 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. End-of-system flows are shown for the Murrumbidgee River at Balranald gauge (410130), Billabong Creek at Darlot gauge (410134), and for outflows through the Forest Creek outlet from Coleambally Canal (410148). The change in storage between 30 June 1895 and 30 June 2006 averaged over the 111-year period is also included.

Diversions are listed based on the different water products in the region, for irrigation corporation licence holders, and for the Lowbidgee Flood Control and Irrigation District. The water products referred to in the Murrumbidgee WSP include local water utility, stock and domestic, high security, general security, supplementary access and conveyance licence share components. Supplementary access licences refer to water previously termed ‘off-allocation’. Conveyance access licences replace historical allowances in the Murrumbidgee and Coleambally Irrigation Areas for water delivery losses. Lowbidgee diversions refer to those volumes diverted out of the WSP area and into the Lowbidgee District. Note that in addition to being used for irrigation, these Lowbidgee diversions provide some benefits to the Lowbidgee Wetlands.

Appendix B contains mass balance tables for gauged inflow subcatchments in the Upper Murrumbidgee model and the Murrumbidgee model upstream of Wagga Wagga. It also includes mass balance tables for river reaches between Wagga Wagga and the end-of-system flows at Balranald and Darlot, and for the Murrumbidgee Irrigation Area. These additional mass balances were reported as most licensed diversions with the Murrumbidgee Regulated River System occur downstream of Wagga Wagga. 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 for scenarios O, A0, A, B, C and D

	O	A0	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	1/7/1892	1/7/1895								
Model end date	30/6/2000	30/6/2006								
	GL/y			percent change from Scenario A						
Storage volume										
Change over period	-4.5	-13.4	-13.4	46%	-10%	8%	48%	-11%	10%	50%
Inflows										
Subcatchments										
Snowy inter-basin transfer	0.0	483.5	483.5	-15%	6%	-4%	-14%	6%	-4%	-14%
Directly gauged	3806.9	3251.7	3256.8	-29%	12%	-8%	-26%	12%	-8%	-26%
Indirectly gauged*	992.2	975.8	975.8	-39%	16%	-15%	-38%	15%	-16%	-39%
Transfers from Murray through Finley's Escape	25.2	40.9	40.9	-17%	-3%	-6%	-17%	-3%	-7%	-18%
Gain from groundwater**	0.0	0.0	35.2	22%	-4%	7%	14%	-4%	7%	14%
Irrigation area returns to Murrumbidgee River and Yanco Creek	100.4	93.7	99.4	-22%	8%	-4%	-25%	8%	-5%	-26%
ACT returns	33.3	33.3	33.3	0%	0%	0%	0%	0%	0%	0%
Sub-total	**4958.1**	**4879.0**	**4924.9**	**-29%**	**12%**	**-9%**	**-27%**	**11%**	**-9%**	**-27%**
Diversions										
Murrumbidgee Irrigation Area										
General security	496.9	507.4	505.8	-14%	7%	1%	-10%	7%	0%	-12%
Supplementary access	38.8	45.1	43.8	-1%	-7%	-5%	-9%	-8%	-5%	-10%
Stock and domestic	7.3	7.3	7.3	0%	0%	0%	0%	0%	0%	0%
High security	246.0	245.6	245.6	-1%	1%	0%	-2%	0%	0%	-2%
Conveyance	238.1	239.5	239.0	-11%	1%	-1%	-9%	1%	-2%	-10%
Sub-total	**1027.2**	**1045.0**	**1041.6**	**-10%**	**4%**	**0%**	**-8%**	**3%**	**-1%**	**-9%**
Coleambally Irrigation Area										
General security	308.6	306.1	305.1	-24%	7%	-2%	-19%	6%	-4%	-21%
Supplementary access	18.0	19.3	18.6	-25%	4%	-9%	-29%	3%	-8%	-31%
Stock and domestic	3.5	3.5	3.5	0%	0%	0%	0%	0%	0%	0%
High security	8.3	8.3	8.3	-1%	1%	0%	-2%	0%	0%	-2%
Conveyance	126.0	126.0	125.9	-6%	1%	-1%	-5%	1%	-1%	-5%
Sub-total	**464.4**	**463.2**	**461.4**	**-18%**	**5%**	**-2%**	**-15%**	**4%**	**-3%**	**-17%**
Non irrigation area diversions										
General security	415.4	412.8	410.4	-28%	7%	-4%	-23%	6%	-5%	-25%
Supplementary access	50.4	48.2	47.7	-49%	12%	-19%	-56%	11%	-21%	-58%
Stock and domestic	25.4	25.4	25.4	-1%	0%	0%	0%	0%	0%	0%
High security	7.1	7.1	7.1	-2%	1%	0%	-2%	0%	0%	-2%
Sub-total	**498.4**	**493.6**	**490.7**	**-29%**	**7%**	**-5%**	**-25%**	**6%**	**-7%**	**-27%**
Lowbidgee flood control and irrigation district										
Sub-total	**302.8**	**300.8**	**300.1**	**-32%**	**6%**	**-7%**	**-37%**	**4%**	**-10%**	**-39%**
Town water supply - NSW	32.7	32.7	32.7	0%	0%	0%	0%	0%	0%	0%
Town water supply - ACT	57.4	57.4	57.4	4%	1%	1%	3%	1%	1%	3%
Sub-total	**2382.9**	**2392.6**	**2383.9**	**-18%**	**5%**	**-2%**	**-16%**	**4%**	**-4%**	**-17%**

* Values in this row are those used in the river modelling. The correct value for scenarios O, A0 and A should also include residual inflows from Tumut River at Jounama Pondage gauge (410094) to Blowering outlet of 66.4 GL/year. The percentage changes for other scenarios are correct. See the next paragraph for more information.

** Values in this row are those used in the river modelling. The correct value for Scenario A should include the net increase in groundwater losses of 25 GL/year that were estimated in the revised Mid-Murrumbidgee groundwater model. See below for more information.

Table4-6 (cont.). River system model average annual water balance for scenarios O, A0, A, B, C and D

	O	A0	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y			percent change from Scenario A						
Outflows										
End-of-system outflow to										
Billabong Creek at Darlot	326.1	321.8	328.6	-32%	13%	-11%	-34%	11%	-12%	-35%
Forest Creek	53.6	56.6	57.8	-37%	11%	-12%	-39%	9%	-13%	-40%
Murrumbidgee River at Balranald	1225.4	1144.7	1151.9	-50%	23%	-19%	-47%	21%	-21%	-49%
Sub-total	**1605.0**	**1523.1**	**1538.3**	**-46%**	**20%**	**-17%**	**-44%**	**18%**	**-19%**	**-45%**
Net evaporation										
NSW public reservoirs and weirs	29.6	28.6	28.9	12%	5%	11%	27%	4%	10%	25%
ACT public reservoirs	7.0	7.0	7.0	27%	1%	10%	33%	1%	10%	33%
River reach evaporation and small on-river wetlands	115.1	113.2	112.9	7%	3%	5%	16%	3%	5%	16%
Sub-total	**151.7**	**148.8**	**148.8**	**9%**	**3%**	**7%**	**19%**	**3%**	**6%**	**19%**
Unaccounted irrigation supply losses	3.2	4.0	4.0	7%	-20%	3%	10%	-15%	6%	6%
Losses to groundwater**	0.0	0.0	29.6	30%	-2%	8%	35%	100%	132%	155%
Lowbidgee unaccounted evaporation	74.7	62.9	65.2	-63%	42%	-25%	-49%	40%	-26%	-51%
Sub-total	**1834.6**	**1738.9**	**1786.0**	**-40%**	**19%**	**-15%**	**-38%**	**19%**	**-15%**	**-37%**
Unattributed fluxes										
Sub-total	**745.2**	**760.9**	**768.4**	**-34%**	**17%**	**-12%**	**-32%**	**16%**	**-13%**	**-33%**

** Values in this row are those used in the river modelling. The correct value for Scenario A should include the net increase in groundwater losses of 25 GL/year that were estimated in the revised Mid-Murrumbidgee groundwater model. See below for more information.

During the report reviewing process, it was discovered that there was a difference between the Scenario P and Scenario A inflows into Blowering Dam. These inflows should be the same once the contributions from the Snowy Mountains Hydro-electric Scheme have been removed from Scenario A. The difference can be attributed to local catchment contributions from Tumut River at Jounama Pondage (410094) to Blowering Dam that had been omitted from Scenario A. Rerunning the river models was not practical at review stage as this would have required rerunning all of the models linked to the Murrumbidgee, including the Murray region models and the Goulburn Simulation Model (which covers the Goulburn-Broken, Campaspe and Loddon-Avoca regions). The solution was to remove the local catchment contribution of 66.4 GL/year from the Snowy Mountain Hydro-electric Scheme contribution in the without-development results so that a comparison could be made with the developed scenarios. This means that the actual inflow contribution of the Snowy Mountain Hydro-electric Scheme for the Scenario P should be 483.4 GL/year rather than the 417 GL/year reported in this chapter. The impact of not including this local catchment contribution and the developed scenarios on the river modelling results is minor and is footnoted in Table 4-6. The additional 66.4 GL (1.4 percent) of inflows would cause a 1 percent decrease in the relative level of use and less than a 1 percent increase in end-of-system flows for Scenario A. It would have a minor impact on diversions and other results presented in this chapter. The main caveats are that omission of this inflow decreases the absolute values of end-of-system flows (but by less than 1 percent; Section 4.3.5) and increases the relative level of use values by up to 1 percent (Table 4-10).

During the report reviewing process, the DWE provided updated extraction data for the Mid-Murrumbidgee groundwater model. The groundwater model was rerun with these updated data, as the differences were significant. The results from this model are reported in Chapter 6. However, rerunning the river models with the revised groundwater results was not practical for the reasons stated above. The impact on the river modelling results is minor and is footnoted in Table 4-6. The values affected are small compared to the other water balance terms, have only a minor impact on other river modelling results presented in this chapter and to some extent, compensate for the omitted inflows discussed in the previous paragraph. The main caveat is that the absolute values of the end-of-system flows (Section 4.3.5) at low flows should be interpreted with some caution, and the relative level of use values (Table 4-10) would be 0.4 percent higher than reported if the additional groundwater–river fluxes were fully and properly accounted for in the river modelling.

4.3.2 Inflows and water availability

Inflows

There are several ways to calculate total inflows into the river system. The obvious way would be to sum all of the inflows in the model including transfers from the Snowy and the Murray rivers through Finley's Escape. This is 4757 GL/year for the Murrumbidgee region (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. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of the different approaches to calibration. In some cases inflows are inflated and subsequently compensated for by loss relationships. In other cases the losses are inherent in the inflows.

An alternative 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 without-development scenarios are not a representation of pre-European settlement conditions.

The without-development model was run for current and future climate scenarios. The without-development model results implicitly include streamflow leakage induced by current groundwater extraction because the historical streamflow data used to calibrate the model was recorded during a period when groundwater extraction affected river flows. So the without-development water availability model outputs are adjusted for the implicit streamflow leakage caused by groundwater extraction to assess the total without-development surface water availability. No adjustments to without-development model results have been made for the impacts of existing farm dams or changes in forest cover in determining surface water availability under scenarios A, B and C. These impacts are not included as they are difficult to quantify and are not relevant for guiding future policy.

The without-development model was run for each of the scenarios and the results adjusted for implicit groundwater-induced streamflow leakage. A comparison between scenarios for reaches along the Murrumbidgee River is presented in Figure 4-2. This shows that the maximum average annual mainstream flow occurs in subcatchment 4100011 at the Wagga Wagga gauge (410001) with a value of 3842 GL/year under Scenario A (Table 4-7).

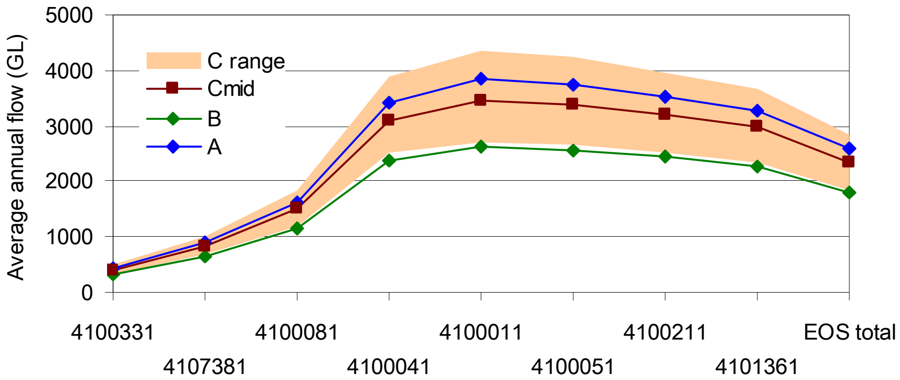

Figure 4-2. Transect of total river flow under scenarios A, B and C (under without-development conditions)

Water availability

Water availability is a function of climate, and thus is assessed for without-development conditions under scenarios A, B and C. Table 4-7 shows (in GL/year):

- the point of maximum water availability for the WSP (DIPNR, 2004) (that is under Scenario O and its associated modelling period) was taken as flows at Wagga Wagga. The value in the Scenario O model was 4340 GL/year. The assessed maximum mainstream flow of 3842 GL/year (Figure 4-2) differs from the Scenario O WSP value because it is for without-development conditions, includes Blowering Dam residual inflows of 66.4 GL/year, excludes the inter-basin volume diverted into the Murrumbidgee River by the Snowy Mountains Hydro-electric Scheme, and is for a different modelling period
- there is no streamflow reduction due to subcatchment inflow reductions caused by current groundwater use
- the water availability calculation is based on the without-development flow at Wagga Wagga. However, in order to account for water diverted into the Murrumbidgee catchment by the Snowy Mountains Hydro-electric Scheme, the inter-basin flow transferred from outside of the Murrumbidgee catchment is added onto the Murrumbidgee without-development flow at Wagga Wagga (assuming all the net additional inflow reaches Wagga Wagga)
- the volume of reductions in streamflow (at the point of maximum flow) caused by river leakage that is induced by current groundwater use and that is implicitly included in the river model calibration is 11 GL/year
- the total surface water availability which is the sum of the above four components is 4270 GL/year.

Table 4-7. Annual water availability under scenarios A, B and C (assessed for without-development conditions, which for Scenario A is synonymous with Scenario P)

	A	B	Cwet	Cmid	Cdry
	GL/y				
Modelled Murrumbidgee without-development maximum average mainstream flow	3842	2613	4368	3466	2710
Mainstream flow reductions					
Due to reductions in inflows caused by current groundwater use	0	0	0	0	0
Due to leakage induced by current groundwater use implicit in model calibration	11	11	11	11	11
Inter-basin volume diverted into Murrumbidgee by the Snowy Scheme*	417	366	437	404	366
Total surface water availability	**4270**	**2990**	**4816**	**3881**	**3087**
		percent change from Scenario A			
Change in surface water availability		-30%	13%	-9%	-28%

*Note: Murrumbidgee without-development inflows include 66.4 GL/year of Blowering residual inflows. The 483.4 GL/year Snowy contribution has been reduced by this amount so the comparison can be made with the developed scenarios

A time series of total annual surface water availability under Scenario A is shown in Figure 4-3. The lowest annual water availability was 1924 GL in 2002 while the highest annual water availability was 13,695 GL in 1955 (assuming a constant net additional inflow into the Murrumbidgee River from the Snowy Mountains Hydro-electric Scheme of 417 GL/year). Figure 4-4 shows the difference in annual total surface water availability from Scenario A to Scenario C. Although the time series includes a constant annual value for the net additional inflow into the Murrumbidgee River from the Snowy Mountains Hydro-electric Scheme, the net additional inflow can vary significantly between individual years, which may impact on these extremes.

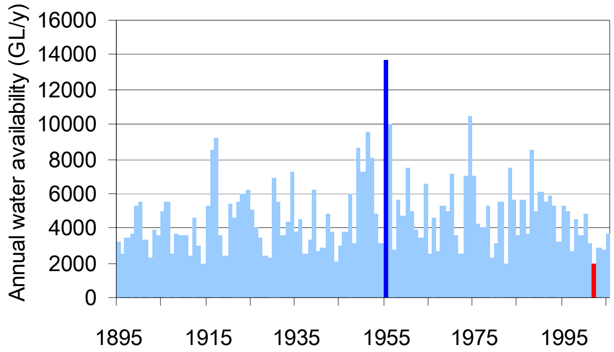

Figure 4-3. Water availability under Scenario A

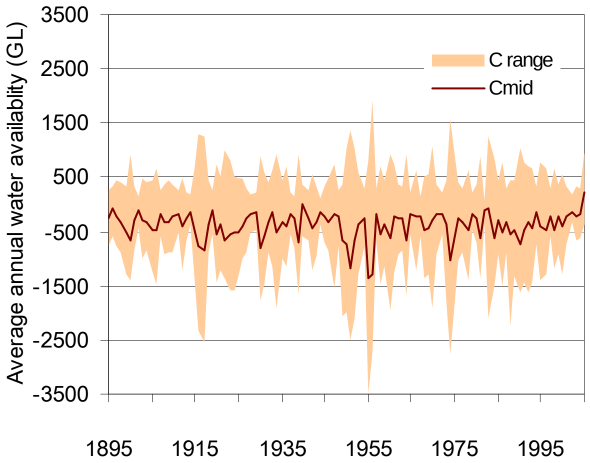

Figure 4-4. Time series of change in total surface water availability under Scenario C relative to Scenario A

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 contains details of the behaviour of each storage for each of the scenarios that includes the lowest recorded storage volume and the corresponding date as well as the average and maximum years between spills. Cotter Dam is not included as the active storage capacity is only 3856 ML and as it is at the bottom of the supply system it is normally full. 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 storage behaviour

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Corin Dam								
Minimum storage volume (ML)	30,242	17,851	34,749	29,230	18,559	34,743	29,228	18,337
Minimum storage date	02/1983	03/1983	02/1983	02/1983	03/1983	02/1983	02/1983	03/1983
Average years between spills	1.3	2.5	1.1	1.9	2.4	1.1	1.9	2.4
Maximum years between spills	5.3	14.4	3.8	7.8	14.4	3.8	7.8	14.4
Bendora Dam								
Minimum storage volume (ML)	7,963	7,963	7,963	7,963	7,963	7,963	7,963	7,963
Minimum storage date	07/1895	07/1895	07/1895	07/1895	07/1895	07/1895	07/1895	07/1895
Average years between spills	1.0	1.9	0.9	1.2	2.0	0.9	1.2	1.9
Maximum years between spills	6.9	12.1	6.8	6.9	12.0	6.8	6.9	12.0
Googong Dam								
Minimum storage volume (ML)	72,141	36,629	71,411	61,404	44,193	70,974	60,832	43,418
Minimum storage date	04/1983	02/1983	04/1983	04/1983	02/1983	04/1983	04/1983	02/1983
Average years between spills	1.0	2.3	0.8	1.4	2.2	0.8	1.4	2.3
Maximum years between spills	4.5	9.2	3.7	4.6	9.2	3.7	4.6	9.2
Burrinjuck Dam								
Minimum storage volume (ML)	26,729	3,250	3,250	3,250	6,327	3,250	3,250	3,250
Minimum storage date	24/2/1909	17/3/1968	8/1/2003	3/2/1909	10/5/1968	3/1/2003	30/1/1909	26/3/1919
Average years between spills	2.7	2.9	2.1	3.6	5.5	2.3	3.8	5.6
Maximum years between spills	16.1	22.2	16	16.2	22.2	16	16.2	24.5
Blowering Dam								
Minimum storage volume (ML)	120,600	25,392	210,670	117,810	32,204	220,390	101,210	24,023
Minimum storage date	20/2/2003	5/4/1968	20/2/2003	21/2/2003	28/4/1968	25/2/2003	21/2/2003	29/6/2006
Average years between spills	3.4	8.6	1.9	4.5	8.4	1.9	5	8.4
Maximum years between spills	14.8	32.8	11.8	17.7	32.7	11.8	17.7	32.7

The time series of storage behaviour for Corin, Bendora, Googong, Burrinjuck and Blowering dams for the maximum period between spills for each of the scenarios is shown in respective figures Figure 4-5 to Figure 4-9. The minimum level in Bendora Dam occurs at the start as the dam does not fall below this minimum over the length of simulation due to the small size of the dam and way in which it is operated.

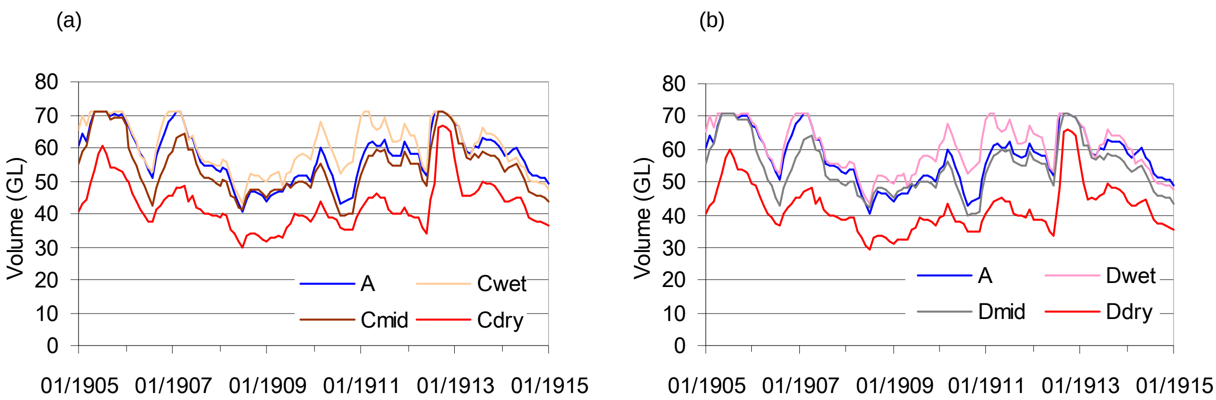

Figure 4-5. Corin Dam behaviour over the maximum days between spills under Scenario A change in storage behaviour under (a) Scenario C and (b) Scenario D

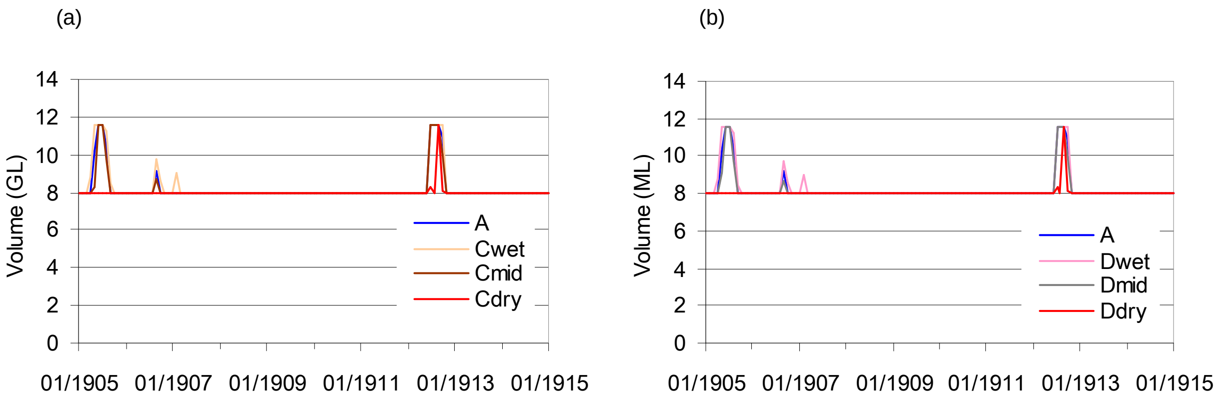

Figure 4-6. Bendora Dam behaviour over the maximum days between spills under Scenario A change in storage behaviour under (a) Scenario C and (b) Scenario D

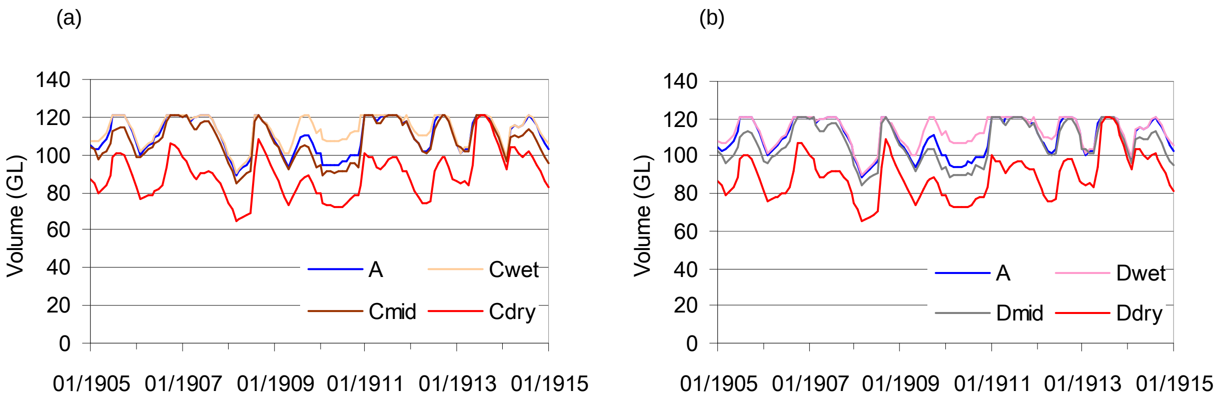

Figure 4-7. Googong Dam behaviour over the maximum days between spills under Scenario A change in storage behaviour under (a) Scenario C and (b) Scenario D

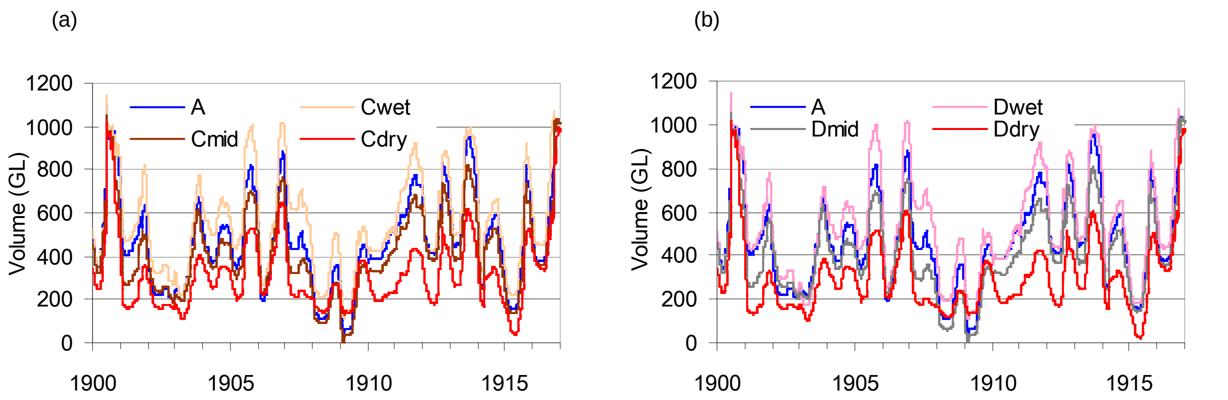

Figure 4-8. Burrinjuck Dam behaviour over the maximum days between spills under Scenario A change in storage behaviour under (a) Scenario C and (b) Scenario D

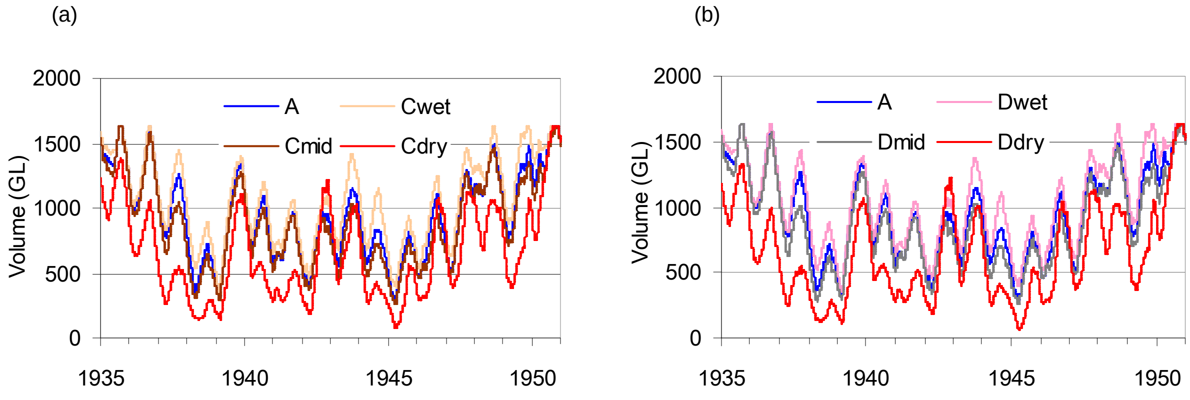

Figure 4-9. Blowering Dam behaviour over the maximum days between spills under Scenario A change in storage behaviour under (a) Scenario C and (b) Scenario D

4.3.4 Consumptive water use

Diversions

Table 4-9 shows the total average annual diversions for each subcatchment () under Scenario A and the percentage change under all other scenarios compared to Scenario A. Figure 4-10 shows total average annual diversions under scenarios A, B, C and D for subcatchment reaches.

Table 4-9. Change in total diversions in each subcatchment relative to Scenario A

Reach	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A						
ACT	57.3	4%	1%	1%	3%	1%	1%	3%
4100041	11.3	-6%	5%	1%	-3%	4%	0%	-4%
4100061	1.6	0%	0%	0%	0%	0%	0%	0%
4100011	11.6	-4%	2%	2%	0%	2%	1%	-1%
4100051	36.1	-23%	6%	-3%	-18%	5%	-5%	-20%
4100211	17.2	-10%	4%	1%	-5%	3%	0%	-6%
4101361	206.6	-32%	8%	-7%	-29%	7%	-8%	-31%
4100401	76.6	-31%	6%	-7%	-27%	5%	-8%	-29%
4100301	17.0	-5%	4%	1%	-2%	3%	1%	-3%
4100341*	125.5	-30%	7%	-5%	-26%	6%	-6%	-28%
Lowbidgee	300.1	-32%	6%	-7%	-37%	4%	-10%	-39%
MIA	1061.3	-10%	4%	0%	-8%	3%	-1%	-9%
CIA	461.5	-18%	5%	-2%	-15%	4%	-3%	-17%
Total	**2383.9**	**-18%**	**5%**	**-2%**	**-16%**	**4%**	**-4%**	**-17%**

* Yanco Creek and Billabong Creek excluding Coleambally Irrigation Area

(a)

(b)

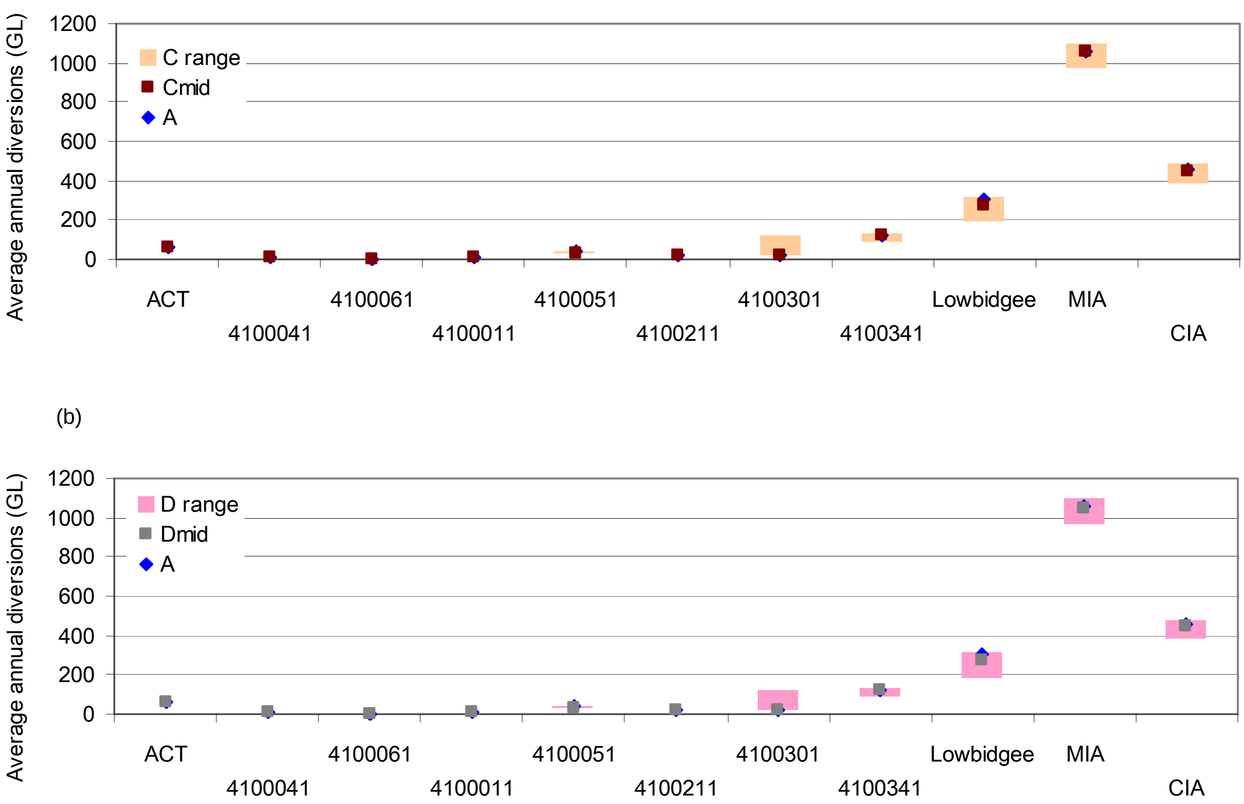

Figure 4-10. Total average annual diversions for subcatchments under (a) scenarios A and C and (b) scenarios A and D

Figure 4-11 shows the annual time series of total diversions under Scenario A and the difference from Scenario A under scenarios B, C and D. The maximum and minimum diversions under Scenario A are 3014 GL in 1959 and 1562 GL in 1902, respectively. These values include diversions into the Lowbidgee Flood Control and Irrigation District from the WSP area.

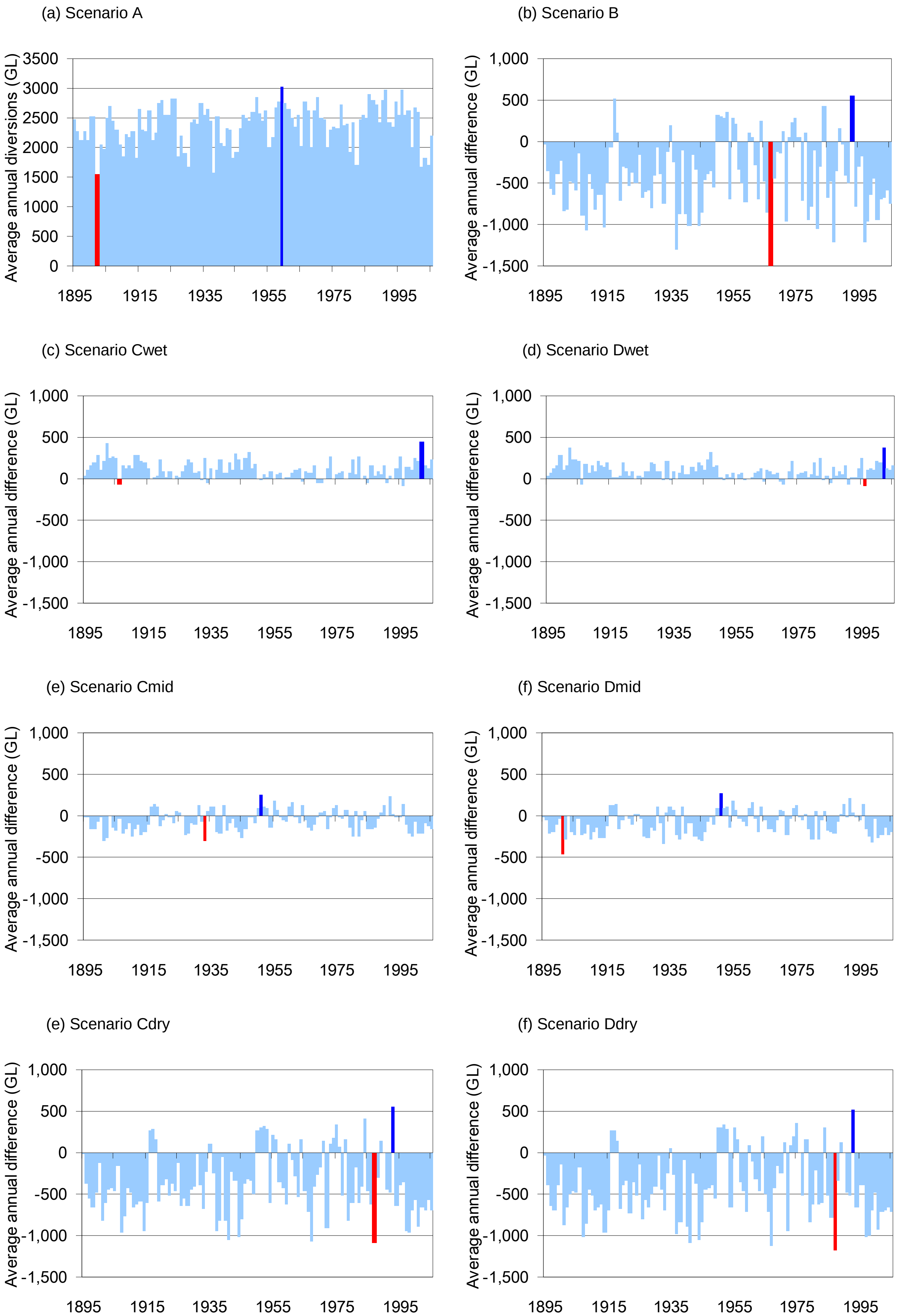

Figure 4-11. Total diversions under (a) Scenario A and difference between total water use under (b) Scenario B, (c) Scenario Cwet, (d) Scenario Dwet, (e) Scenario Cmid, (f) Scenario Dmid, (g) Scenario Cdry and (h) Scenario Ddry

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 was no groundwater use implicit in the inflows during model calibration, however future development modelled in Scenario D will effect subcatchment inflows) and 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, including Snowy inflows (4259 GL/year) to total inflow (4716 GL/year)).

Streamflow use includes:

- leakage to groundwater induced by groundwater use. This includes groundwater use explicitly included in the river models, as well as 11 GL/year of leakage caused by groundwater use implicit in the model calibration (under scenarios A, B, Cwet and Cmid simulation of the long-term equilibrium indicates a net reduction in groundwater loss relative to that implicit in the IQQM model. For example, under Scenario A long-term simulation indicates an overall reduction of 6 GL/year in leakage to groundwater, which in conjunction with an 11 GL/year leakage implicit in the model calibration, gives an actual net leakage of 5 GL/year)
- total net diversions, defined as the net water diverted for the full range of water products. Net diversions are calculated as the total diversions less irrigation area returns and urban returns. 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.

Table 4-10 shows the level of use indicators for each of the scenarios for the Murrumbidgee region and the Murrumbidgee WSP area. The Scenario A level of use for the region is extremely high with 53 percent of the total available surface water resource being diverted for use (including Australian Capital Territory town water supply and regulated diversions to the Lowbidgee Flood Control and Irrigation District). The Scenario A net diversion for Australian Capital Territory town water supply is 24 GL/year and Lowbidgee is 300 GL/year. The level of use for the Murrumbidgee WSP area can be calculated by subtracting these from the usage, which gives a very high level of usage of 45 percent under Scenario A. This differs from the WSP limit of 44 percent (Chapter 2) because of the different modelling period where common modelling period inflows are 1 percent less and also because the Blowering Dam residual inflows were not considered, which also accounts for approximately 1 percent of inflows.

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

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Total surface water availability	4270	2990	4816	3881	3087	4816	3881	3087
	GL/y							
Subcatchment use*								
Groundwater use impacts	0	0	0	0	0	0	0	0
Future farm dam impacts	-	-	-	-	-	20	18	16
Future plantation forestry impacts	-	-	-	-	-	6	5	5
Streamflow use								
Use outside Water Sharing Plan area								
ACT water supply net diversion	24	27	24	25	26	24	25	26
Lowbidgee flood control and irrigation district	300	204	317	279	189	312	271	184
Sub-total	**324**	**230**	**341**	**303**	**214**	**336**	**295**	**210**
Use in Water Sharing Plan area								
Total net diversions	1927	1622	2015	1894	1677	2004	1876	1651
Leakage induced by groundwater use**	5	7	6	5	11	36	42	46
Sub-total	**1932**	**1628**	**2021**	**1899**	**1688**	**2040**	**1918**	**1697**
Total use	**2257**	**1859**	**2363**	**2202**	**1902**	**2402**	**2237**	**1928**
	percent							
Relative level of use - Water Sharing Plan area	45%	54%	42%	49%	55%	43%	50%	56%
Relative level of use - region	53%	62%	49%	57%	62%	50%	58%	62%

*Note usage in the Upper Murrumbidgee and Murrumbidgee subcatchments is implicit in the model calibration and derived inflows and has not been considered as part of the use in the region.

**Values in this row are those used in the river modelling. The correct value for Scenario A should include the net increase in groundwater losses of 25 GL/year that were estimated in the revised Mid-Murrumbidgee groundwater model.

Use during dry periods

Table 4-11 shows the average use for all water products, as well as the average annual use 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 impact on water use during dry periods.

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

Annual Diversion	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A						
Lowest 1-year period	1561.9	-58%	12%	-17%	-52%	12%	-18%	-53%
Lowest 3-year period	1731.7	-38%	14%	-8%	-37%	12%	-12%	-40%
Lowest 5-year period	1996.6	-37%	8%	-8%	-35%	7%	-11%	-37%
Average	2383.9	-18%	5%	-2%	-16%	4%	-4%	-17%

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. The WSP refers to licence shares rather than licence volumes for high security, general security, conveyance and supplementary access licences. Reliability is calculated here by comparing diverted volumes in ML against the total share components of 2,043,432 unit shares for general security irrigation, 298,021 unit shares for high security irrigation, 373,000 unit shares for irrigation corporation conveyance, and 220,000 unit shares for supplementary access irrigation. Stock and domestic licences and high security town water supply (local utility) licence volumes are referred to in ML. These are 35,572 ML/year and 23,400 ML/year, respectively.

The actual volume reported for town water supply in the Murrumbidgee model is significantly greater than 23.4 GL/year because the model includes town water supply diversions that are not part of the regulated river system covered by the WSP. Consequently the reliability is reported as a ratio to Scenario A. The increases in reliability for the Australian Capital Territory in drier conditions are due to increased demands caused by increased evapotranspiration (Table 4-12).

The Murrumbidgee WSP does not include the Lowbidgee Flood Control and Irrigation District. Reliability of Lowbidgee diversions under different climate change and development scenarios is reported as a ratio to Scenario A diversions as there are no specific licence volumes for the diversion into the Lowbidgee area. Table 4-12 shows the average reliability under Scenario A and the relative change under scenarios B, C and D.

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

Licensed private diversions	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	fraction diverted at 1 ML/unit share							
General security (2,043,432 unit shares)	0.60	0.47	0.64	0.59	0.50	0.64	0.58	0.49
High security (298,021 unit shares)	0.88	0.86	0.88	0.87	0.86	0.88	0.87	0.86
Conveyance (373,000 unit shares)	0.98	0.89	0.99	0.97	0.90	0.99	0.96	0.90
Supplementary access (220,000 unit shares)	0.50	0.37	0.52	0.44	0.34	0.51	0.44	0.33
Stock and domestic (35,572 unit shares)	1.02	1.02	1.02	1.01	1.02	1.02	1.02	1.02
Lowbidgee flood control and irrigation district (compared to existing diversion)	1.00	0.68	1.06	0.93	0.63	1.04	0.90	0.61
Town water supply (compared to existing diversion)	1.00	1.03	1.00	1.01	1.02	1.00	1.01	1.02
NSW	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ACT	1.00	1.04	1.01	1.01	1.03	1.01	1.01	1.03

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 shows the difference between the maximum yearly allocated general security water for the Murrumbidgee system for each of the scenarios in volume reliability plots. The Murrumbidgee system is limited to a maximum allocation of 100 percent including a 15 percent carryover. The total general security volume is 2043 GL/year where the long-term extraction limit for the Murrumbidgee allows a diversion of 1 ML per unit share.

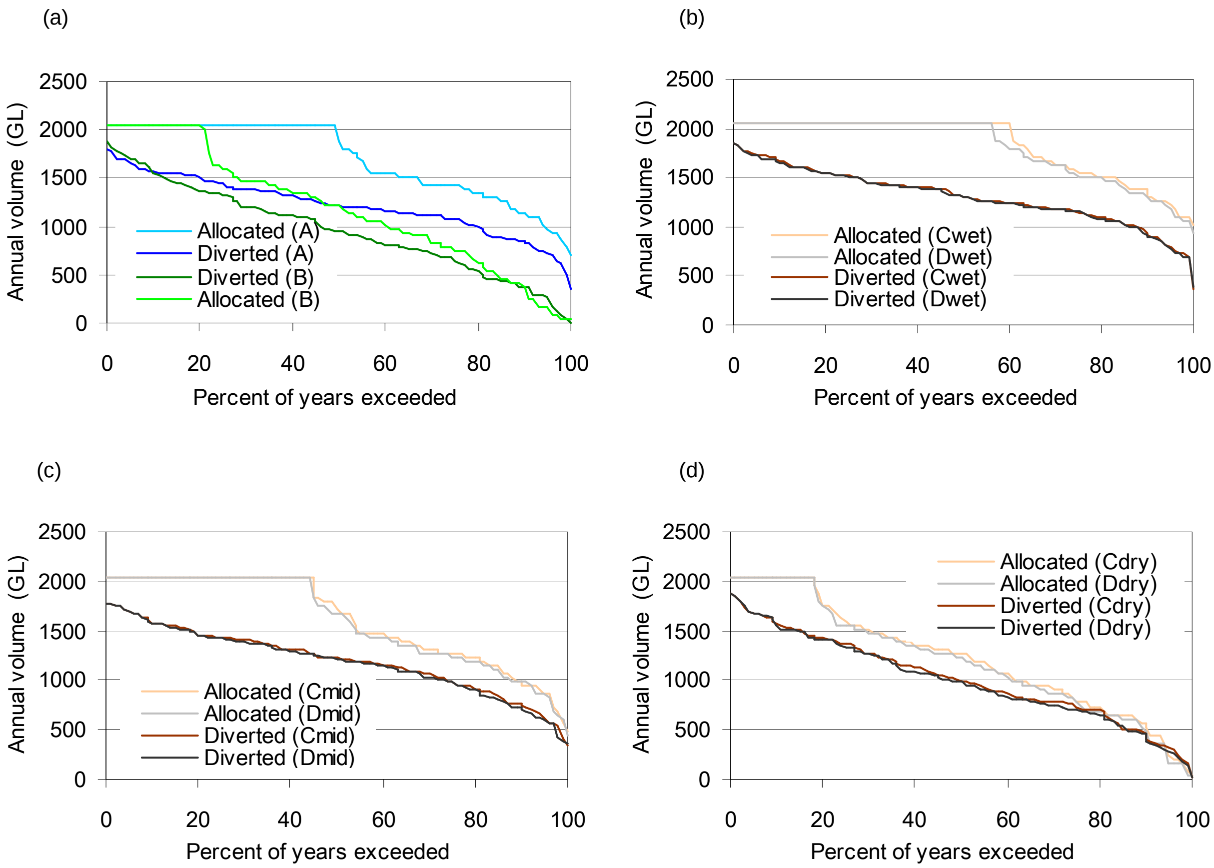

Figure 4-12. Murrumbidgee general security reliability under scenarios (a) A and B (b) Cwet and Dwet, (c) Cmid and Dmid, (d) Cdry and Ddry

Figure 4-13 shows the reliability of the New South Wales supplementary access for the Murrumbidgee under each of the scenarios including the ranges for scenarios C and D.

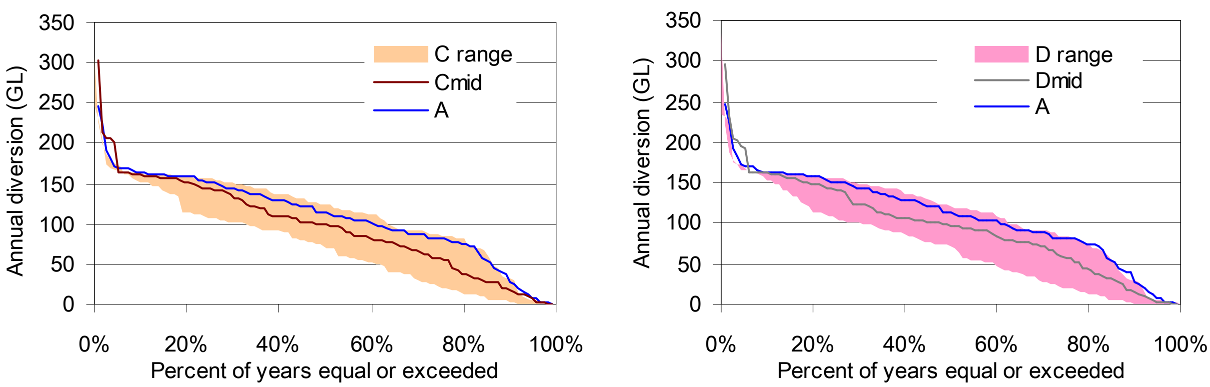

Figure 4-13. Reliability of supplementary access for New South Wales unregulated diversion reliability under scenarios A, C and D

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

Table 4-13. Summary of average general security reliabilities

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y							
Allocated water	1702.5	1187.8	1825.5	1621.5	1229.4	1803.0	1602.0	1202.1
Diversion	1221.3	960.6	1307.8	1201.9	1014.9	1298.6	1185.0	992.3
Difference	481.2	227.2	517.6	419.6	214.4	504.4	417.0	209.8

Table 4-14 shows the reliability of supply for Canberra water supply based on levels of demand restriction in the Australian Capital Territory Water Supply model for the different scenarios. Restrictions act to constrain urban demands during periods of low storage or inflow. Different restrictions are applied according to the model's assessment of the available water resource. The Australian Capital Territory Water Supply model represents four different levels of demand restriction – Levels 1 to 4 where Level 4 represents the most severe case where a 100 percent reduction in non-discretionary water use is applied. Table 4-14 presents the number of water-years when different levels of demand restrictions occurred under each scenario. The maximum level of restriction that occurred in any of the scenarios was Level 3.

The results under Scenario A indicate that there are no restrictions during the common modelling period. This is different to what has been happening more recently in the water supply system. The reason that these results differ is because the model includes current infrastructure and water saving measures such as:

- reinstating Cotter Dam to the system
- extracting water from the Murrumbidgee River
- infrastructure that allows Cotter River and Murrumbidgee River extractions to be stored in Googong Dam
- reductions in environmental releases
- permanent water conservation measures and other demand reduction policies.

The combined result of all these changes is a substantial improvement in water supply security from that observed historically.

Table 4-14. Summary of Canberra urban supply restrictions

	Australian Capital Territory urban water restrictions							
Level	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	percent of years (July - June) which have restrictions							
1	0.0%	7.2%	0.0%	0.0%	7.2%	0.0%	0.0%	7.2%
2	0.0%	0.9%	0.0%	0.0%	0.9%	0.0%	0.0%	0.9%
3	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

4.3.5 River flow behaviour

There are many ways of considering the flow characteristics in river systems. Three different indicators are provided: daily flow duration, seasonal average flows and daily event frequency. These are considered for two locations: mid-river where the river changes from gaining to losing flow and end-of-system where the model terminates.

The river flow behaviour for the development scenario does not include the residual inflows from Tumut River at Jounama Pondage gauge (410049) to Blowering Dam which is 66.4 GL/year for Scenario A.

Mid-river flow characteristics

The flow regime will vary depending on the location in the river that is selected. The location of the middle of the system for this analysis is defined as the position where the river changes from gaining to losing. The selection of this site is discussed in Section 4.3.2 and is the Wagga Wagga gauge (410001).

Figure 4-14 shows the daily flow duration curves under scenarios A, P and B, 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 at lower flows.

Regulation of the river has significantly redistributed the magnitude of flow in the river at Wagga Wagga, changing the shape of the flow duration curve from Scenario P. The frequencies of floods of all magnitudes are reduced, except for the very largest floods. Regulated system storage redistributes these high flows to produce a consistent increase in the frequency of all flows smaller than approximately 15,000 ML/day.

Comparison of Scenario P and Scenario A with the Scenario Cmid indicates that the effect of Scenario C relative to Scenario A is considerably smaller than the effect of Scenario A relative to Scenario P.

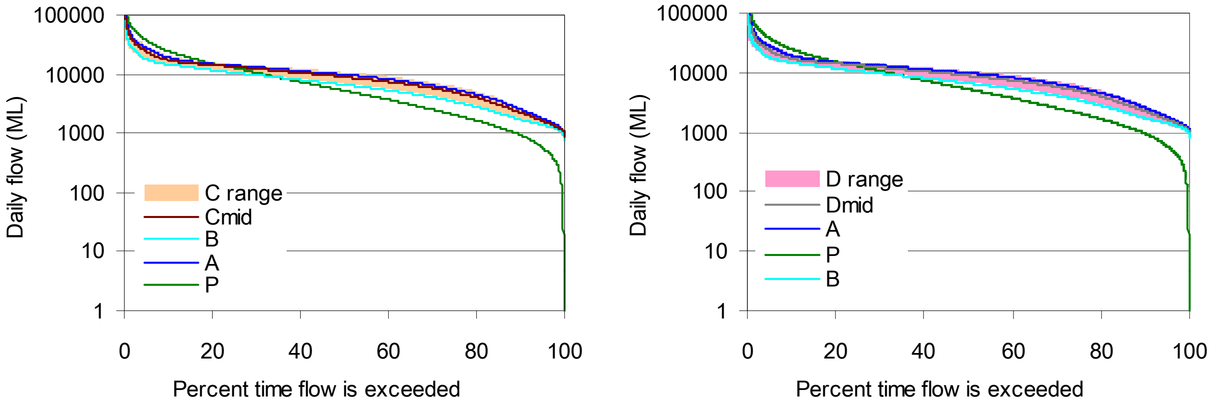

Figure 4-14. Daily flow duration curves under scenarios P, A, B, C and D at Wagga Wagga gauge (410001)

Figure 4-15 shows the mean monthly flow under scenarios P, A, B, C and D. The plot shows that regulation of the river has affected the seasonality of the river, especially in summer and early autumn when storage releases are being conveyed to the large irrigation areas downstream of Wagga Wagga. This produces a relatively constant flow regime in the river during this period. Burrinjuck Dam WSP translucency rules between April and October and unregulated winter tributary inflow downstream of the dams preserve some of the winter month seasonality.

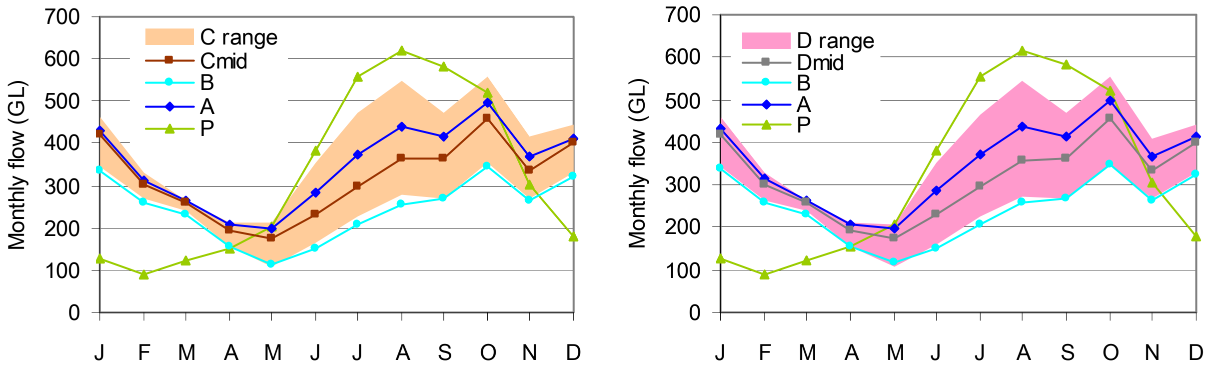

Figure 4-15. Average monthly flow at the end of the gaining reach under scenarios P, A, B, C and D

Table 4-15 shows the size of daily events with two-, five- and ten-year recurrence intervals under scenarios P, A, B, 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. Relative to Scenario P, Scenario A has a 32 percent reduction in the size of two-year events and a 25 percent reduction in the larger five- and ten-year return interval events. Scenario Cmid indicates a further 21 percent reduction in the size of ten-year events relative to Scenario A, or a 39 percent reduction relative to Scenario P. These changes demonstrate the impact of regulation on small- to medium- sized flood flows. Scenario Cmid indicates a further reduction in flood flow magnitudes. This is due to lower long-term average storage inflows and lower average storage volumes in Burrinjuck and Blowering reservoirs, resulting in increased capture of flood volumes.

Table 4-15. Daily flow event frequency under scenarios P, A, C and D

Return interval	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
years	ML/d			percent change from Scenario A					
2	71,121	48,240	-29%	35%	-2%	-28%	34%	-7%	-29%
5	112,951	83,700	-33%	24%	-5%	-36%	24%	-6%	-36%
10	170,376	130,146	-41%	13%	-21%	-42%	12%	-22%	-43%

End-of-system flow characteristics

Figure 4-16, Figure 4-17 and Figure 4-18 show the flow duration curves for the Murrumbidgee River at Balranald gauge (410130), Forest Creek (410148) and Billabong Creek at Darlot gauge (410134). No without-development model was available for Forest Creek, so it is not included on the Forest Creek figures. Regulation of the river has significantly changed the volume and timing of flows reaching Balranald. The shape of the Scenario P flow duration curve is similar to that seen at the Wagga Wagga gauge (410001), except that the Scenario P river loses sufficient water to cause cease-to-flow within the modelled period. The shape of the regulated river Scenario A flow duration is different to that seen at Wagga Wagga. This reflects the removal of regulated licensed flows between Wagga Wagga and Balranald. The Scenario A flow duration also shows the effect of the minimum flow condition at Balranald of 200 ML/day or 300 ML/day, depending on regulated system allocations. The flow regime in Billabong Creek at Darlot is also changed by regulated releases into Billabong Creek at Jerilderie Weir. The Scenario P model indicates that the creek only flows in wet periods when there is sufficient floodplain flow. Minimum flow requirements and irrigation drainage returns produce a flat and relatively static flow regime under Scenario A regulation.

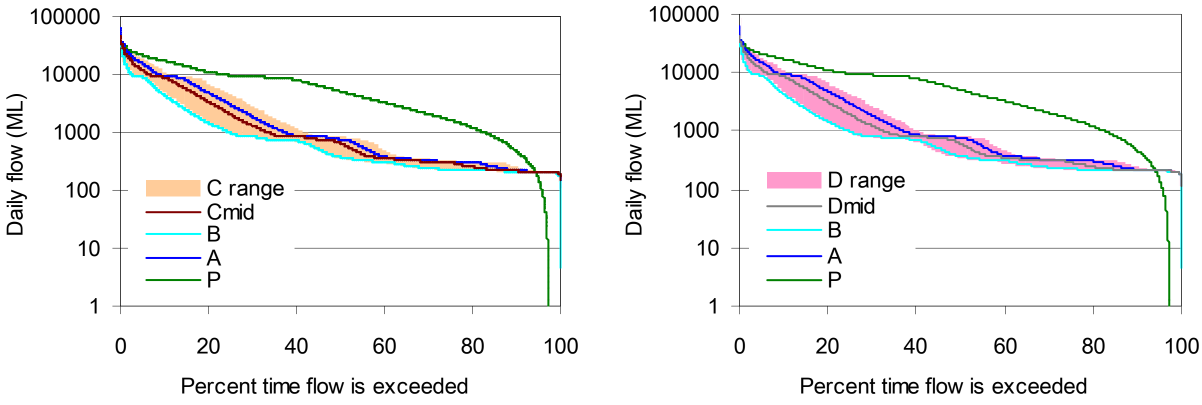

Figure 4-16. Daily flow duration curves for the end-of-system flows at Balranald gauge (410130) under scenarios P, A, B, C and D

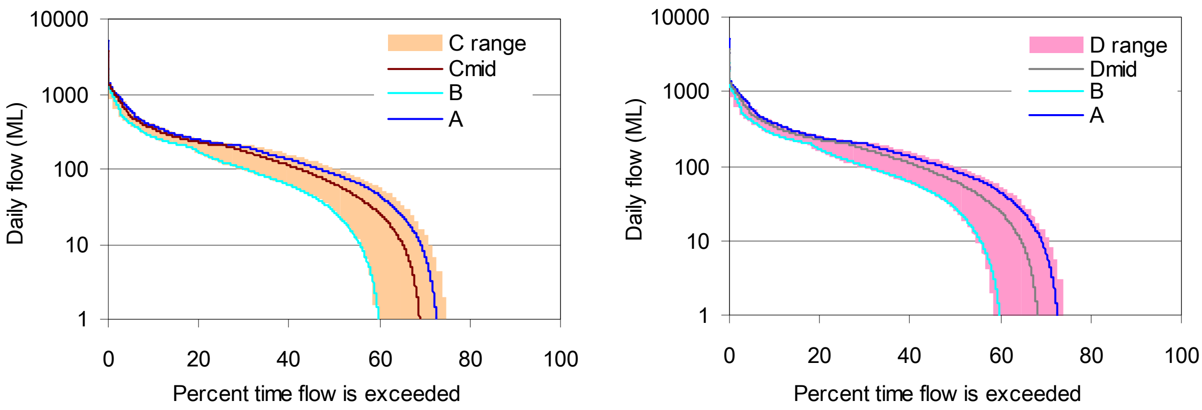

Figure 4-17. Daily flow duration curves for the end-of-system flows for Forest Creek (410148) under scenarios A, B, C and D

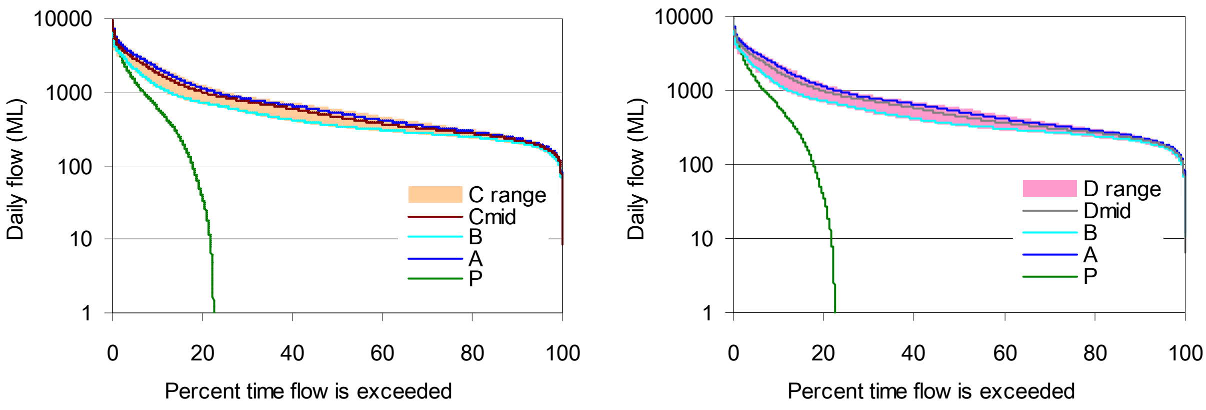

Figure 4-18. Daily flow duration curves for end-of-system flows for Billabong Creek at Darlot (410134) under scenarios P, A, B, C and D

Figure 4-19, Figure 4-20 and Figure 4-21 show the mean monthly flow under scenarios P, A, B, C and D for each of the end-of-system flow gauges. No without-development model was available for Forest Creek, so it is not included on the Forest Creek figures. The figures show the large change in end-of-system flows at both Balranald, and in Billabong Creek at Darlot compared to without-development conditions under all scenarios. Natural flows in the Murrumbidgee River are significantly reduced due to flow diversions, while flows in Billabong Creek are significantly increased by irrigation drainage flows relative to natural catchment runoff especially between December and May. The seasonality at

Balranald is restored compared to Wagga Wagga but are significantly smaller in winter when storages are storing inflows. The seasonality at Billabong Creek in summer and autumn is significantly altered from a non-flowing regime to constant flow.

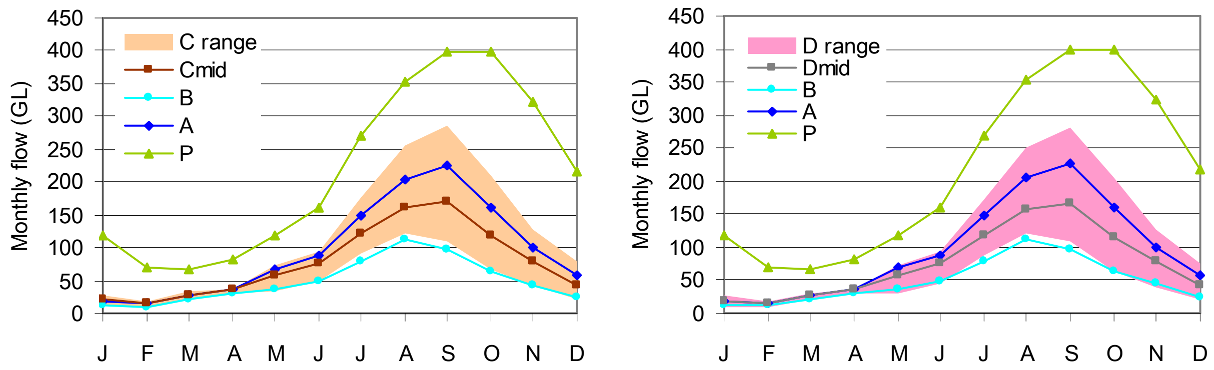

Figure 4-19. Seasonal flow curves at Balranald gauge (410130) under scenarios P, A, B, C and D

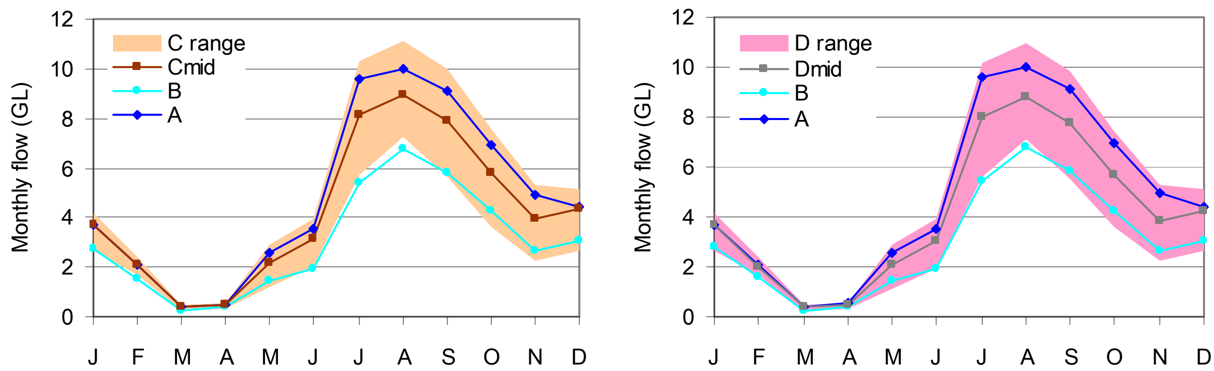

Figure 4-20. Seasonal flow curves at Forest Creek (410148) under scenarios A, B, C and D

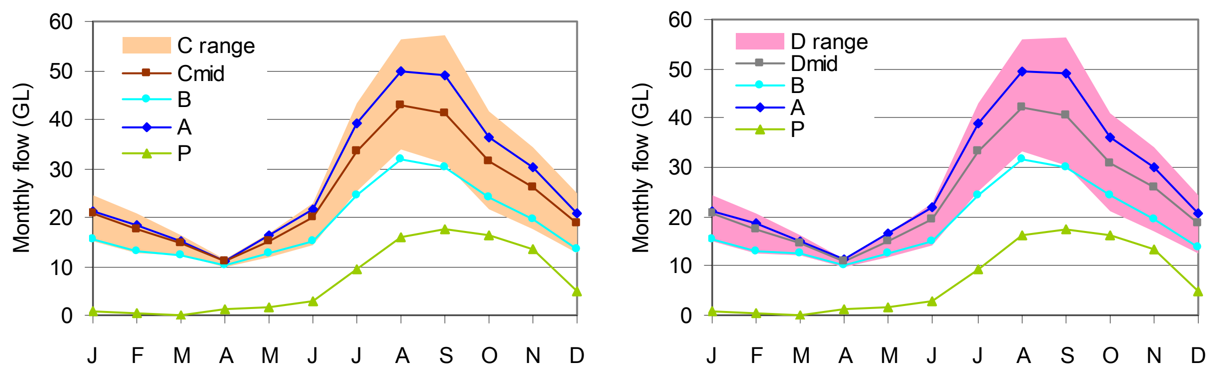

Figure 4-21. Seasonal flow curves at Billabong Creek at Darlot gauge (410134) under scenarios P, A, B, C and D

The percentage of time that flow occurs under these scenarios is presented in Table 4-16. 'Cease-to-flow' is when model flows are less than 1 ML/day.

Table 4-16. Percentage of time flow occurs at the end-of-system under scenarios P, A, B, C and D

Outflow Name	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Billabong Creek at Darlot	23%	100%	100%	100%	100%	100%	100%	100%	100%
Murrumbidgee River at Balranald gauge	97%	100%	100%	100%	100%	100%	100%	100%	100%
Forest Creek	0%	73%	60%	74%	69%	59%	74%	68%	58%

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 4-17 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 and as a proportion of the maximum mainstream average annual flow under Scenario A.

Table 4-17. Relative level of available water not diverted for use under scenarios A, B, C and D

Relative level of non-diverted water	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Non-diverted water as a percent of total surface water availability	47%	38%	51%	43%	38%	50%	42%	38%
Non-diverted share relative to Scenario A non-diverted share	100%	56%	122%	83%	59%	120%	82%	58%

Combined water shares

Figure 4-22 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.

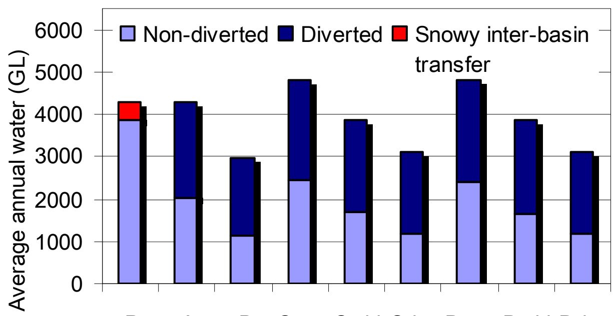

Figure 4-22. Comparison of diverted and non-diverted shares of water under scenarios P, A, B, C and D

4.4 Discussion of key findings

Scenarios

This project used models of the Snowy Mountains Hydro-electric Scheme, the unregulated Upper Murrumbidgee, the Murrumbidgee below the major irrigation dams, and the Australian Capital Territory water supply system. The Murrumbidgee model was used by DWE to prepare a WSP for the Murrumbidgee Regulated River Water Source (DIPNR, 2004). Results presented in this report may differ from numbers published in the original WSP modelling related reports due to the different modelling period, the new flow inputs from upstream models and the consideration of feedback between the Murray region models and the Murrumbidgee model and between the Murrumbidgee model and the Snowy Hydro model. There is a 1 percent decrease in inflows for the common modelling period used in this project compared to those used to develop the WSP (Table 4-6).

Scenarios A0 and A are presented so that the impacts of current levels of groundwater extraction at dynamic equilibrium can be considered (Chapter 6). Results for scenarios A0 and A are slightly different as there is a 5.6 GL/year net groundwater gain (Table 4-6).

Future farm dam and plantation forestry development would cause a 0.6 percent (20 GL/year) and 0.1 percent (6 GL/year) respective decrease in inflows into the system (Chapter 3). Future groundwater development would increase regulated river leakage losses to groundwater by a further 37 GL/year. The combined impact of these changes is a 2 percent reduction in total net diversions and a 2 percent reduction in end-of-system outflows.

The combined effect of future development with the best estimate 2030 climate would be a 9 percent reduction in inflows. This scenario would also cause a 4 percent reduction in diversions and a 19 percent reduction in end-of-system flows. The diversion and end-of-system flows impacts are based on current WSP rules that may change in the future to accommodate environmental needs and as a response to the impacts of drought, bushfires and climate change.

Storage behaviour

Burrinjuck and Blowering dams significantly affect the flow regime in the Murrumbidgee and Tumut rivers and regulate 77 percent and 87 percent of inflows, respectively. The maximum number of years between spills for Burrinjuck and Blowering dams is 16 and 14 years, respectively under Scenario A. The average number of years between spills is considerably less at 3 years for Burrinjuck and Blowering dams, due to the wetter climatic conditions after 1950.

Consumptive use

There is no impact on high security users in any of the scenarios as general security allocations are greater than zero for the entire period modelled (Figure 4-12). When there is a general security allocation the high security users (irrigation and town water supply) will receive their full entitlement due to carryover reserve in the resource assessment. The average annual volume of water supplied to Canberra does not vary significantly between Scenario A and the best estimate 2030 climate scenario. The WSP rules try to preserve the security of irrigators, particularly in the Murrumbidgee Irrigation Area where most high security licences are held. Reductions in inflow do not impact uniformly on all water users. Lower priority licences and discharge into the Lowbidgee Flood Control and Irrigation District incur higher impacts. Figure 4-12 shows that the under-utilisation of general security licences in Scenario A is almost fully utilised in the dry climate scenarios. End-of-system flows are reduced by a disproportionately high amount relative to the changes in inflows and licensed diversions. Under the dry climate scenarios B, Cdry and Ddry, water security is not fully preserved at the expense of end-of-system flows.

Modelling is based on the WSP and changes may result in a redistribution of impacts between licence holders and the environment.

The Australian Capital Territory water supply is met under all scenarios and with only level 2 restrictions in the dry climate scenarios. This reflects the reliability of the Australian Capital Territory water supply system under current infrastructure and operating rules. The demands in the model represent current population and water saving policies. If population growth was considered to 2030 there would be considerably more restrictions.

Flow behaviour

Mid-river flows in the Murrumbidgee were altered significantly by regulation causing a ‘flattening’ of the flow duration curve at Wagga Wagga, a reduction in flood volumes and an increase in lower flows. Regulation also changed the seasonal cycle in the river, increasing flows in summer and early autumn and reducing flows in winter. The best estimate climate would not significantly change the current flow regime but it would reduce the size of flows across the entire flow duration curve. The impact of development to-date is greater than the best estimate climate impact.

The impact of current development on average end-of-system flows for the Murrumbidgee River at Balranald gauge (410130) is also considerably more than the reduction in inflows due to climate change and development (Figure 4-19).

Current development has reduced the volume of flows at Balranald and diversions upstream of the gauge and minimum flow conditions have altered the shape of the flow duration curve.

Regulation has also altered the flow regime in Billabong Creek from its ephemeral without-development conditions (Figure 4-21). Current development flows in the creek are preserved by a minimum flow condition and irrigation drainage return flows. The best estimate and dry extreme 2030 climates would cause less flow at end-of-system points consistently across all months. The wet climate extreme and future development scenario has slightly more flow across all months.

Without-development seasonal flow patterns at end-of-system points have generally been preserved in scenarios A, B, C and D. The volume of flow at Balranald was reduced by regulation and would be reduced further under the best estimate climate, particularly during higher flow periods in winter months. The volume of flow in Billabong Creek at Darlot is increased by regulation. The best estimate climate would reduce the size of this increase in winter months.

Water availability and level of use

The water availability considers inter-basin transfers from the Snowy Mountains Hydro-electric Authority as part of the available resource. This water is in excess of natural inflows and is estimated by taking the difference between modelled developed and without-development inflows. The difference is assessed below Tantangra Dam (291 GL/year less inflow for Scenario A) and at the Tumut gauge (410006) on the Tumut River (708 GL/year additional inflow for Scenario A). This makes the net gain from inter basin transfers 417 GL/year for Scenario A. As the developed models are missing the residual inflows from Jounama Pondage to Blowering Dam (66 GL/year for Scenario A) the inter basin transfer should be 483 GL/year. For reasons stated earlier this was left as 417 GL/year so comparisons could be made against the developed scenarios. The estimate of the inter-basin transfer from the original DWE models is 496 GL/year for the period 1 July 1913 to 30 June 2003. If this is adjusted for the change in inflows over the longer common modelling period of 1 July 1895 to 30 June 2006 this is approximately 484 GL/year.

There are differences between the level of use numbers quoted in the WSP (DIPNR, 2004) and this assessment (Table 4-9 and Table 4-10). The WSP assesses the long-term average water use as 1925 GL. This assessment is based on the 1999/2000 level of development and the water management rules specified in the WSP. In this project the comparable average annual water use is 2257 GL, or 1933 GL excluding net Australian Capital Territory town water supply diversions and Lowbidgee District diversions. The small difference in numbers, after the additional diversions have been removed, is due to the different historical periods simulated and the omission of Blowering Dam residual inflows. Currently 53 percent of the available resource is diverted or 45 percent if Murrumbidgee WSP area is considered. Some of the diversions to the Lowbidgee District are not consumed and have environmental benefits to the Lowbidgee Wetlands.

The best estimate climate (Scenario Cmid) would increase the proportion of the resource diverted to 57 percent. Inflows under the best estimate climate would be reduced by 9 percent while the current WSP restricts the reduction in diversions to 2 percent. This reduces the remaining volume of non-diverted flows. Scenario D would increase the proportion of the available resource diverted to 58 percent. The additional losses to groundwater from the river under Scenario D would further reduce diversions by 2 percent.

4.5 References

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5 Uncertainty in surface water modelling results

The following assessment of uncertainty in the surface water modelling results was conducted to provide an independent comparison of the river 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 modelling (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 the main points of reference to actual conditions, and (ii) ungauged inferred inflows and losses in the models 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 models might predict future patterns of flow.

5.1.1 Issues and observations

- The Murrumbidgee region has a denser climate and streamflow gauging network than the Murray-Darling Basin (MDB) average. The region is gauged and understood well enough for reliable modelling.
- Water accounts were established for 12 reaches: one isolated reach in the upper Murrumbidgee and 11 reaches covering the system from the two main storages to the end of the Murrumbidgee River and Billabong Creek. Overall model performance was very good to excellent for the accounted reaches.
- Uncertainty in future climate is greater than uncertainties internal to the river models. Future developments in cropping practices, water use efficiency and water trade are the next greatest uncertainties, because of the limited accuracy and completeness of diversion records and the importance of diversions in the overall water balance.

5.1.2 Key messages

- The modelling reproduces observed streamflow patterns very well and produces estimates that agree well with water balance accounts.
- The projected changes in flows due to climate change are greater than model uncertainty under the dry scenarios and within model uncertainty under the wet and medium scenarios in some cases.
- The modelling provides strong evidence of changes in flow pattern due to prior development and some evidence that projected impacts of future development may be significant towards the end of the Murrumbidgee River.

5.2 Approach

5.2.1 General

River modelling was undertaken 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 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 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 performance in simulating observed stream flow patterns
- the projected changes in flow pattern under the scenarios compared to model performance in reproducing historical flow patterns.

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 boundary conditions are outside historically observed conditions, such as in similar climate change studies.

Qualitative model assessment is preferably done by consulting experts (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.

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

Overall river model uncertainty is the sum 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 project 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 is not attempted herein. A possible framework for considering the implications of the assessed uncertainties is shown in Table 5-1.

Table 5-1. 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 the New South Wales Department of Water and Energy (DWE)). A report that included the results of the river model (IQQM) calibration for the Murrumbidgee River was provided (Salbe et al., 2007). 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

Purpose

Water balance accounting provides the independent set of different water balance components (by reach and by month) needed to inform the uncertainty analysis undertaken for this project. Chapter 1 describes generic aspects of the water accounting methods and also covers the aspects of the remote sensing analyses used to estimate wetland and irrigation water use and inform calculations for attribution of apparent ungauged gains and losses. Aspects of the methods that are region specific are presented below.

Framework

The available streamflow data for this region was adequate for water accounting for 1990/91 to 2005/06. Water accounts were established for 12 successive reaches: one isolated reach of the upper Murrumbidgee River, two reaches of the Tumut River and Billabong Creek, and seven reaches of the mid and lower Murrumbidgee River. Figure 5-1 shows associated catchment areas, the reaches for which river water accounts were developed (‘accounting reach’) and tributary catchments with gauged inflows (‘contributing catchment’). ‘Ephemeral waterbodies and floodplain’ are areas classified as subject to periodic inundation. Black dots and red lines are nodes and links in the river model respectively. The catchment areas are also related to model reaches in Table 5-2.

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

Water accounting reach	Subcatchment code(s)	Description
1	4100501, 4100670	Murrumbidgee River @ Billilingra
2	4100061	Tumut River @ Tumut
3	4100391, 4100590, 4100710	Tumut River @ Brungle Bridge
4	4100041	Murrumbidgee River @ Gundagai
5	4100017, 4100430, 4100450, 4100013, 4100016, 4100015, 4100014, 4100480	Murrumbidgee River @ Wagga Wagga
6	4100051	Murrumbidgee River @ Narrandera
7	4100161	Billabong Creek @ Jerilderie
8	4100211	Murrumbidgee River @ Darlington Point
9	4101341	Billabong Creek @ Darlot
10	4101361	Murrumbidgee River @ d/s Hay Weir
11	4100401, 4101303	Murrumbidgee River @ d/s Maude Weir
12	4101301	Murrumbidgee River @ d/s Balnarald Weir
Not assessed		Reason
	4100331, 4100620, 4105430	Contributing headwater catchment (to reach 1)
	4101021, 4100570	Contributing headwater catchment (to reach 2)
	4100081, 4100380, 4100440, 4100250	Contributing headwater catchment (to reach 4)
	4100610, 4100470	Contributing headwater catchment (to reach 5)
	4101030	Contributing headwater catchment (to reach 6)
	4100910	Contributing headwater catchment (to reach 7)
	4100770, 4107171, 4107420, 4107041, 4107001, 4107900, 4107050, 4107564, 4107563, 4107291, 4107611, 4107381, 4107601, 4107750, 4105710, 4107480, 4100721, 4100321, 4105451, 4105421, 4110020, 4107450, 4101761	Insufficient streamflow data for water accounts
	4100240, 4100760, 4101070, 4101410, 4107130, 4107310, 4100260	Sufficient streamflow data but do not contribute to any assessed reach
	4101302	Ungauged subcatchment

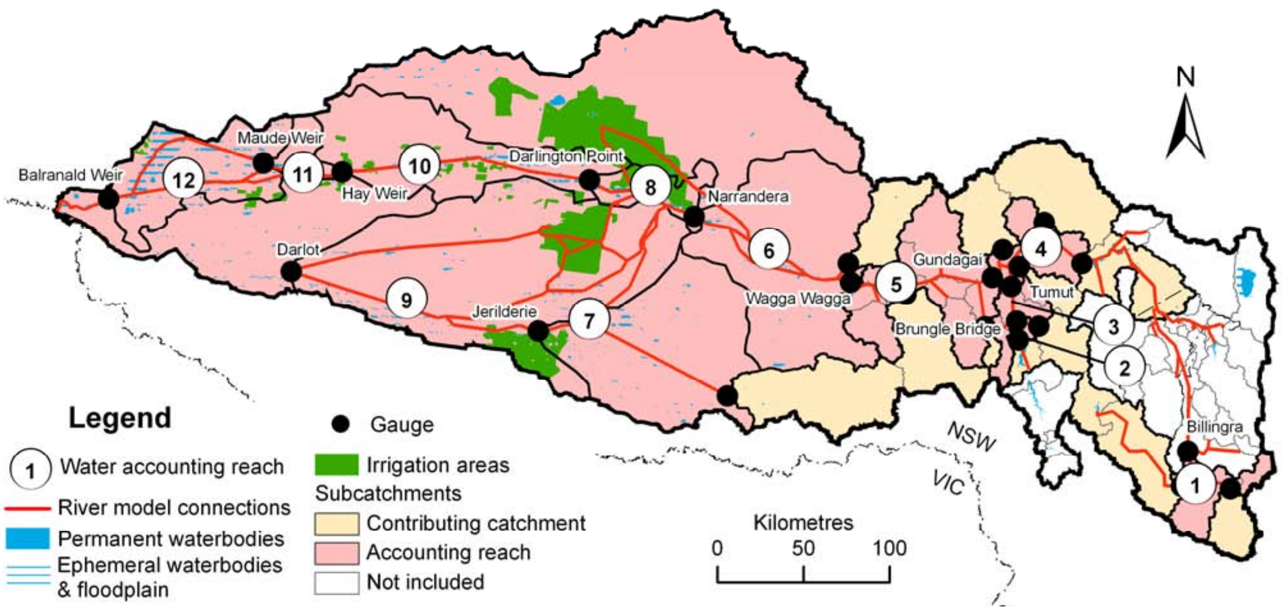

Figure 5-1. Map showing the subcatchments used in modelling, and the water accounting reaches

5.2.4 Diversion Data

Wetland and irrigation water use

The results of the remote sensing analyses (Chapter 1) are shown in Figure 5-1. Extensive irrigation areas and wetlands were identified along the Murrumbidgee River and Billabong Creek below Narrandera (reaches 7 to 12).

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.

5.2.5 Model uncertainty analysis

River modelling results and water accounts were used to derive measures of model uncertainty. The different analyses are described below. Details on the equations used to calculate the indicators are not provided here but can be found in Kirby et al. (2008). Calculations were separate for each reach 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 offtakes, 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 also presented in Appendix C.

Comparison of modelled and accounted reach water balance

The water balance terms for river reaches were compared for the period of water accounting period as produced by the baseline river modelling (Scenario A) and as accounted. Large divergence is likely to indicate large uncertainty in reach water fluxes and therefore uncertainty in the river modelling 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. NSME 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 undertaken 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 for river modelling. 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. 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 change-uncertainty ratio 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 region is the ninth most densely gauged region in the MDB. The density of the streamflow, rainfall and evaporation gauging networks is up to twice the MDB average. Most of the streamflow gauging covers the Murrumbidgee and Tumut rivers, Billabong and Mirrool creeks, and the upper Murrumbidgee contributing tributaries. Rainfall gauging is well distributed but more concentrated in the upper Murrumbidgee and the Australian Capital Territory. Evaporation gauging occurs mostly in the irrigation areas, Wagga Wagga and the Australian Capital Territory.

Table 5-3. Some characteristics of the gauging network of the Murrumbidgee region (87,348 km^2) compared with the entire Murray-Darling Basin (1,062,443 km^2)

Gauging network characteristics	Murrumbidgee		Murray-Darling Basin	
	number	per 1000 km^2	number	per 1000 km^2
Rainfall				
Total stations	819	9.38	6,232	5.87
Stations active since 1990	419	4.80	3,222	3.03
Average years of record	43		45	
Streamflow				
Total stations	116	1.33	1,090	1.03
Stations active since 1990	89	1.02	881	0.83
Average years of record	23		20	
Evaporation				
Total stations	20	0.23	152	0.14
Stations active since 1990	8	0.09	104	0.10
Average years of record	27		27	

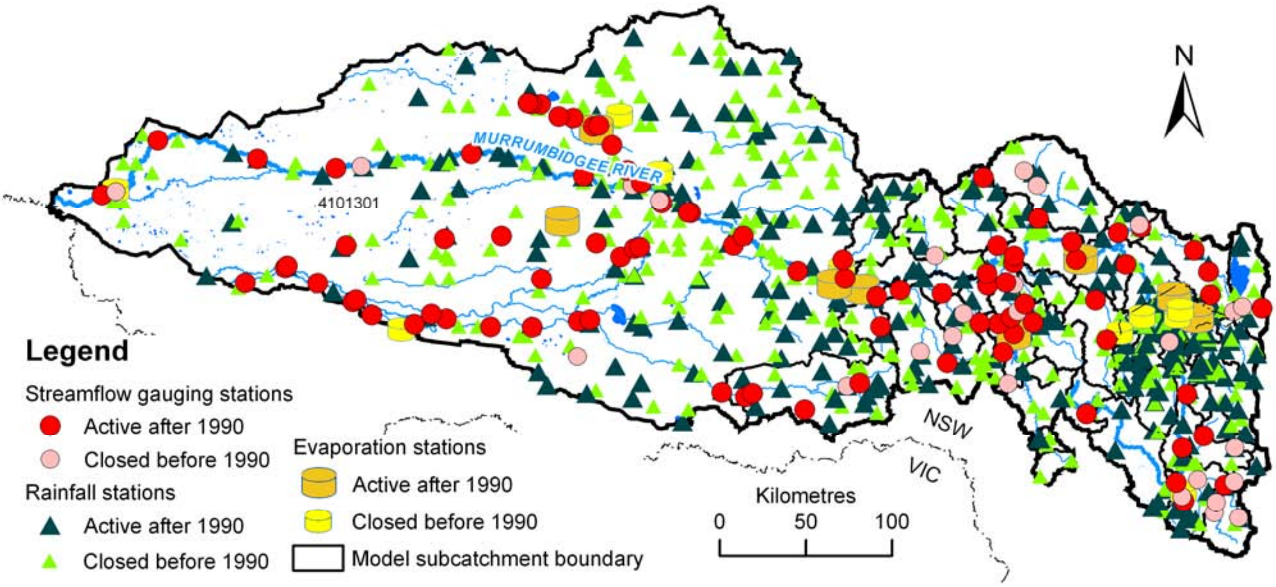

Figure 5-2. Map showing the rainfall, stream flow and evaporation observation network, along with the subcatchments used in modelling

5.3.2 Review of model calibration and evaluation information

The river modelling for the Murrumbidgee region (see Chapter 4) used a combination of four models:

- the Murrumbidgee model – for the Murrumbidgee below the major irrigation dams (Salbe et al., 2007)
- the newly developed Upper Murrumbidgee model of the upper Murrumbidgee River system between Tantangara Dam and Burrinjuck Dam (CSIRO, 2008)
- the Snowy Hydro model of the Snowy Mountains Hydro-electric Scheme
- the Australian Capital Territory Water Supply model of the territory's water supply system (ActewAGL, 2004).

This section summarises the Murrumbidgee model – for the Murrumbidgee below the major irrigation dams – and the data used for its calibration and validation. This model's performance is then assessed based on information reported for the lower part of the Murrumbidgee River system.

Model description

The Murrumbidgee River is a complex and highly regulated system with numerous effluents, billabongs and other wetlands, two major headwater storages and a number of re-regulating storages, major irrigation developments, and various environmental needs. The two headwater storages in the Murrumbidgee Valley are Burrinjuck Dam on the Murrumbidgee River and Blowering Dam on the Tumut River.

An IQQM was developed and implemented (Salbe et al., 2007) for the Murrumbidgee Valley from the headwaters of Burrinjuck and Blowering dams to the confluence of the Murray and Murrumbidgee rivers, Yanco Creek, Colombo Creek, Forest Creek above Warriston Weir, and Billabong Creek from its confluence with Colombo Creek to the Murray River.

The aim of developing the Murrumbidgee IQQM was to establish a water management tool capable of simulating the major hydrologic processes in the valley on a daily basis over a period of more than 100 years. The modellers assessed impacts of the Murray-Darling Basin Ministerial Council Cap on surface water diversions and the Murrumbidgee Regulated River Water Sharing Plan (DIPNR, 2004) under long-term climatic conditions. River operation rules and water saving options were also examined using the model. The Murrumbidgee IQQM was first developed in the mid-1990s and was updated regularly to best represent catchment inflows, river flow routing parameters, transmission losses and water demands within the valley. The latest flow calibration includes the recent drought up to 2001/02.

The IQQM Lowbidgee sub-model relies on a simple empirical representation of district diversions (gauging of diversions is limited). The model covers available surplus, sharing of that surplus between the Maude and Redbank systems, environmental needs, and the limited amount of available water in any one year. No modelling of the internal flow processes beyond a crude estimate of return flows in high diversion years is done.

No allowance was made in the IQQM calibration for concurrent surface and groundwater use or for the possible impact of groundwater use on river flow losses (Salbe et al., 2007).

Data availability

Thirteen long-term rainfall stations with good quality and continuous data were selected to represent the spatial rainfall distribution and to simulate crop water requirements. Rainfall data was also used to: compute the contribution of rain falling onto the surface of reservoirs and river reaches, approximate major irrigation canal offtake rain rejections, and generate and extend tributary inflows using the Sacramento rainfall-runoff model. The rainfall data prior to July 1997 was gap-filled using regression relationships. SILO-generated gridded rainfall data was used after July 1997.

Evaporation data is required by IQQM to drive irrigation demand, compute evaporation losses from reservoirs, and generate catchment inflows using rainfall-runoff models. A limited number of ‘daily-read’ evaporation pans exist and selection of appropriate gauges relied on: the availability of records (>15 years), continuity and quality of data, and availability of nearby rainfall stations covering long-term record. Three available long-term evaporation stations were selected. Estimated crop evapotranspiration data from CSIRO at Griffith (075174) was used exclusively to simulate crop water demands. The main irrigation areas (Murrumbidgee and Coleambally) are close enough to Griffith to use the same evapotranspiration estimates (Salbe et al., 2007). Crop factors for rice, wheat, pasture and other enterprises relied on experimental work carried out by CSIRO at Griffith. Some changes were made to these factors in the calibration process.

Streamflow data are required for all main stream and tributary inflow gauging stations represented in the model to derive loss and flow routing parameters for each river reach, to achieve mass balance within each river reach, to model extended sequences of tributary inflows and as inputs to scenario modelling. An extensive network of main stream gauging stations measures flows in the Murrumbidgee River. There are also a number of tributary gauging stations measuring inflow contributions downstream of Burrinjuck and Blowering dams. The gauging stations on the tributaries are located some distance upstream from the confluence with the main river, resulting in large areas of ungauged catchment. There are also some ungauged contributions from smaller streams and local area runoff. Fifteen stations were selected on the main stem using enough sites to limit the length of river reaches. The sites had good quality long-term records with a minimum number of missing periods (Table 5-4).

The fourteen gauging stations were selected on the tributaries and 18 stations on the Yanco-Colombo-Billabong system (Table 5-4). Selection relied on the significance of flow contribution, availability of long-term, good quality records, and availability of nearby streamflow stations. Ungauged inflows were estimated during flow calibration using simple relationships with gauged flows.

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

Station	Location	Period of record
Murrumbidgee River main stem		
410001	Murrumbidgee River @ Wagga	1968 to 2004
410003	Murrumbidgee River @ Balranald	
410004	Murrumbidgee River @ Gundagai	1969 to 2004
410005	Murrumbidgee River @ Narrandera	1984 to 2004
410006	Tumut River @ Tumut	1970 to 2004
410008	Murrumbidgee River @ d/s Burrinjuck Dam	1990 to 2006
410021	Murrumbidgee River @ Darlington Point	1984 to 2004
410023	Murrumbidgee River @ d/s Berembed Weir	1999 to 2004
410036	Murrumbidgee River @ d/s Yanco Weir	1984 to 2004
410039	Tumut River @ Brungle Bridge	1970 to 2004
410040	Murrumbidgee River @ d/s Maude Weir	
410073	Tumut River @ Oddy's Bridge	1975 to 2006
410078	Murrumbidgee River @ Carrathool	
410082	Murrumbidgee River @ d/s Gogeldrie Weir	1984 to 2004
410130	Murrumbidgee River @ d/s Balranald Weir	
Tributary inflows		
410012	Billabong Creek @ Cocketgedong	1973 to 2006
410013	Main Canal @ Berembed	
410024	Goodradigbee River @ Wee Jasper	1914 to 2006
410025	Jugiong Creek @ Jugiong	1914 to 2006
410038	Adjungbilly Creek @ Darbalara	1967 to 2006
410044	Muttama Creek @ Coolac	1938 to 2006
410047	Tarcutta Creek @ Old Borambola	1938 to 2006
410057	Goobarragandra River @ Lacmalac	1957 to 2006
410061	Adelong Creek @ Batlow Road	1947 to 2006
410083	Yanco Main Southern Drain @ Outfall	
410091	Billabong Creek @ Walbundrie	1981 to 2006
410093	Old Man Creek @ Kywong	1976 to 2006
410103	Houlaghans Creek @ Downside	1965 to 2006
410137	Beavers Creek @ Mundowey	1999 to 2006
Yanco-Colombo-Billabong system		
410007	Yanco Creek @ Offtake	1979 to 2006
410012	Billabong Creek @ Cocketgedong	1973 to 2006
410014	Colombo Creek @ Morundah	1978 to 2006
410015	Yanco Creek @ Morundah	1977 to 2006
410016	Billabong Creek @ Jerilderie	1984 to 2006
410017	Billabong Creek @ Conargo (Puckawidgee)	1968 to 2006
410091	Billabong Creek @ Walbundrie	1981 to 2006
410108	Coleambally Drainage Canal 800 @ Outfall	1992 to 2006
410110	Drainage Canal 500 @ Outfall	1977 to 2006
410133	Coleambally Outfall Drain @ Near Bundy	1993 to 2006
410134	Billabong Creek @ Darlot	1978 to 2006
410135	Coleambally Catchment Drain @ Farm 544	1992 to 2003
410148	Forest Creek @ Warriston Weir	1980 to 2006
410168	Billabong Creek @ d/s Hartwood Weir	1995 to 2006
410169	Yanco Creek @ Yanco Bridge	1995 to 2006
410170	Billabong Creek @ u/s Innes Bridge	1995 to 2006
410191	Coleambally Catchment Drain @ Outfall into Yanco Creek	2002 to 2006
41010309	Forest Creek @ Offtake	2006 to 2007

Town water supply was not modelled in detail in the Murrumbidgee IQQM and is represented as a fixed annual demand with a monthly pattern of use. Twelve significant towns were identified and modelled with a combined annual entitlement of 39 GL in the regulated sections of the Murrumbidgee and Tumut rivers.

Stock and domestic entitlements total approximately 36 GL in the valley. Use of stock and domestic licences by general security irrigators were not recorded explicitly and are incorporated into the general security irrigation diversions data.

Data for diversions from the Murrumbidgee River into the Murrumbidgee Irrigation Area (MIA) at the Sturt Canal offtake, Main Canal flows, and diversions to the Coleambally Irrigation Area (CIA) were available for the entire calibration period. Farm-gate deliveries were also available. Most diversions are by the two major irrigation corporations for which daily diversion totals are available. Quality control on these measurements is done by hydrographers. All river pumping via private entitlements of 20 ML or more requires flow metering. Records of individual meter readings exist from the early 1980s and enable calculation of annual diversion totals. Meters are read monthly for only larger users making it difficult to obtain accurate monthly diversion totals. However, operational monthly use totals that include estimated use and irrigation orders are available from the late 1970s. The operational data were used in conjunction with meter readings to estimate monthly diversions (Salbe et al., 2007).

On-allocation and off-allocation usage were not recorded separately in the licensing database. Daily totals were inferred for the MIA and the CIA from the period of off-allocation data commencing in the 1989/90 season. Canal diversion measurements at both Coleambally and Sturt Canal offtake structures and under submerged conditions are complicated and historical diversions are in error. Recorded Coleambally Canal diversions were recalculated in 2001 using more accurate discharge coefficients, and updated again in 2004. The Coleambally offtake was fitted in 2002 with an ultrasonic direct flow measurement device that compares well with the revised flow estimation procedure. No recalculation of Sturt Canal diversions was undertaken.

Estimates from water orders of crop type and area irrigated were available for the irrigation areas except for 1988 to 1997 for the CIA and 1988 to 2002 for the MIA. Similar irrigated cropping information was available for the river pumping based on annual surveys conducted up to 1995. Crop area information was collected in the Yanco Creek system via the automated central water ordering system for three years, starting in 2000. Since the mid-1990s the New South Wales Department of Natural Resources also collected remote sensing information of rice areas annually as part of its environmental monitoring. These estimates correspond reasonably well with rice areas previously collected as part of the water ordering systems described above (Salbe et al., 2007).

Crop area data were available throughout the calibration period for the CIA but were incomplete in some years. No data were available at a finer resolution than district totals. Spatial crop data in the MIA were available for a very limited period. River pumping data were available until the mid-1990s. Negligible flow measurement occurs within the Lowbidgee district and there was none during the calibration period. No systematic crop area data collection occurs within the Lowbidgee district.

Model calibration and validation procedures

The selection of a calibration period was constrained by the availability of crop area data and the need to represent a wide range of climatic conditions. Rice deregulation occurred in 1988 and cropping became summer dominated. The period of 1982 to 1995 was selected for overall calibration.

A calibration process was developed to proceed sequentially down the river system and progressively eliminate unknowns. It included the following steps:

- 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 varied between reaches but was generally from 1984 to 2004.
- Diversion calibration reproduced observed irrigation extractions given observed crop areas and the crop mix. Crop factors and irrigation efficiency, soil moisture storage and initial rainfall losses were calibrated. Licence river pumping volumes from around 2000 were used to represent data for the 1990s because it was more reliable and not much permanent trade occurred in the intervening period. Pump capacity data were unreliable but this did not matter because no on-farm storages were represented. The calibration period was 1992 to 1995.
- The area planting decision step involved calibrating an irrigator’s decision-making process in reproducing observed planted crop areas. Maximum and minimum area, crop mix and farmers planting decision process are calibrated. Water allocations were at least 100 percent all years of the calibration period and no explicit area calibration was done other than to set the maximum planted areas. Anecdotal information and observations for the 2002 to 2007 drought were used to calibrate area planting decisions.

- Storage calibration reproduced observed volumes in the major on-river storages and involved calibrating irrigation ordering and river operation processes. The calibration period was 1982 to 1995.

In each step of the calibration, specific parameters were estimated and all other parameters replaced with observed data. Inflow estimates contributed from ungauged catchments were made during the flow calibration process using a correlation with streamflow gauging data for a nearby catchment. Calibration performance was assessed separately for the total regulated system (on- and off-allocations and total diversions), MIA and CIA (diversions and deliveries), river pumping and Lowbidgee diversions. Overall model calibration quality was assessed using a combination of selected key indicators for diversions, storage behaviour and flow at key gauging sites.

Model performance

A quality assessment guideline was adopted to assess overall model performance. It had 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 (greater than 20 percent). The above limits were varied in some cases depending on the indicator and uncertainty in the measured data (Salbe et al., 2007).

The quality of flow calibration was high to very high for the whole flow range and low to moderate for low flows at some sites (Darlington Point, Yanco Creek Offtake, Billabong Creek at Darlot and Balranald). Storage behaviour at both Burrinjuck and Blowering dams were simulated very closely to the observed data (high quality rating).

Reproduction of diversions was rated very high for all irrigation areas except for the Murrumbidgee River pumpers where there was a mismatch in the earlier years of the calibration period. Lower watertables may have caused higher seepage and therefore higher demand. The pre-1990 river pumping data were not as accurate as later data and this might have also contributed to the mismatch. The assumption that all pasture was winter pasture (rather than annual pasture) was accurate for more recent times. This assumption was inaccurate for practice in the 1980s and caused underestimation of diversions as annual pasture requires more water than winter pasture. The quality of model simulated end-of-system flows was adequate for the comparison of alternate management options. The overall model calibration quality was assessed using a combination of these indicators and considered of very high quality in reproducing historical behaviour.

Identified areas of weakness or improvements

A number of uncertainties and weaknesses in the model were identified (Salbe et al., 2007):

- There is considerable uncertainty in the measurement of farm gate deliveries. For example, underestimation of diversions because of the use of Dethridge wheels for measurement was around 14 percent, with greater errors at lower diversion rates. This weakness does not impact on the results of the current project, as model results are expressed as water diversions at the river offtake.
- Crop areas (other than rice) were based on farmer estimates obtained in annual surveys and also may not be very accurate. These differences are expected to be minor however (DWE, pers. comm.).

Three priority areas for model improvement were identified:

- Licensed water users extracting water from unregulated streams were not included in the Murrumbidgee IQQM. Until 2000 these licences operated on the basis of a maximum irrigable area and pumping limit (usually an indicated flow level at the nearest flow gauging station). In 2000 these licences were converted to volumetric limits. Generally very little data was collected on historical water extractions and cropping through these licences. Also hidden in streamflow data is the effect of extractions using unregulated licences outside the influence of regulated flows from Burrinjuck and Blowering dams. This effect was negligible for the purposes of determining the Cap for the regulated system, but important for general model performance.

- No allowance was made in the model for conjunctive surface and groundwater use or the possible impact of groundwater use on river flow losses. Unaccounted losses recently increased markedly in the mid-Murrumbidgee and were related to surface–groundwater interactions. The model uses a stationary flow-loss relationship and therefore cannot simulate these dynamics. Surface–groundwater interactions were included in the modelling undertaken as part of the current project.

5.3.3 Model uncertainty analysis

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. Eleven of these reaches are included in the Murrumbidgee model and one reach (Reach 1) is included in the Upper Murrumbidgee model. Conclusions follow:

- Gains in the reaches with water accounts are generally well to extremely well gauged (73 to 99 percent) except for Reach 7 where only 48 percent of gains appear to be gauged. The high level of gauging is mainly due to the importance of regulated flows from upstream in the water balance of the various reaches. Reach 7 is a part of Billabong Creek and has considerable local inflows.
- Outflows and losses are dominated by outflows in reaches 1 to 5 (that is, above Narrandera) and therefore extremely well gauged (93 to 99 percent) but less so in the lower reaches where river and floodplain losses, distributary flows and errors in diversion records become more important (reaches 6 to 12; 50 to 73 percent gauged).
- Overall, the river reach water balance is gauged very to extremely well (83 to 96 percent) in reaches 1 to 5, and fairly to very well in reaches 6 to 12 (65 to 83 percent).
- Attribution of gains and losses using SIMHYD estimates of local runoff, diversion data and remote sensing help to explain much of the ungauged gains and losses (82 to 99 percent of the combined reach gains and losses), particularly where gauging is most incomplete.
- Overall, most gains and losses are gauged or can be attributed, and therefore the water balance of the part of the Murrumbidgee River assessed is well understood.

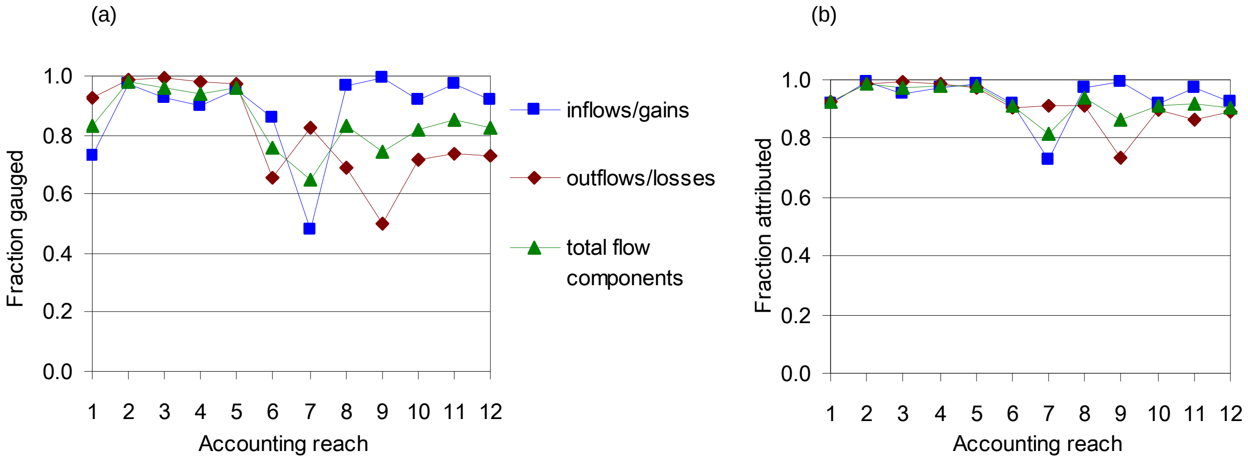

Figure 5-3. The fraction of inflows/gains, outflows/losses and the total of water balance components that (a) is gauged or (b) could be attributed in the water accounts

Comparison of modelled and accounted reach water balance

A summary of water balance for the reaches as simulated by the river modelling and derived by water accounting can be found in Appendix C. The water balances for reaches 2 to 12 are combined in Table 5-5. An interpretation follows:

- The system is strongly to slightly gaining above Wagga Wagga (reaches 1 to 5) and in Billabong Creek (reaches 7 and 9). The remaining part of the system, that is, the Murrumbidgee River between Wagga Wagga and Balranald Weir (reaches 6, 8 and 10 to 12), loses more water than it gains.
- The definition of tributary and local inflows sometimes varies between the model and the water accounting and therefore only the sum of inflows can be compared.
- No attempt was made to estimate groundwater exchanges in water accounting due to the lack of direct data. It was simulated through the modelling done for this project and was estimated to represent a net gain of 5 GL/year (about 0.1 percent of total simulated gains) given historical groundwater extraction rates.

- The combined main stem inflows (2848 GL/year) derive from the Tumut River above Oddy's Bridge (1689 GL/year or 60 percent of total main stem inflows), from Burrinjuck Dam in the Murrumbidgee River (1044 GL/year or 37 percent) and from Billabong Creek above Walbundrie (115 GL/year or 4 percent). The simulated corresponding inflows (2765 GL/year) are 83 GL/year or 3 percent less than this gauged volume (mainly due to a 7 percent lower estimate of Tumut River inflows; Appendix C).
- Combined end-of-system outflows accounted for are 1091 GL/year, passing Balranald in the Murrumbidgee River (816 GL/year or 75 percent of outflows) and Darlot on Billabong Creek (275 GL/year or 25 percent). The simulated total outflows are very close to this (8 GL/year or 1 percent difference).
- The sum of simulated local and tributary inflows (1370 GL/year) is very close to the sum of accounted equivalent terms (gauged tributary inflows and SIMHYD estimates; 1345 GL/year), differing by 25 GL/year or 2 percent.
- Simulated diversions for the water accounting period (1970 GL/year) are almost identical to diversion records used in accounting (1974 GL/year), with a difference of only 4 GL/year.
- Simulated losses from the river and floodplains, groundwater net exchange and unspecified losses (1042 GL/year) exceed the accounted river and floodplain losses (668 GL/year), by 375 GL/year or 56 percent. Part of this difference is likely to be included in the high unattributed losses and noise of 1597 GL/year.
- Gauged water balance terms (including diversion records) represent 60 percent of the total water balance. Another 14 percent can be attributed using SIMHYD local runoff estimates (811 GL/year) and estimates of river and floodplain losses (668 GL/year).
- Unattributed gains are slightly smaller than unattributed losses: for the entire accounted system combined unattributed gains (including measurement noise and errors in estimates used in accounting) represent 1138 GL/year or 21 percent of total apparent gains, whereas unattributed losses (including measurement noise) represent 1597 GL/year or 30 percent of total apparent losses. Their sum represents 26 percent (2735 GL/year) of the total water balance.
- The greatest part of the unattributed gains and losses occurs in Reach 6 (30 percent of the total) and is probably due to errors in the disaggregation of annual diversions at the weir, and reaches 8 (14 percent) and 10 (12 percent) where both diversions and estimated river and wetland losses are considerable and therefore errors in estimates of either terms may be responsible.
- Overall, the system is reasonably well gauged and well understood. Gauged and ungauged inflows, end-of-system flows and diversions are very close between simulations and accounts and suggest relatively low uncertainty. The greatest uncertainty is associated with the estimation of monthly diversions and river and wetland losses that appear to occur in reaches 6, 8 and 10 in particular, but also in other reaches in the lower part of the Murrumbidgee.

Table 5-5. Regional water balance modelled and estimated on the basis of water accounting

Water balance (Jul 1990 – Jun 2006)	Model (A)	Accounts	Difference	Difference
		GL/y		percent
Inflows				
Main stem inflows	2765	2848	-83	-3%
Tributary inflows	870	534	336	63%
Local inflows	500	811	-311	-38%
Subtotal gains	**4134**	**4192**	**-58**	**-1%**
Unattributed gains and noise	-	1138	-1138	na
Outflows				
End-of-system outflows	1083	1091	-8	-1%
Distributary outflows	46	0	46	na
Net diversions	1970	1974	-4	0%
River flux to groundwater	-5	0	-5	na
River and floodplain losses	443	668	-224	-34%
Unspecified losses	604	0	604	na
Subtotal losses	**4141**	**3732**	**408**	**11%**
Unattributed losses and noise	-	1597	-1597	na

na – not applicable

Climate range

The representative period used for calibration of the Murrumbidgee model was from 1982 to 1995. Only five years in the entire 111-year record used in modelling were drier than those included in this calibration period, and only one year was wetter. The average rainfall for the calibration period (569 mm/year) was 7 percent higher than the long-term average (533 mm/year). The historical 111-year rainfall record had seven years that were drier and five years that were wetter than the extremes during the period of water accounting (1990 to 2006). Overall, the calibration period appears to provide an excellent representation of the longer climate record. The water accounting period provides a good representation of long-term climate variability. The climate range is extended during calibration and allows assessment of model performance for more recent years (that is, 1995 to 2006).

Performance of river modelling 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 reach by reach of the model's performance in reproducing different aspects of the patterns in historically measured monthly and annual flows (all are variants of Nash-Sutcliffe model efficiency). Figure 5-4 shows the relative performance of the modelling in explaining the observed streamflow pattern (as model efficiency). Reach 7 (Billabong Creek above Jerilderie) was not explicitly modelled in IQQM and therefore performance could not be evaluated for this reach. Observations follow:

- Model performance for annual flow totals is very good to excellent (NSME=0.89–0.97) in all reaches except reaches 2 and 3 (NSME=0.62–0.67) where performance is reasonable. Similarly, model performance is very to extremely good for monthly totals in all reaches (NSME=0.79–0.88) but slightly less in reaches 2 and 3 (NSME=0.75). These two reaches in the Tumut River are strongly dominated by releases from Blowering Dam. These are not exactly reproduced by the model, particularly between 1990 and 1994 and after 2004 (Appendix C).
- Performance in reproducing the 10 percent highest flows is moderate to very good in reaches 1 and 8 to 11 (NSME=0.53–0.95). It is very poor in reaches 2 to 4 due to the difficulty in exactly reproducing dam operations.
- Performance in reproducing the 10 percent lowest flows is very poor in all cases (NSME<0) although a comparison of monthly time series and flow duration curves suggests that low flow patterns are generally reasonably well reproduced in the right order of magnitude (Appendix C).
- The simulated and observed flow duration curves agree well for all reaches. Low flows appear somewhat over estimated in Reach 1, which is part of the Upper Murrumbidgee model (Appendix C).

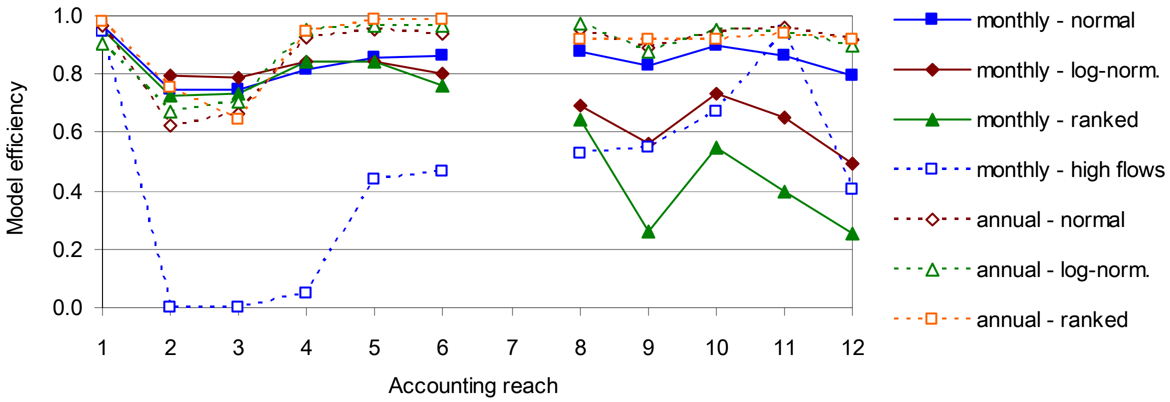

Figure 5-4. Changes in the model efficiency (the performance of the river model in explaining observed streamflow patterns) along the length of the river (no model data were available for Reach 7)

Scenario change-uncertainty ratio

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

- Change-uncertainty ratios are generally smaller for monthly totals than for annual totals due to the greater variability in monthly flows that is harder to simulate than annual patterns (Figure 5-5).
- The significance of the simulated change from without-development to current flow pattern is reasonably to very strong when compared to model performance (CUR 6 to 100). Flows are reduced in the upper Murrumbidgee (Reach 1) and in the lower Murrumbidgee below Narrandera (reaches 8 and 10 to 12) but strongly increased in the Tumut River (reaches 2 and 3) and Billabong Creek (Reach 9) (Appendix C). Flows have become less variable in many cases and very low flows do not occur anymore due to the construction of the Snowy Mountains Hydro-electric Scheme which has rerouted water through Tumut River, and the diversion of Murrumbidgee flows into Billabong Creek.
- The projected changes under Scenario Cdry are very similar to those under scenarios B and Ddry. The projected change in all three cases is greater than model uncertainty (CUR 2.6 to 5.1 for monthly totals and CUR 6 to 29 for annual totals). The most significant changes are predicted for the Murrumbidgee River downstream of Wagga Wagga (Appendix C).
- The projected changes under scenarios Cmid and Dmid are of low to fair significance when compared to model uncertainty (CUR 1.0 to 6.8) whereas projected changes under scenarios Cwet and Dwet are slightly lower in significance again (CUR 0.9 to 4.2). The exception is Reach 1, where projected changes are fairly significant (CUR 3.1 to 5.6) (Appendix C).
- The projected changes under scenarios C and D are almost identical for the Murrumbidgee River upstream of Wagga Wagga (zero to 1.0 percent of average flows without further development) and therefore have almost identical CUR values. Differences between scenarios C and D increase downstream of Wagga Wagga to between 3 and 5 percent of flows without development in the lower two reaches (reaches 11 and 12). The difference is strongest under the wet climate change scenarios (Note that numbers here may vary from those in Chapter 4 due to the different period considered).

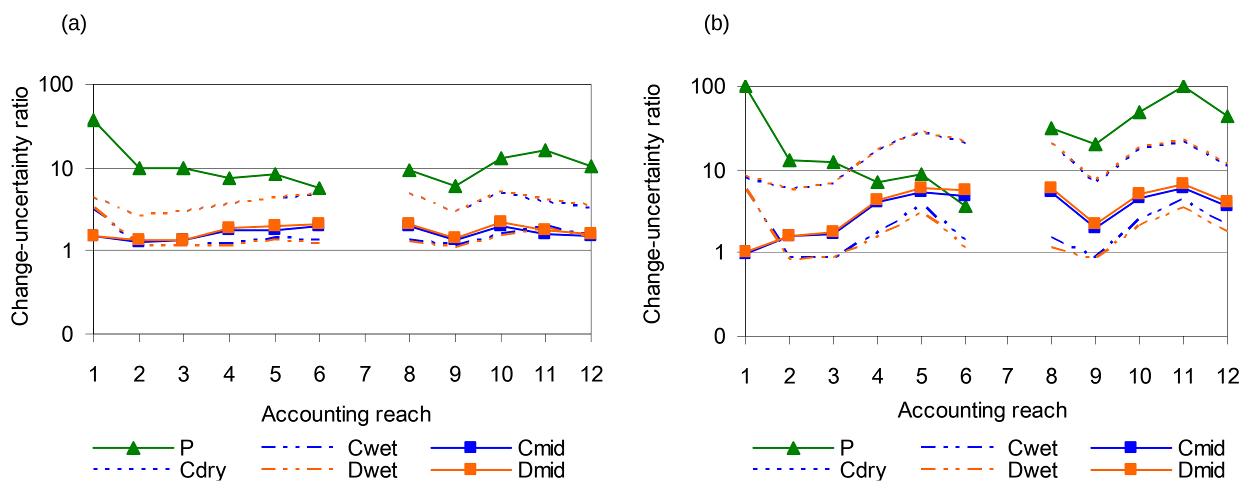

Figure 5-5. Pattern along the river of the ratio of the projected change over the river model uncertainty for the different scenarios modelled for (a) monthly and (b) annual flows

Conclusions follow:

- The projected changes in flow pattern due to past development are much larger than model uncertainty. The modelling therefore provides strong evidence that regulation has considerably changed flow patterns in the system.
- Scenarios B, Cdry and Ddry cause changes in flow that are moderately to fairly significant when compared with internal model uncertainty. Changes under the wet scenarios are closer to model uncertainty, but are still significant in several reaches.
- The projected impact from development is small when compared to the projected impact from climate change. The impact increases down the Murrumbidgee River main stem and is reasonably strong for outflows at the end of system at Balranald Weir (3 to 5 percent reduction relative to average streamflow for the water accounting period under equivalent C Scenarios). This may be relevant to the management of the wetlands in this reach.

5.4 Discussion of key findings

Gauging and understanding of the hydrology of the Murrumbidgee region

The hydrology of the Murrumbidgee surface water system is well gauged. The density of gauging is greater than the MDB average. Water accounts were established for 11 reaches from Burrinjuck (Murrumbidgee River) and Blowering (Tumut River) storages down to Balranald Weir (Murrumbidgee River) and Darlot (Billabong Creek). One additional reach of the upper Murrumbidgee River was also considered. The system changes from gaining to losing around Wagga Wagga. Overall, the region is gauged and understood well enough for reliable modelling.

The conceptual understanding of the current hydrology of the region is good. Groundwater interactions appear to play a role in the accounted part of the Murrumbidgee surface water system. Modelling by this project suggests that it represents a very small net gain of about 5 GL/year or 0.1 percent of total gains. However, it was an important uncertainty indentified in a prior review (Section 5.3.2; Salbe et al., 2007). Future development is estimated to cause flow reductions that increase towards the end of the Murrumbidgee River by up to 5 percent of Scenario C flows (equivalent to about 2 percent of current diversions).

The system is highly regulated and surface water diversions are a very important component of total inflows: around 48 percent of total (attributed) inflows are diverted for use. Unforeseen changes in river regulation, irrigation and development are possible and are therefore an important component of overall uncertainty. Prior model assessment suggested that there are uncertainties associated with unregulated extractions and the quality of records of on-farm gate deliveries and cropping areas (Section 5.3.2). Future developments in cropping practices, water use efficiency and water trade may be one of the greatest uncertainties after the uncertainty around future climate because of the importance of diversions in the overall water balance.

About 26 percent of the water balance can not be attributed in water accounting. Much of this is related to uncertainty in disaggregating annual diversion volumes and in estimating river and wetland losses. Diversions and wetland losses are estimated to represent approximately 53 and 18 percent of total losses in accounting, which provides an indication of the importance of these respective terms. The associated uncertainty cannot easily be separated as wetland losses and diversions mainly occurred in the same reaches.

The model uses empirical functions to correct overestimation of flows between gauges. Compensating errors that cause uncertainty in modelling can occur where local ungauged inflows are important. The effect of this uncertainty on the overall balance is limited due to relatively complete gauging. Local (ungauged) inflows (500 GL/year) represent only 12 percent of total simulated inflows, whereas unspecified losses (604 GL/year) represent 15 percent of total losses.

Model performance in explaining observations and comparison to water accounts

Overall model performance was very good to excellent for the accounted part of the system. This confirms prior model evaluation results. The least, but still reasonable, performance is the simulation of releases from Blowering Dam. The calibrated climate range is excellent and provides a comprehensive mix of wet and dry years. The water accounting extended the period of model evaluation to 2006 which further increases confidence in the reliability of the modelling under climate change scenarios. The accounted and simulated water balance terms agreed reasonably well, with differences being less than 4 percent where water balance terms can be compared directly.

Implications for the use of these results

River modelling reproduces observed streamflow patterns very well and produces estimates of water balance terms that agrees well with water balance accounts. The projected changes in flows due to future climate are greater than model uncertainty under the dry scenarios and within model uncertainty under the wet and best estimate scenarios, in some cases. The modelling provides strong evidence of changes in flow pattern due to prior development and some evidence that impacts of future development are potentially significant towards the end of the Murrumbidgee. Overall it is well suited for the purpose of this project.

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6 Groundwater assessment

This chapter describes the groundwater assessment for the Murrumbidgee region. It has eight 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
- a description of conjunctive use indicators
- a discussion of key findings.

6.1 Summary

6.1.1 Issues and observations

There are seven groundwater management units (GMUs) covering the entire Murrumbidgee region. The reported assessments for the Mid-Murrumbidgee and Lower Murrumbidgee alluvium GMUs use a model developed specifically for the project (though based partly on an existing New South Wales Department of Water and Energy (DWE) model) and an existing draft numerical groundwater model developed by DWE, respectively. Assessments of the remaining GMUs rely on simple water balance analyses.

6.1.2 Key messages

- Total groundwater extraction in the region for 2004/05 was 407 GL. This represents 17 percent of total water use in the region on average and 26 percent of total water use in years of lowest surface water diversion. The majority (90 percent) was from the Mid-Murrumbidgee and Lower Murrumbidgee alluvium GMUs.
- Extraction from the Lower Murrumbidgee Alluvium GMU in 2004/05 was 324 GL or 67 percent of recharge on average. This is a medium level of development. Entitlements in the Lower Murrumbidgee Alluvium GMU are being reduced to the long-term average extraction limit of 280 GL/year. Extraction at this limit would eventually lower the groundwater levels by up to 8 m adjacent to extraction zones. Water levels however, are expected to rise slowly in areas away from extraction zones. Total recharge exceeds extraction in all years. A large fraction of the total recharge (almost equivalent to the extraction volume) is recharge from surface water irrigation. However, this recharge transits the saline Shepparton Formation prior to extraction from lower layers, thus potentially degrading the quality of the water. Extraction can be maintained at this level and will eventually decrease streamflow by 53 GL/year. Additionally, groundwater rises caused by surface water irrigation will lead to increases in streamflow. Overall, these increases lead to an overall increase in streamflow of 31 GL/year.
- Extraction from the Mid-Murrumbidgee Alluvium GMU in 2004/05 was 48 GL/year or 54 percent of recharge on average. This is a medium level of development. Total recharge nearly always exceeds groundwater extraction. Dynamic equilibrium with stable groundwater levels would be attained at an extraction level of about 40 GL/year. At this level of extraction groundwater levels would fall by up to 10 m adjacent to extraction zones of the lower aquifer. Extraction has impacted on flows in the Murrumbidgee River. The eventual net streamflow loss due to groundwater extraction at 40 GL/year would be 31 GL/year. Of the 31 GL/year, 11 GL/year has been incorporated into the current river system model implementation, implying a potential ‘double accounting’ error of 20 GL/year in the separate surface and groundwater assessments supporting water sharing plans.
- The total 2004/05 extraction for the remaining GMUs was 35 GL/year. Extraction is less than half of rainfall recharge in all cases, representing low to moderate levels of development.
- Under a long-term continuation of the recent climate, recharge to the Lower Murrumbidgee Alluvium GMU would be reduced by 6 percent but total recharge would still exceed extraction and water levels would rise. Total

recharge to the Mid-Murrumbidgee Alluvium GMU would fall by 20 percent due mainly to longer periods between floods. Net streamflow loss to groundwater would increase to 42 GL/year. The level of development would remain moderate to low for all remaining GMUs.

- Under the best estimate 2030 climate, conditions in the Lower Murrumbidgee Alluvium GMU would change streamflow impact by 7 GL/year. In the Mid-Murrumbidgee Alluvium GMU, total recharge would fall by 7 percent and net streamflow loss to groundwater would increase to 34 GL/year; however, extraction could be maintained at 40 GL/year with the existing bore distribution. The level of development would remain moderate to low for all remaining GMUs.
- By 2030, total groundwater extraction for the region is projected to reach 496 GL/year, representing 21 percent of total water use on average and 33 percent of total water use in years of lowest surface water diversion. The projected increases are primarily for the Lachlan Fold Belt GMU, with moderate increases in the Mid-Murrumbidgee Alluvium GMU (69 GL/year by 2030). These increases in extraction represent what could happen under current plans and the impacts of such extraction. This enables appropriate management responses. For the Mid-Murrumbidgee Alluvium GMU, this future extraction level could be supported with the existing bore distribution and could reach dynamic equilibrium assuming current streamflow leakage rates continue and assuming flood recharge occurs rapidly post-flooding. However, large groundwater drawdowns across the GMU would result.
- The level of development of all remaining GMUs would remain low to moderate under best estimate climate change conditions. Billabong Creek GMU would move to a high level of development under the dry extreme 2030 climate at either the current or future extraction level; unassessed streamflow recharge could help support extraction from this GMU and effectively reduce the development level to moderate.
- The total eventual impact of future groundwater extraction across the region would be a net streamflow loss of 161 GL/year, including nearly 57 GL/year in the Mid-Murrumbidgee Alluvium GMU and nearly 45 GL/year in the lower priority GMUs. These impacts could be higher depending on how the 'cone of depression' associated with groundwater extraction expands and intercepts other recharge sources. This loss due to irrigation is partially offset by returns to the river via groundwater from surface water of about 70 GL/year.

6.1.3 Uncertainty

The current form of the groundwater model for the Lower Murrumbidgee Alluvium GMU produces results that have a low level of uncertainty. The Mid-Murrumbidgee Alluvium GMU modelling results in a moderate level of uncertainty. Further work on the Lower Murrumbidgee groundwater model may be needed to include flood recharge and to simulate the without-development scenario with a more realistic recharge estimate.

The Mid-Murrumbidgee groundwater model has been developed for this project and while it has been peer reviewed, further scrutiny and testing will increase confidence in the model. More specifically, the model outputs are dependent on a particular conceptual model of river leakage and a process of flood recharge that needs further investigation.

Both models are unsuitable for use as water allocation tools. This is because local aquifer use rules are not currently implemented and the redistribution of groundwater extraction resulting as pumping bores dry out is not incorporated realistically. The level of analysis of the Lower Murrumbidgee Alluvium GMU matches its priority ranking in the project context. The level of analysis for the Mid-Murrumbidgee Alluvium GMU does not match its priority ranking as the groundwater model would require further testing and development to be appropriate for this level of priority.

The two models could have been configured to model an increased level of sustainable extraction but it was not intended to demonstrate upper bounds to possible groundwater extractions in any of the models that have been developed and used. The models that were developed represent the prevailing hydrogeological setting including the existing bore distribution and pumping levels. All groundwater model predictions have a level of uncertainty associated with non-unique calibration.

There is considerable uncertainty in the groundwater development projections in other GMUs but the estimates do show the importance of the GMUs. The projected extractions generally represent upper limits and can be constrained by pumping rules, groundwater quality and land suitability. However, the analysis is conservative because current entitlements are used to determine stream impacts, subcatchments where streamflow impacts are less than 2 GL/year are ignored, and connectivity estimates are based effectively on conservative 'best guesses'.

6.2 Groundwater management units

The region is subdivided into seven GMUs for management purposes (Figure 6-1). Three out of the seven GMUs are completely contained in the region and four GMUs overlap from surrounding regions. Also shown on the map are the Upper Murray Alluvium GMU (N15) and the Lower Murray Alluvium (Calivil/Renmark) GMU (N16) which are assessed in the Murray region, and the Lower Lachlan Alluvium GMU (N12) which is assessed in the Lachlan region.

Table 6-1 shows a ranking of GMU priority and the level of assessment undertaken. The priority ranking is defined to help focus efforts on those GMUs that affect most the overall groundwater or surface water resource in the MDB. It ranges from very low to very high in the context of the project, and is based on the level of groundwater use, potential for growth in use and the potential for groundwater to impact on streamflow.

The assessments of the GMUs vary depending on the availability of data and analysis tools as well as the priority of the GMU. Assessments range from minimal to very thorough.

A simple ranking denotes a simple water balance approach while a moderate to thorough rating denotes either an uncalibrated or calibrated numerical groundwater model, with neither 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 Mid-Murrumbidgee Alluvium GMU. Here a very thorough assessment would be required as opposed to the thorough assessment carried out in the project. While the range of assessments is appropriate within the constraints and for the terms of reference of the project, additional work may be required for local management of groundwater resources.

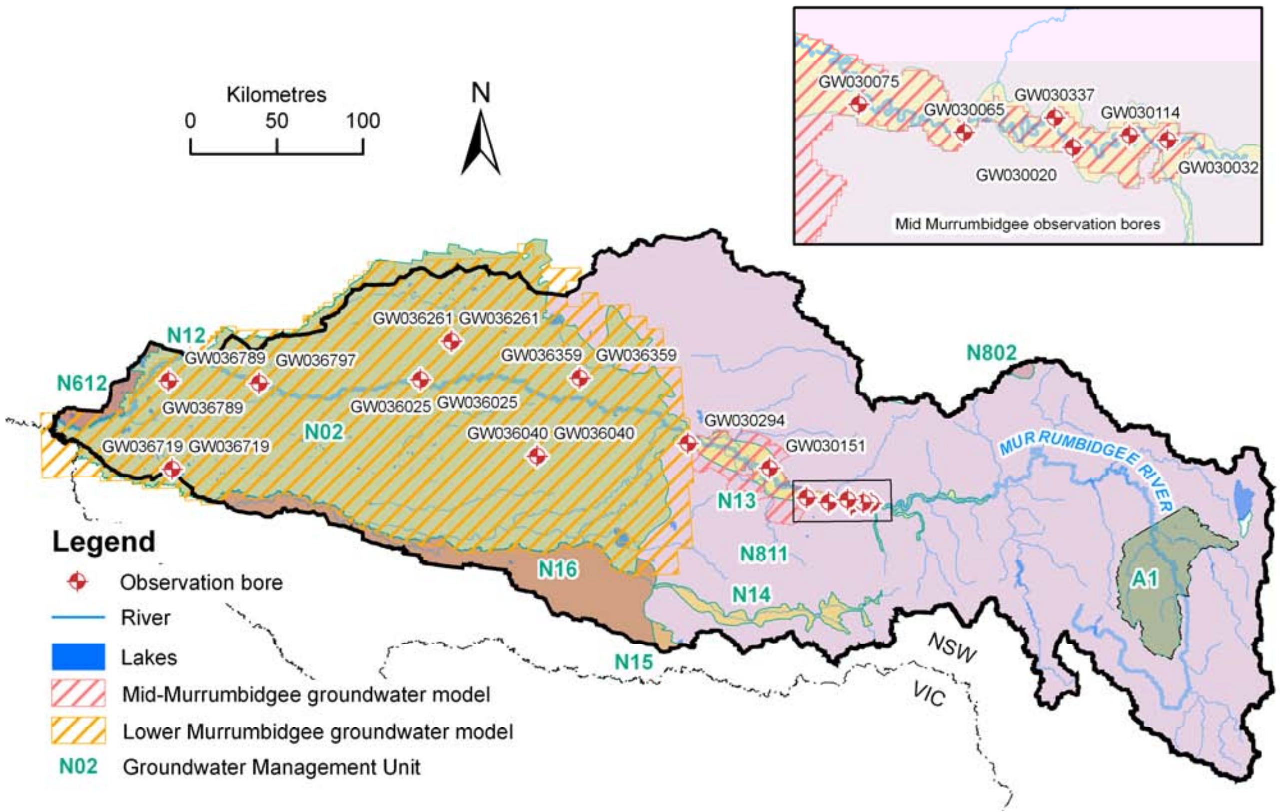

Figure 6-1. Map of groundwater management units in the Murrumbidgee region showing the extent of models and key observation bores, with inset showing the locations of key observation bores in the Mid-Murrumbidgee Alluvium GMU (N13)

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

Code	Name	Priority	Assessment	Entitlement	Extraction[(1)] 2004/05	Long-term average extraction limit	Recharge [(2)]
				GL/y			
N02	Lower Murrumbidgee Alluvium (d/s of Narrandera)	very high	thorough	280.0	323.8	[(3)]280.0	[(3)]400.0 (plus basic landholder rights)
N13	Mid-Murrumbidgee Alluvium (u/s of Narrandera)	high	thorough	80.1	48.2	[(4)]8.5	12.1
N14	Billabong Creek Alluvium (u/s of Mahonga)	low	simple	7.2	5.7	7.4	12.3
N612	Western Murray Porous Rock	very low	minimal	0.1	0.1	5.6	7.9
N802	Young Granite	low	simple	1.1	0.7	1.4	2.3
N811	Lachlan Fold Belt	low	simple	37.8	27.5	541.9	1086.7
A1	Australian Capital Territory	very low	minimal	1.0	0.5	7.0	78.9
Total				**407.3**	**406.5**	**851.8**	**1600.2**

(1) 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.
(2) This value incorporates all sources of recharge in water sharing plan (WSP) areas but represents only rainfall recharge in macro plan areas. Where indicated the recharge volume does not include the amount of groundwater available for basic rights, which is an additional volume. The volume of recharge does not include recharge to national park areas, which has generally been allocated to environmental purposes and is not available for consumptive use.
(3) Source: DIPNR, 2006.
(4) There is no WSP for the Mid-Murrumbidgee Alluvium GMU and the LTAEL reflects calculations based on rainfall recharge only. An Extraction Limit determined in a future WSP would have regard to the acceptable impacts on river flow and maybe substantially higher.

6.2.1 The ‘Achieving Sustainable Groundwater Entitlements’ structural adjustment program

The ‘Achieving Sustainable Groundwater Entitlements’ structural adjustment program, announced in June 2005, reduced entitlements in the Upper and Lower Namoi, Lower Macquarie, Lower Lachlan, Lower Murray, Lower Gwydir and Lower Murrumbidgee groundwater sources. 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 to each source will be gradually reduced from the current levels to the long term average extraction limit (LTAEL) over the ten years of the water sharing plan. The LTAEL forms the assumed level of extraction for all scenarios for the Lower Murrumbidgee Alluvium GMU.

6.3 Surface–groundwater connectivity

Objectives of the surface–groundwater connectivity mapping are to provide a catchment context for surface–groundwater interactions, constrain the surface water balance and constrain groundwater balances. The main output is a map of groundwater fluxes (magnitude and direction) to and from the main streams. The approach uses Darcy’s Law and hence estimates hydraulic conductivity and groundwater gradients about the streams. The method is dependent on availability of appropriate groundwater monitoring and previous work estimating hydraulic conductivity.

River 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 date selected for production of the flux map and associated calculations was November 2004, as this was the most recent date which had a large quantity of both bore and river elevation data available. This date represents a low flow period in the historical context with an average depth of 1.9 m at Wagga Wagga (stream gauge 410001). This depth compares with the average depth of 2.3 m over the period of record (1985 to 2005). There was a trend to lower peak flows and shallower minimum depths annually for the last five to six years.

The thickness of the upper aquifer varies from 45 m in the lower reaches below Yanco Weir, 30 m between Yanco and Berembed weirs in the middle reaches, and 20 m for the reaches upstream of Berembed Weir. Hydraulic conductivity of the aquifer is estimated at 5 m/day for the lower reaches, rising to about 20 m/day for the middle reaches. A hydraulic conductivity of 1 m/day was assigned to the fractured rock areas upstream of Burrinjuck Dam.

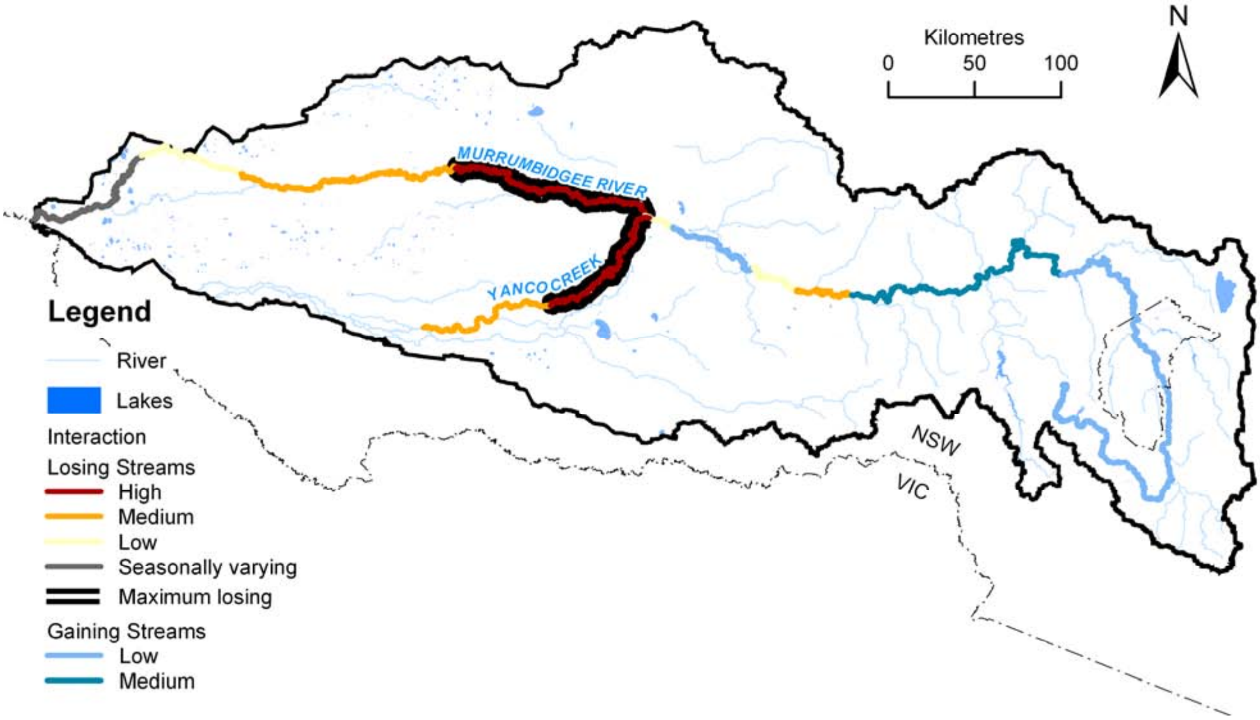

Figure 6-2. Map of surface–groundwater connectivity

Figure 6-2 shows the surface–groundwater connectivity results. The assessment found that:

- the Murrumbidgee River below Narrandera is losing and over a substantial length loses at a maximum rate
- Yanco Creek is a losing stream at a maximum rate
- the river changes from losing around Wagga Wagga to gaining around Narrandera. (At Wagga Wagga prior to groundwater development the stream was gaining. From the mid 1970s the losing reach has increased due to extraction of groundwater for urban purposes (M Williams, pers. comm.))
- the Murrumbidgee River above Wagga Wagga is a gaining stream.

This result is consistent with previous hydrogeological interpretations. Comparisons were made between river levels at two gauging stations and adjacent groundwater levels to obtain information on how these fluxes change with time. The analysis showed groundwater levels were at an historical low in 2004, compared with records dating back to the late 1970s. The higher previous groundwater levels resulted in lower rates of losses where the stream is losing, and higher rates of gains where the streams are gaining.

6.4 Groundwater modelling

Most groundwater extraction from the region comes from the Mid-Murrumbidgee and Lower Murrumbidgee alluvium GMUs. Separate groundwater models were used to assess each of these GMUs (Figure 6-1). The Lower Murrumbidgee groundwater model was developed by DWE between 1994 and 2005. The Mid-Murrumbidgee groundwater model was developed during the project and relied on two models from DWE that were under development. It was calibrated against measured groundwater hydrographs over the period 1975 to 2005.

6.4.1 Lower Murrumbidgee Alluvium GMU modelling approach

The Lower Murrumbidgee groundwater model lies at the lower end of the Murrumbidgee River catchment and covers all of the Lower Murrumbidgee Alluvium GMU (N02).

The aquifers of the Lower Murrumbidgee Alluvium GMU consist of unconsolidated alluvial fan sediments that broaden at the point where the Murrumbidgee River emerges onto the riverine plain near Narrandera. The sediments are subdivided into a broad and highly heterogeneous 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 river, infiltration of irrigation accessions and rainfall are the main sources of recharge. There is a regional flux of groundwater from east to west across the model area. The alluvial sediments form a relatively narrow aquifer at the upstream model boundary and the aquifers broaden substantially towards the western, downstream boundary.

The model begins at Narrandera in the east and extends to the confluence of the Murrumbidgee and Murray rivers in the west. The model is bounded by Billabong Creek and the Edward River in the south, the Lachlan River to the north-west, and exposed Palaeozoic bedrock to the east. While the Murrumbidgee River is the dominant watercourse in the area, minor flows also occur in a number of other watercourses that interact with the groundwater system.

Large-scale extraction for irrigation commenced in the late 1980s and has increased steadily to current levels of more than 300 GL/year. Recent extraction has fallen. Water level monitoring bores located in the model area indicate that groundwater levels in the vicinity of the extraction bores have declined significantly since extraction commenced.

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

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

The model consists of a mesh of square grid cells measuring 2500 by 2500 m.

The model includes boundary conditions that define the interaction between the rivers and the groundwater system (river boundary cells). The boundary conditions also allow water to enter or leave the model through its external boundaries (via general head and constant head boundaries). The river boundary cell conductance terms (used to regulate flow at the boundary) vary spatially across the model.

A percentage of recharging rainfall is assumed constant over the entire model (spatial and temporal) area and is applied to Layer 1. The model assumes that 9.6 percent of irrigation water that is applied to the ground surface becomes groundwater recharge. No flood recharge is included within the model.

Groundwater evapotranspiration is represented in the Lower Murrumbidgee groundwater model through the evapotranspiration package of MODFLOW which simulates the effects of plant transpiration and direct evaporation in removing water from the saturated groundwater regime. A 2 m extinction depth was used.

In 2004/05 simulated extraction from the Lower Murrumbidgee groundwater model was 324 GL/year. This was compared to the recharge budget in the calibration model and it represented about 67 percent of the current total groundwater recharge to the GMU area. This is a moderate to high level of development. Total recharge is greater than extraction for 100 percent of the time. This level of extraction results in groundwater levels falling up to 8 m in some parts of the lower aquifer adjacent to extraction zones by the end of the model scenario period. Levels were still falling slowly at the end of simulation and equilibrium was not reached. Water levels rose slowly in other areas of the model away from zones of extraction. The scenario models (Section 6.4.4) were run using an extraction of 280 GL/year as this is the LTAEL consistent with the WSP for the Lower Murrumbidgee Groundwater Sources (DIPNR, 2006) and 'Achieving Sustainable Groundwater Entitlements' program (DNR, 2005).

The mass balance for the last 5 years of the calibration run (1996 to 2001) of the Lower Murrumbidgee model is presented graphically in Figure 6-3. Lateral groundwater flow out of the model is an important groundwater discharge.

This flow is predominantly across the western model boundary. Inflow to the aquifers is made up of fluxes from the Murrumbidgee River to groundwater, recharge (rainfall recharge and irrigation recharge) and lateral groundwater flow in.

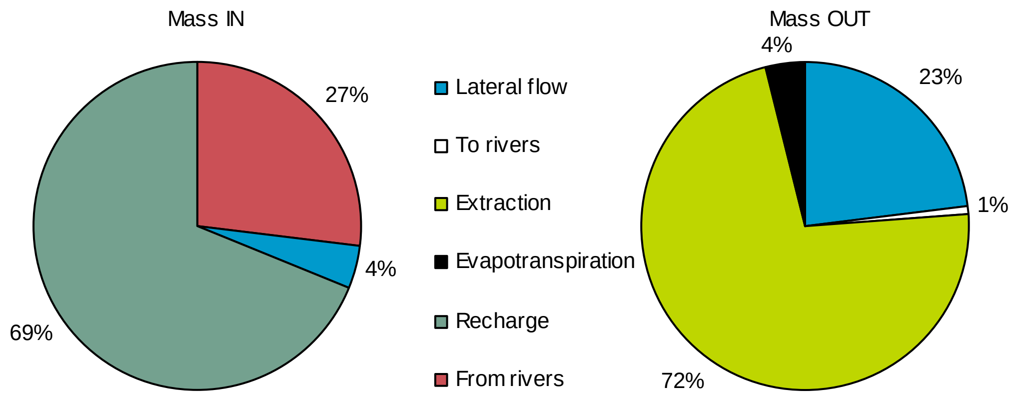

Figure 6-3. Mass balance for the Lower Murrumbidgee groundwater model during the last five years of the calibration period (1996 to 2001). Total mass in was 424 GL/year and total mass out was 308 GL/year.

6.4.2 Mid-Murrumbidgee Alluvium GMU modelling approach

The Mid-Murrumbidgee groundwater model covers Zones 2 and 3 of the Mid-Murrumbidgee Alluvium GMU and is a combination of two existing groundwater models. These models were developed by DWE and are at differing levels of completion. The Zone 2 model is a fully constructed and well calibrated model used for water resource planning of the Wagga Wagga town water supply. The Zone 3 model was in its early phases of construction when the project began.

The Mid-Murrumbidgee groundwater model area consists of alluvium filling a deep 'V' shaped valley in the weathered basement. It is divided into two main geological layers: the upper unconfined Cowra Formation and the lower confined Lachlan Formation. The Cowra Formation consists of unconsolidated sand, gravel, silt and clay. The thickness of the Cowra sands varies from 15 m near Gundagai to 35 m near Narrandera (Watt and Khan, 2006). It has a maximum thickness of 80 m. The Lachlan Formation also has a maximum thickness of approximately 80 m and is made up of well sorted, clean quartz sand and gravel (CSIRO, 2005; Watt and Khan, 2006). The deeper Lachlan Formation forms the main aquifer and exhibits horizontal hydraulic conductivity values of 20 m/day, but can be as high as 50 m/day near Wagga Wagga (O'Neill, pers. comm.). The overlying Cowra Formation (comprising finer sediments) has lower horizontal hydraulic conductivity values of 1 to 5 m/day. There is a distinct hydraulic separation between the Lachlan and Cowra formations particularly in the east near Wagga Wagga and the Cowra Formation behaves as a semi-confining unit (low vertical conductivity).

The Mid-Murrumbidgee groundwater model extends from just upstream of Wagga Wagga to Narrandera at the downstream end (to the west). The numerical model grid consists of 500 m by 500 m cells and includes two layers that represent the Cowra and Lachlan formations. Recharge represented in the groundwater model included rainfall, irrigation and recharge from floods. Evapotranspiration was set uniformly across the model area using the standard MODFLOW approach with a maximum rate of 150 mm/year and an extinction depth of 2 m. The mass balance for the calibrated model is shown in Figure 6-4 and illustrates the average annual water balance fluxes over the whole model calibration period (1975 to 2006). The dominant model inflow processes are recharge from flooding, rainfall infiltration and river leakage. Groundwater flow across boundaries represents only a very minor component of the water balance. Groundwater discharge is dominated by evapotranspiration and groundwater extraction (groundwater extraction increases substantially over the calibration period).

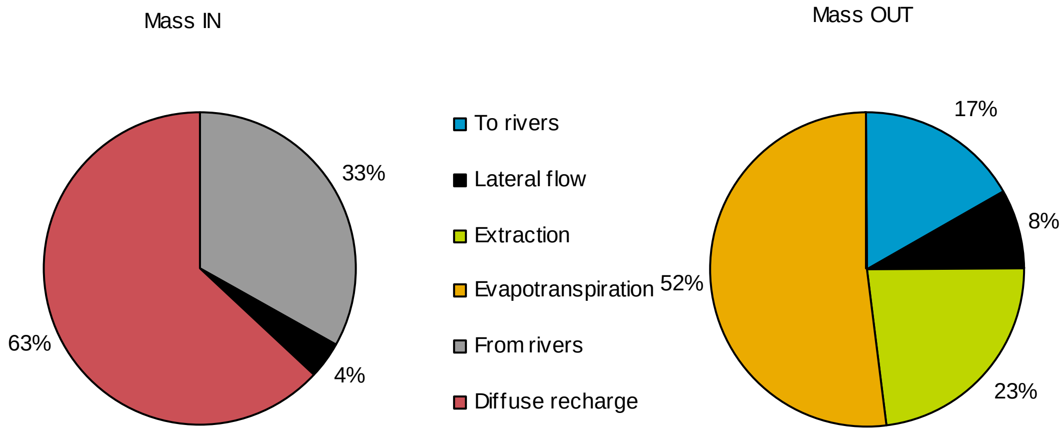

Figure 6-4. Mass balance for the Mid-Murrumbidgee groundwater model over the full calibration period (1975 to 2006). Mass in and out are approximately balanced at 84 GL/year.

6.4.3 Climate impacts on dryland recharge

Both the groundwater modelling and the simple water balance described later in this chapter use recharge scaling factors (RSFs). The RSFs are used to multiply diffuse dryland recharge values to derive scenario impacts on recharge. These are reported as percent changes from Scenario A (Table 6-2). The RSF is 1.0 for Scenario A and close to 1.0 for the other scenarios. The RSFs can be obtained by dividing percent changes by 100 and adding to 1. The three variants of Scenario C (Cdry, Cmid and Cwet) represent a range of global climate model (GCM) output selected by ranking mean annual runoff (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. In semi-arid to sub-humid areas extreme events become more important. A number of GCMs show an increase in extreme events, but the scenario variants are selected on 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) has been 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 shows the percent change in the modelled mean annual recharge averaged over the region under Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percent change in the mean annual recharge and rainfall from the corresponding GCMs are also tabulated in Table 6-2. The plots show that there is a wide range in results across GCMs and scenarios for the 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. In subsequent modelling and reporting only the 'dry', 'mid' and 'wet' variants of Scenario C are shown. These variants are based on 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 35th percentile for RSF. The large variability in RSFs is related to the large variability in rainfall produced by the various GCMs. Changes in mean annual recharge for GMUs and model zones are shown in Table 6-3 and Table 6-4, respectively.

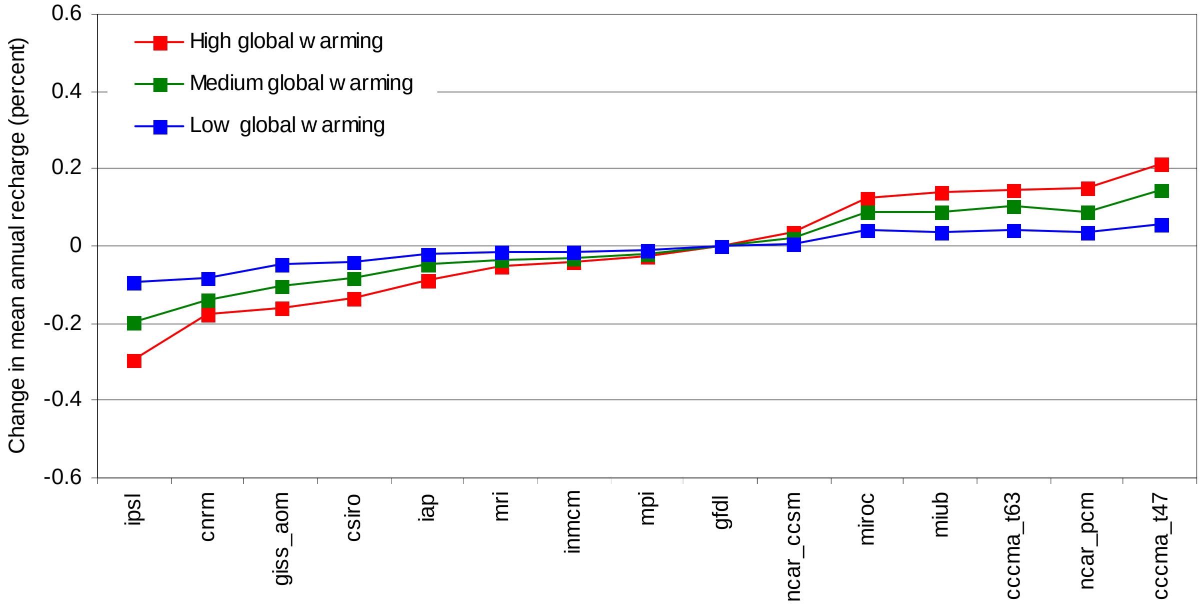

Figure 6-5. Percent change in mean annual recharge under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A

Table 6-2. Summary results under the 45 Scenario C simulations. Numbers show percent 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	**-19%**	**-30%**	ipsl	-12%	-20%	ipsl	-5%	-10%
cnrm	-14%	-18%	cnrm	-9%	-14%	cnrm	-4%	-8%
giss_aom	-15%	-16%	giss_aom	-10%	-10%	giss_aom	-4%	-5%
csiro	-11%	-13%	csiro	-7%	-8%	csiro	-3%	-4%
iap	-4%	-9%	iap	-3%	-5%	iap	-1%	-2%
mri	-4%	-5%	**mri**	**-2%**	**-4%**	inmcm	-1%	-2%
inmcm	-5%	-4%	inmcm	-3%	-3%	mri	-1%	-1%
mpi	-6%	-3%	mpi	-4%	-2%	mpi	-2%	-1%
gfdl	-6%	0%	gfdl	-4%	0%	gfdl	-2%	0%
ncar_ccsm	2%	3%	ncar_ccsm	1%	2%	ncar_ccsm	1%	1%
miroc	5%	13%	ncar_pcm	4%	9%	miub	1%	4%
miub	5%	14%	miroc	3%	9%	ncar_pcm	2%	4%
cccma_t63	4%	14%	miub	3%	9%	miroc	1%	4%
ncar_pcm	**6%**	**15%**	cccma_t63	3%	10%	cccma_t63	1%	4%
cccma_t47	4%	21%	cccma_t47	2%	14%	cccma_t47	1%	6%

NB: The rainfall for some GCM simulations in Table 6-2 differs very slightly (no more than 1 percent) from the analogous table presented in Chapter 3. This is due to use of an earlier version of data in the recharge modelling assessment. The timeframes of the project precluded use of the revised climate data for the recharge modelling. This inconsistency would not significantly affect the values of the estimated RSFs.

Table 6-3. Percent change in mean annual recharge for groundwater management units in the Murrumbidgee region under scenarios B and C relative to Scenario A

Code	Name	B	Cdry	Cmid	Cwet
		percent change relative to Scenario A			
N02	Lower Murrumbidgee Alluvium	-18%	-44%	-3%	15%
N14	Billabong Creek Alluvium	-27%	-40%	-3%	16%
N13	Mid-Murrumbidgee Alluvium	-26%	-38%	-3%	15%
N612	Western Murray Porous Rock	-17%	-29%	-1%	21%
N802	Young Granite	-21%	-25%	0%	15%
N811	Lachlan Fold Belt	-16%	-22%	-4%	18%
A1	Australian Capital Territory	-17%	-24%	-7%	12%

Table 6-4. Percent change in recharge applied to model scenarios for model zones under scenarios B and C

Model zone	B	Cdry	Cmid	Cwet
Lower Murrumbidgee	-18%	-42%	-3%	15%
Mid-Murrumbidgee	-26%	-41%	-3%	15%

6.4.4 Scenario implementation

The objective of the numerical modelling is to assess the impacts (groundwater and surface water) under scenarios that alter groundwater extraction from the Lower Murrumbidgee and Mid-Murrumbidgee 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. For these models, areas of irrigation have not changed. 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) 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 surface–groundwater 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 period 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.

Groundwater extraction was applied to the existing distribution of production bores in both model areas using the actual calibration amounts. The individual extractions were simply scaled to give the higher scenario total volume where the total extraction volume in any scenario was higher than the calibration extraction. This may have introduced errors as individual bore extraction was not checked against its entitlement. Also the adopted method may have biased production to particular areas especially where current production is not evenly spread. Extraction was also aimed towards the deeper aquifers at any one pumping site to try to avoid premature drying of the upper model layers. This process did not allow the models to demonstrate the maximum possible yield from the aquifer.

Lower Murrumbidgee Alluvium GMU

The following scenarios were modelled for the Lower Murrumbidgee Alluvium GMU:

- *Historical climate and current development (Scenario A).* Groundwater extraction levels were set at the LTAEL for the aquifer. The LTAEL is 280 GL/year, of which 270 GL/year is from the Calivil Formation and 10 GL/year from the Lower Shepparton Formation. Climatic stresses including rainfall recharge were obtained from recorded data over the period 1895 to 2006. River stage was obtained from an interpolation of stage heights obtained from the river model run over the same time and assumed climatic conditions.
- *Recent climate and current development (Scenario B).* Climatic stresses (rainfall and evaporation) were obtained from the last ten years (1997 to 2006) of measured climatic data.
- *Future climate and current development (Scenario C)*. There were three different groundwater models for this scenario as dry, mid and wet variants are defined for Scenario C. River stage, recharge and 'river bed conductance enhancement' were calculated separately for these models given the climatic and river flow modelling results. Recharge fluxes were obtained by scaling the recharge fluxes included in Scenario A.
- *Future climate and future development (Scenario D).* Extraction was maintained at LTAEL. This scenario also included assumptions of changes in land use, river diversions and groundwater extraction in areas upstream of the groundwater model. Dry, medium and wet variants were defined using the same climatic assumptions as Scenario C. River stage and recharge were all calculated separately for these variants given the climatic and river flow modelling results.
- A *without-development* scenario was run to illustrate the net impact of groundwater extraction on river flows. This was determined by comparing the Scenario A river losses with the without-development river losses. The without-development scenario was exactly the same as Scenario A except all groundwater pumping was removed. Recharge due to irrigation accessions was not removed. This will bias the model towards a positive water balance (more recharge than discharge) and tend to under estimate river loss.

For future climate scenarios the level of irrigation development was held constant at current conditions. This adds some uncertainty as changing land use patterns in response to climate change are a distinct possibility.

Mid-Murrumbidgee Alluvium GMU

The following scenarios were modelled for the Mid-Murrumbidgee Alluvium GMU:

- *Historical climate and current development (Scenario A).* Groundwater extraction levels were set at 39.6 GL/year. Climatic stresses including rainfall recharge and flooding inundation were obtained from recorded data over the period 1895 to 2006. River stage was obtained from an interpolation of stage heights obtained from the river model run over the same time and assumed climatic conditions.
- *Recent climate and current development (Scenario B).* Climatic stresses (rainfall and evaporation) were obtained from the last ten years of measured climate data.
- *Future climate and current development (Scenario C)*. There were three different groundwater models for this scenario as dry, medium and wet variants are defined for Scenario C. River stage, recharge and 'river bed conductance enhancement' were all calculated separately for these models given the climatic and river flow modelling results. Recharge fluxes were obtained by applying a scaling factor to the recharge fluxes included in Scenario A.
- *Future climate and future development (Scenario D).* Extraction was set at 68.6 GL/year (LTAEL). This scenario also included assumptions of changes in land use, river diversions and groundwater extraction in areas upstream of the groundwater model. Dry, medium and wet variants were defined using the same climatic assumptions as Scenario C. River stage and recharge were all calculated separately for these variants given the climatic and river flow modelling results.
- A *without-development* scenario was run to illustrate the net impact of groundwater extraction on river flows. This was determined by comparing the Scenario A river losses with the without-development river losses. The without-development scenario was exactly the same as Scenario A except all groundwater pumping was removed.

All these scenarios were revised model runs late in the project using significantly updated extraction data from DWE. The results of this modelling were not fully incorporated in the river modelling for reasons explained in Chapter 4. For the future climate scenarios the level of irrigation development was held constant at current conditions. This adds some uncertainty as changing land use patterns in response to climate change are a distinct possibility.

6.5 Modelling results

6.5.1 Lower Murrumbidgee Alluvium GMU time lags following development

Figure 6-6 shows the difference between river losses under Scenario A relative to the without-development scenario. It indicates that at the end of the simulation the difference in net river loss is 53 GL/year. The without-development scenario included irrigation accessions that continue to cause the modelled aquifers to fill up with water. Groundwater levels rise close to the river and river losses decrease and river gains increase. The net river loss during the groundwater calibration period is about 159 GL/year. Because if the rises in groundwater, the river losses under both the without development scenario and Scenario A is less than this.

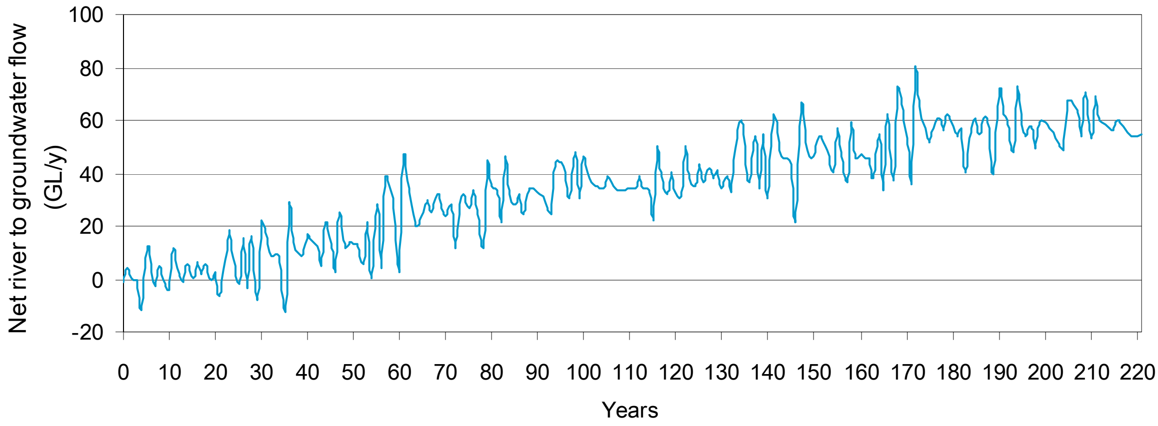

Figure 6-6. Reduction is river flow in the Lower Murrumbidgee Alluvium GMU under Scenario A relative to the without-development scenario

6.5.2 Mid-Murrumbidgee Alluvium GMU time lags following development

Figure 6-7 shows the difference between the river losses under Scenario A relative to the without-development scenario. It indicates the additional river flow that would have been measured had there been no groundwater extraction over the duration of Scenario A. The figure shows the warm-up period as well as the 'dynamic equilibrium' period of about ten years during the initial time. The impacts of groundwater development as indicated by a loss of river flow attain a dynamic equilibrium at about 31 GL/year.

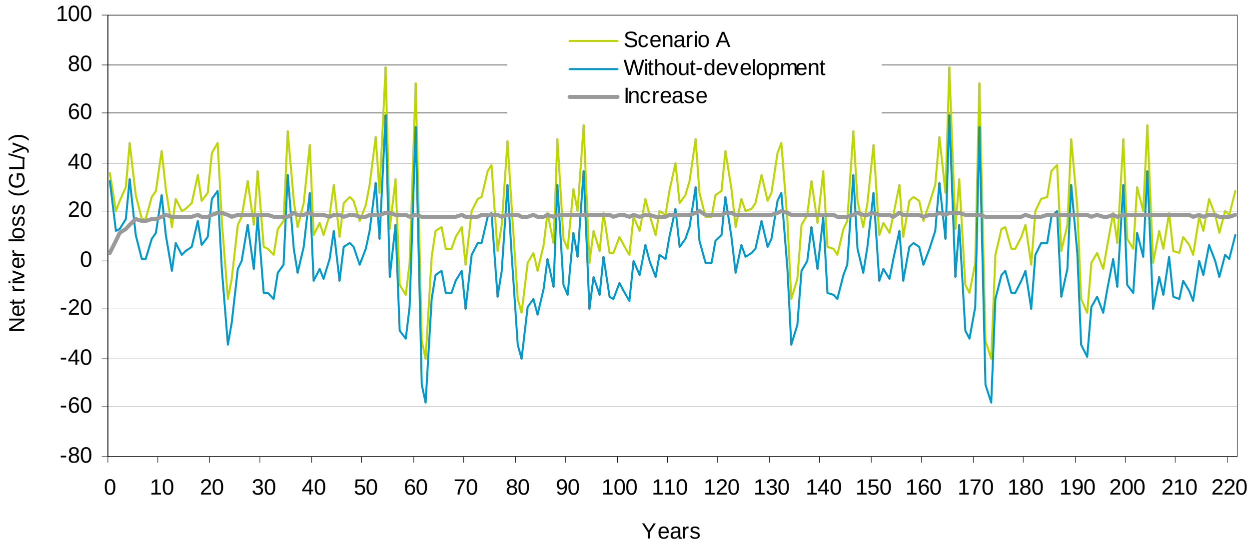

Figure 6-7. Reduction in river flow in the Mid-Murrumbidgee under the without-development scenario and Scenario A, showing the increase in net river loss due to groundwater extraction

6.5.3 Lower Murrumbidgee Alluvium GMU groundwater levels

Groundwater levels rose gradually in most model areas (due to the positive water balance). Levels fell by up to 8 m in the major central irrigation areas in response to groundwater extraction and were still falling at the end of Scenario A simulation. Dynamic equilibrium was not attained at the end of the model run but the magnitude of change was very small.

Groundwater levels in key indicator bores are shown in Table 6-5 and Table 6-6 for the second 111-year simulation period. Table 6-5 shows the difference in groundwater levels between model layers under all scenarios relative to Scenario A. Table 6-6 shows the difference in groundwater levels between key indicator bores under all scenarios relative to Scenario A. The results show minor reductions (less than 1.0 m) in groundwater levels under all scenarios (apart from scenarios Cwet and Dwet) relative to Scenario A.

Table 6-5. Lower Murrumbidgee: median groundwater level in model layers under Scenario A, and difference in median groundwater level under scenarios B, C and D relative to Scenario A

Model layer	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A						
Layer 1	82.4	-0.5	-0.8	-0.1	0.3	-0.8	-0.1	0.3
Layer 2	76.8	-0.5	-0.8	-0.1	0.3	-0.8	-0.1	0.3
Layer 3	76.7	-0.5	-0.8	-0.1	0.3	-0.8	-0.1	0.3
Average	78.6	-0.5	-0.8	-0.1	0.3	-0.8	-0.1	0.3

Table 6-6. Lower Murrumbidgee Alluvium GMU: median groundwater level in individual bores under Scenario A, and difference in median groundwater level under scenarios B, C and D relative to Scenario A

Observation bore	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A						
GW036025.1	89.8	-0.4	-0.6	-0.1	0.2	-0.6	-0.1	0.2
GW036025.2	76.1	-0.4	-0.8	-0.1	0.3	-0.8	-0.1	0.3
GW036025.3	76.0	-0.4	-0.8	-0.1	0.3	-0.8	-0.1	0.3
GW036040.1	101.4	-0.9	-1.6	-0.2	0.6	-1.6	-0.2	0.6
GW036040.2	87.3	-0.8	-1.5	-0.2	0.6	-1.5	-0.2	0.6
GW036040.3	87.4	-0.9	-1.5	-0.2	0.6	-1.5	-0.2	0.6
GW036261.1	80.5	-0.4	-0.8	-0.1	0.3	-0.8	-0.1	0.3
GW036261.2	79.5	-0.4	-0.8	-0.1	0.3	-0.8	-0.1	0.3
GW036261.4	79.5	-0.4	-0.8	-0.1	0.3	-0.8	-0.1	0.3
GW036359.1	103.5	-0.9	-1.4	-0.2	0.5	-1.4	-0.2	0.5
GW036359.2	96.7	-1.1	-1.5	-0.3	0.6	-1.6	-0.3	0.6
GW036359.3	96.5	-1.1	-1.5	-0.3	0.6	-1.6	-0.3	0.6
GW036719.1	63.0	-0.2	-0.5	-0.1	0.2	-0.5	-0.1	0.2
GW036719.2	63.0	-0.2	-0.5	0.0	0.2	-0.5	0.0	0.2
GW036719.4	63.0	-0.2	-0.4	0.0	0.2	-0.4	0.0	0.2
GW036789.1	65.1	-0.2	-0.3	0.0	0.1	-0.3	0.0	0.1
GW036789.2	63.8	-0.2	-0.3	0.0	0.1	-0.3	0.0	0.1
GW036789.4	63.8	-0.2	-0.3	0.0	0.1	-0.3	0.0	0.1
GW036797.1	73.5	-0.3	-0.4	-0.1	0.1	-0.4	-0.1	0.1
GW036797.2	71.0	-0.3	-0.5	-0.1	0.2	-0.5	-0.1	0.2
GW036797.3	70.9	-0.3	-0.5	-0.1	0.2	-0.5	-0.1	0.2

6.5.4 Mid-Murrumbidgee Alluvium GMU groundwater levels

Groundwater levels in the Mid-Murrumbidgee Alluvium are relatively stable. Median groundwater levels under all scenarios in all key indicator bores are shown in Table 6-7. Table 6-8 compares model layer groundwater levels. Under Scenario Ddry, groundwater levels would be up to 8 m below those found under Scenario A.

Table 6-7. Mid-Murrumbidgee Alluvium GMU: median groundwater level in individual bores under Scenario A, and difference in median groundwater level under scenarios B, C and D relative to Scenario A

Observation bore	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A						
30020.1	170.4	-1.2	-1.2	-0.3	0.4	-1.7	-0.6	0.2
30020.2	169.0	-1.3	-1.2	-0.3	0.4	-0.2	-0.8	0.1
30032.1	174.5	-1.1	-1.1	-0.3	0.3	-7.4	-0.4	0.5
30032.2	165.7	-1.1	-1.1	-0.3	0.3	-1.6	-0.8	0.1
30065.1	168.4	-0.7	-0.7	-0.2	0.3	-1.3	-0.5	0.1
30075.3	163.4	-0.8	-0.8	-0.2	0.3	-4.7	-2.4	-1.6
30093.3	147.6	-1.1	-1.2	-0.3	0.2	-4.4	-2.8	-1.7
30114.1	174.2	-0.6	-0.6	-0.2	0.3	-0.8	-0.3	0.2
30114.2	170.3	-0.9	-0.9	-0.3	0.3	-1.7	-0.9	-0.3
30126.2	160.2	-0.6	-0.6	-0.2	0.2	-1.3	-0.8	-0.3
30151.3	155.1	-1.0	-1.1	-0.3	0.3	-2.6	-1.7	-0.7
30164.2	155.7	-0.5	-0.5	-0.1	0.2	-1.4	-1.0	-0.6
30294.2	138.4	-0.7	-0.7	-0.2	0.2	-1.1	-0.5	0.3
30337.1	169.7	-1.9	-1.9	-0.4	0.5	-0.1	1.2	2.1
30337.2	167.5	-1.8	-1.8	-0.4	0.4	-2.0	-0.5	0.5

Table 6-8. Mid-Murrumbidgee Alluvium GMU: median groundwater level in model layers under Scenario A, and difference in median groundwater level under scenarios B, C and D relative to Scenario A

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A						
Layer 1	171.8	-1.0	-1.0	-0.3	0.3	na	-1.3	-0.3
Layer 2	159.7	-1.0	-1.0	-0.3	0.3	-8.0	-2.3	-1.3
Average	163.7	-1.0	-1.0	-0.3	0.3	-7.7	-2.0	-0.9

6.5.5 Lower Murrumbidgee Alluvium GMU water balance

The mass balance components under all scenarios for the Lower Murrumbidgee model are summarised in Table 6-9. Rainfall recharge shows the greatest variation in flux. Approximately 120 GL/year flows from rivers to groundwater and 7 GL/year flows the other way. The net river loss ranges from 110 to 118 GL/year depending on the scenario. Scenario C and D annual fluxes are almost identical because the only difference between these scenarios is the interaction between rivers and groundwater.

Total recharge is larger than total discharge under all scenarios and causes average groundwater levels to rise in most parts of the model area. There are gradual decreases in groundwater levels in the major irrigation districts where there is sustained groundwater extraction. The different rises in groundwater levels under each scenario are linked to the variation in rainfall recharge. One interpretation of the significant annual change in storage (level rise) is that a 'dynamic equilibrium' state assumed to be reached in the second 111-year run is actually not reached in the Lower Murrumbidgee groundwater model.

Table 6-9. Average annual water balances in the Lower Murrumbidgee Alluvium GMU under scenarios A, B, C and D

Average annual water balance components	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y							
Recharge (gains)								
Rainfall	102.2	83.9	57.5	98.9	117.4	57.5	98.9	117.4
Irrigation	245.0	245.0	245.0	245.0	245.0	245.0	245.0	245.0
Lateral flow	8.6	9.3	10.0	8.8	8.2	10.0	8.8	8.2
From rivers	122.9	112.0	115.0	119.2	126.5	114.8	119.0	126.2
Total	**478.7**	**450.2**	**427.5**	**471.9**	**497.1**	**427.4**	**471.7**	**496.8**
Discharge (losses)								
Evapotranspiration	48.4	42.6	39.2	46.9	52.0	39.2	46.9	52.0
Extraction	280.0	280.0	280.0	280.0	280.0	280.0	280.0	280.0
To rivers	7.0	4.5	4.0	6.1	8.4	4.0	6.1	8.4
Lateral flow	100.5	95.8	91.0	99.4	103.8	91.0	99.4	103.8
Total	**435.8**	**422.8**	**414.3**	**432.5**	**444.3**	**414.2**	**432.4**	**444.1**
Annual change in storage	42.9	27.4	13.3	39.4	52.8	13.2	39.3	52.7
Net loss from river	115.9	107.5	111.0	113.1	118.1	110.8	112.9	117.4

Figure 6-8 shows a comparison between the total annual recharge included in the Scenario A model and the groundwater pumping flux. In this case total recharge includes rainfall, irrigation accessions, leakage from rivers and lateral groundwater fluxes into the region. The data shows that total recharge exceeds extraction for all times.

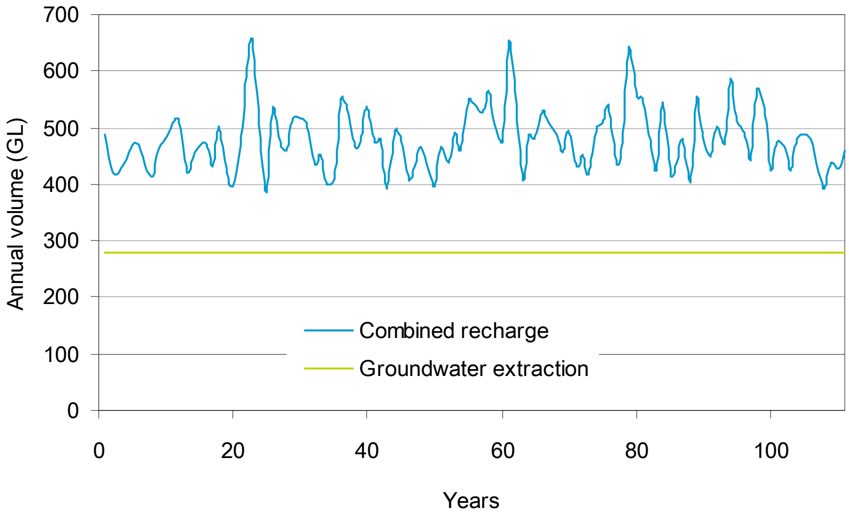

Figure 6-8. Total annual recharge compared to groundwater extraction in the Lower Murrumbidgee Alluvium GMU under Scenario A

Figure 6-9 provides exceedence curves for annual recharge under scenarios A, C and D. 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 and different fluxes across head dependent boundary conditions included in the model (river and general head boundary conditions). The total recharge data for all scenarios shows that for 90 percent of the time recharge will exceed 388 GL/year, for 50 percent of the time recharge will exceed 420 GL/year and for 10 percent of the time recharge will exceed 476 GL/year.

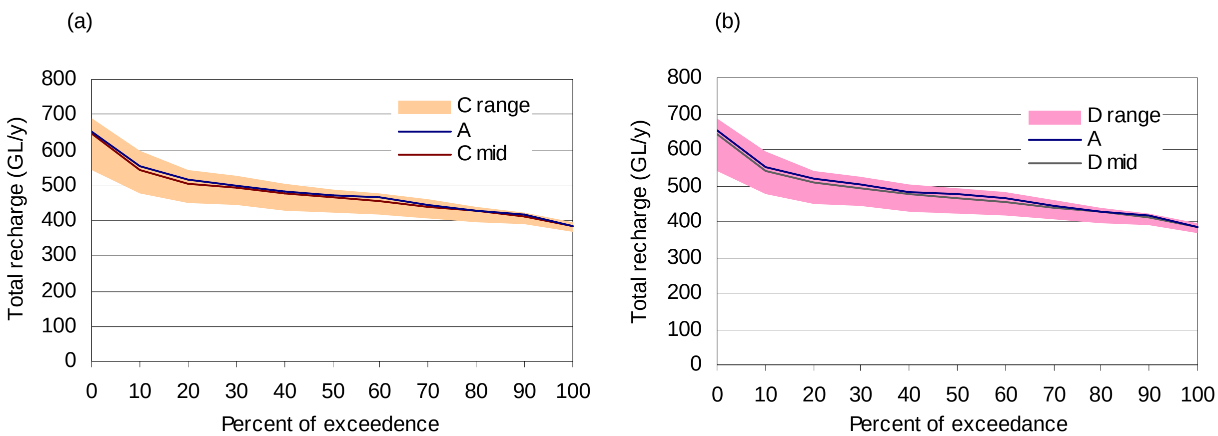

Figure 6-9. Exceedence probability curve for total recharge in the Lower Murrumbidgee model under (a) scenarios A and C, and (b) scenarios A and D

6.5.6 Mid-Murrumbidgee Alluvium GMU water balance

The mass balance components under all scenarios are summarised in Table 6-10. Lateral fluxes of groundwater in and out of the model area are insignificant in all scenarios considered. There is a significant increase in net river losses to groundwater due to increased extraction under Scenario D. The additional 35.6 GL/year lost to groundwater under Scenario Ddry results from the combined stresses of increased extractions and a drier climate. There is a substantial decrease in groundwater evapotranspiration under Scenario D due to lower watertables. Groundwater evapotranspiration is reduced by 13.5 GL/year (Cmid to Dmid) with this reduction being approximately 47 percent of the increase in pumped groundwater volume.

There are two possible environmental consequences of reduced evapotranspiration: reduced groundwater availability to groundwater dependent ecosystems such as wetlands, and the associated reduced groundwater levels may actually decrease the risk of land and stream salinisation.

The average annual recharge from flood inundation is 7.5 GL/year under the dry scenarios (20 GL/year less than under Scenario A). Such a reduction in recharge would represent the largest threat to the groundwater resource and groundwater dependent ecosystems.

Table 6-10. Average annual water balances in the Mid-Murrumbidgee Alluvium GMU under the without-development scenario and under scenarios A, B, C and D

Groundwater balance	Without-development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	48.3	48.2	22.6	21.0	40.8	53.6	20.4	40.8	64.9
Rainfall recharge*	20.0	20.0	15.4	13.0	20.2	19.5	12.9	20.2	24.0
Flood inundation recharge*	27.8	27.8	6.2	7.5	19.7	33.7	7.6	20.0	40.8
Irrigation recharge*	0.5	0.5	0.7	0.6	0.6	0.5	0.6	0.6	0.6
From rivers	20.2	39.9	46.2	47.17	41.4	40.4	68.8	60.6	52.3
Lateral flow	3.6	3.7	4.1	4.1	3.8	3.7	4.2	4.0	3.7
Total	**72.0**	**91.8**	**72.8**	**72.3**	**86.0**	**97.7**	**93.4**	**105.3**	**120.9**
Outflows									
Groundwater pumping	0.0	39.6	39.6	39.6	39.6	39.6	68.7	68.7	68.8
Lateral flow	7.6	6.6	5.8	5.8	6.4	6.8	5.1	5.7	6.5
Groundwater evapotranspiration	44.3	37.1	24.0	23.6	33.2	40.7	18.4	27.2	38.1
River discharge	20.3	8.7	3.8	3.9	7.0	10.6	2.0	4.0	7.6
Total	**72.1**	**92.0**	**73.3**	**72.9**	**86.2**	**97.8**	**94.2**	**105.6**	**121.0**
Total river losses to groundwater	-0.1	31.2	42.3	43.3	34.4	29.8	66.8	56.6	44.7

* The contributions of rainfall, flood inundation and irrigation may not sum exactly to the 'total diffuse recharge' because these three rows show groundwater model inputs and the total is a groundwater model output – dry model cells will create a difference between these sums.

Figure 6-10 compares the combined annual recharge included in the Scenario A model with the groundwater pumping flux. In this case combined recharge includes rainfall, leakage from rivers, flood inundation and lateral groundwater fluxes into the model area. Groundwater pumping rarely exceeds total effective recharge over the duration of Scenario A.

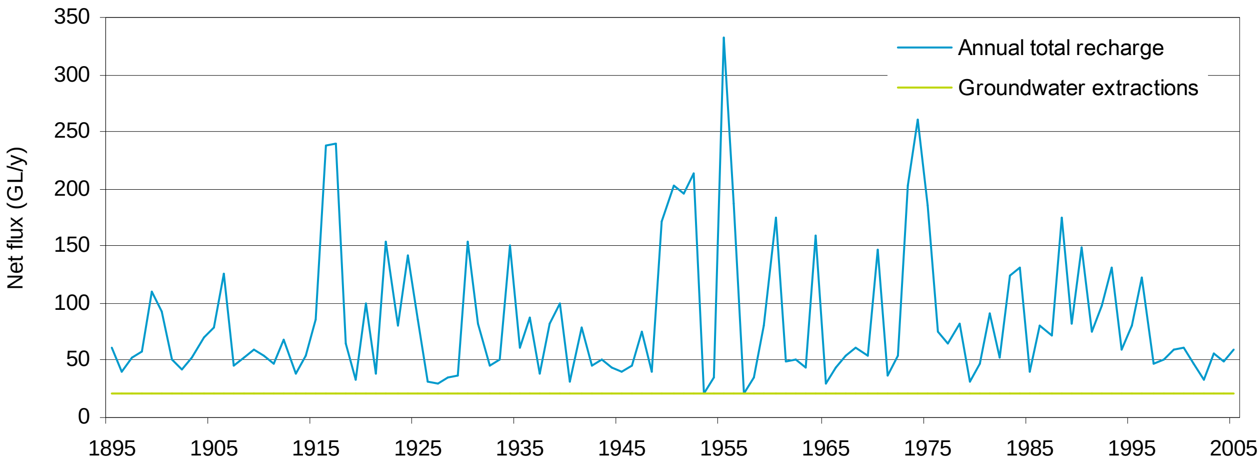

Figure 6-10. Combined recharge compared to groundwater extraction in the Mid-Murrumbidgee Alluvium GMU under Scenario A

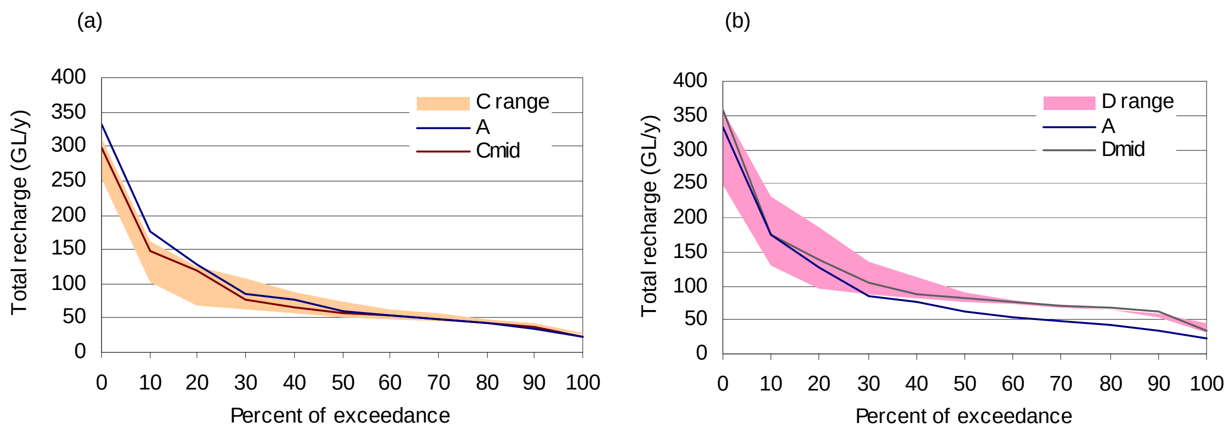

Figure 6-11. Exceedence probability curve for total annual recharge (minus evapotranspiration) in the Mid-Murrumbidgee model under (a) scenarios A and C, and (b) scenarios A and D

Effective recharge exceedence curves under all scenarios are shown in Figure 6-11.

Figure 6-11 also shows that for 90 percent of the time recharge will exceed 35 GL/year, for 50 percent of the time it will exceed 60 GL/year and for 10 percent of the time it will exceed 120 GL/year depending on the scenario.

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 6-11.

Table 6-11. Definition of groundwater indicators

Groundwater indicators	
Groundwater security indicator	Percentage of years in which extraction is less than the average recharge (E/R) 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 E/R ratio. Values of more than 1.0 indicate a long-term depletion of the groundwater resource and consequential long-term environmental impacts.
Groundwater 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 drawdown under each scenario.
Conjunctive use indicator	Percentage of years in which groundwater extraction is more than 50% of the total water use in the region. This indicates the relative importance of groundwater compared with surface water for the region.

Lower Murrumbidgee Alluvium GMU

A range of groundwater resource condition indicators for the Lower Murrumbidgee Alluvium GMU are presented in Table 6-12. The data shows that groundwater security is high under all scenarios as total groundwater recharge always exceeds extraction. The difference from the exceedence curves in Section 6.5.6 is that the recharge was averaged over a ten-year period. The environmental indicator shows all scenarios have values of about 0.6. An increase in this value towards 1 represents a decrease of water for environmental purposes. There is generally less than a 5 m change in head according to the drought indicator.

Table 6-12. Groundwater indicators for the Lower Murrumbidgee under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Groundwater security indicator	percent							
Years E/R >1	100%	100%	100%	100%	100%	100%	100%	100%
Environmental indicator	ratio							
E/R	0.58	0.62	0.65	0.59	0.56	0.66	0.59	0.56
Drought indicator	m							
Average	**-0.7**	**-1.2**	**-1.6**	**-0.8**	**-0.4**	**-1.6**	**-0.8**	**-0.4**
Observation bore								
GW036025.1	-0.7	-1.0	-1.1	-0.8	-0.5	-1.1	-0.8	-0.5
GW036025.2	-1.1	-1.5	-1.9	-1.2	-0.9	-1.9	-1.2	-0.9
GW036025.3	-1.1	-1.5	-1.9	-1.2	-0.9	-1.9	-1.2	-0.9
GW036040.1	-0.6	-1.7	-2.6	-0.9	0.1	-2.6	-0.9	0.1
GW036040.2	-1.9	-3.0	-3.9	-2.2	-1.2	-3.9	-2.2	-1.2
GW036040.3	-1.9	-3.1	-3.9	-2.2	-1.2	-3.9	-2.2	-1.2
GW036261.1	-0.2	-0.7	-1.2	-0.3	0.2	-1.2	-0.3	0.2
GW036261.2	-0.6	-1.0	-1.6	-0.7	-0.3	-1.6	-0.7	-0.3
GW036261.4	-0.6	-1.0	-1.6	-0.7	-0.3	-1.6	-0.7	-0.3
GW036359.1	-0.6	-1.8	-2.4	-0.9	0.1	-2.4	-0.9	0.1
GW036359.2	-3.6	-4.9	-5.5	-3.9	-2.9	-5.5	-3.9	-2.9
GW036359.3	-3.6	-5.0	-5.6	-4.0	-2.9	-5.6	-4.0	-2.9
GW036719.1	-0.7	-1.0	-1.2	-0.8	-0.6	-1.2	-0.8	-0.6
GW036719.2	-0.6	-0.8	-1.1	-0.7	-0.5	-1.1	-0.7	-0.5
GW036719.4	-0.6	-0.8	-1.0	-0.7	-0.5	-1.0	-0.7	-0.5
GW036789.1	-0.3	-0.5	-0.6	-0.3	-0.2	-0.6	-0.3	-0.2
GW036789.2	-0.3	-0.5	-0.6	-0.3	-0.2	-0.6	-0.3	-0.2
GW036789.4	-0.3	-0.5	-0.6	-0.3	-0.2	-0.6	-0.3	-0.2
GW036797.1	-0.5	-0.7	-0.8	-0.5	-0.4	-0.8	-0.6	-0.4
GW036797.2	-0.5	-0.8	-1.0	-0.6	-0.4	-1.0	-0.6	-0.4
GW036797.3	-0.5	-0.8	-1.0	-0.6	-0.4	-1.0	-0.6	-0.4

Mid-Murrumbidgee Alluvium GMU

A range of groundwater resource condition indicators for the Mid-Murrumbidgee Alluvium GMU are presented in Table 6-13. Groundwater security is at 100 percent under all scenarios. The environmental indicator is between 0.43 and 0.55 under scenarios A, B and C and increases to around 0.65 under Scenario D. There is a less than 5 m change in head according to the drought indicator.

Table 6-13. Groundwater indicators for the Mid-Murrumbidgee under scenarios A, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Security indicator				percent				
Years E/R<1	100%	100%	100%	100%	100%	100%	100%	100%
Environmental indicator				ratio				
E/R	0.43	0.54	0.55	0.46	0.41	0.74	0.65	0.57
Drought indicator				m				
Average	**-1.3**	**-2.2**	**-2.2**	**-1.4**	**-1.1**	**-3.3**	**-2.2**	**-1.7**
Observation bore								
30020.1	-1.4	-3.3	-3.1	-1.6	-1.1	-4.1	-2.2	-1.6
30020.2	-1.6	-3.4	-3.2	-1.9	-1.3	-4.3	-2.5	-1.9
30032.1	-1.4	-2.0	-1.9	-1.5	-1.2	-2.1	-1.6	-1.3
30032.2	-2.8	-3.6	-3.5	-3.0	-2.6	-4.2	-3.5	-3.1
30065.1	-1.0	-1.4	-1.3	-1.1	-0.9	-2.6	-1.6	-1.2
30075.3	-1.0	-1.5	-1.5	-1.1	-0.9	-7.2	-4.4	-3.3
30093.3	-0.8	-1.4	-1.5	-1.0	-0.7	-5.0	-3.8	-3.1
30114.1	-1.1	-1.5	-1.4	-1.2	-0.9	-1.7	-1.3	-1.0
30114.2	-1.4	-2.3	-2.2	-1.6	-1.2	-3.3	-2.3	-1.9
30126.2	-0.8	-1.2	-1.2	-0.9	-0.6	-1.9	-1.5	-1.2
30151.3	-1.0	-1.5	-1.5	-1.1	-0.8	-3.0	-2.6	-2.2
30164.2	-0.8	-1.1	-1.1	-0.9	-0.7	-2.1	-1.9	-1.7
30294.2	-0.7	-1.0	-1.0	-0.8	-0.7	-1.3	-1.1	-0.9
30337.1	-1.7	-4.2	-4.1	-2.1	-1.3	-2.1	-0.3	0.3
30337.2	-1.9	-4.5	-4.4	-2.3	-1.5	-4.7	-2.6	-1.8

6.6 Water balances of other groundwater management units

There are another five GMUs in the region (apart for the Mid-Murrumbidgee and Lower Murrumbidgee alluvium GMUs) that require analysis (Table 6-1).

6.6.1 Groundwater extraction

Estimated groundwater extraction from other GMUs within the Murrumbidgee region is shown in Table 6-14. These volumes cover areas controlled by New South Wales macro groundwater plans on the basis of 1.5 ML/year for each stock and domestic bore. Estimates of the current extraction and the likely maximum extraction volumes were provided by DWE.

The macro groundwater planning program is a broad-scale planning process covering areas of New South Wales not under a WSP. The macro groundwater plans contain a standard set of rules extended across catchments with similar attributes and values (social, economic and environmental). The macro groundwater plans (like WSPs) reflect the priorities of environment, basic landholder rights, town water and licensed domestic and stock use and other extractive uses (including irrigation). LTAELs have been set based on the calculation of rainfall recharge to each GMU.

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

Table 6-14 also shows future likely extraction rates for the other GMUs of the region.

Table 6-14. Estimated current and future groundwater extraction for the other GMUs in the Murrumbidgee region

Code	Name	Current extraction* (2004/05)	Total entitlement	Future extraction
			GL/y	
N14	Billabong Creek Alluvium	5.7	7.2	7.2
N612	Western Murray Porous Rock	0.1	0.1	2.8
N802	Young Granite	0.7	1.1	1.1
N811	Lachlan Fold Belt	27.5	37.8	(1)135.5
A1	Australian Capital Territory	0.5	1.0	1.0
	Total	**34.5**	**47.1**	**147.5**

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.
(1) This volume represents 25% of the LTAEL (see Table 6.1) and is termed the unassigned water trigger, which may trigger an embargo on use until further work is undertaken.

The 'likely maximum use without plan revision' that is used as the estimate of future extraction in Table 6-14 is based on the historical development of irrigation, urban, and stock and domestic water supply works. The growth rate is estimated based on historical growth. All new domestic and stock water supply works are assumed 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 using 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 the largest component of the 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 was analysed using RSFs (Section 6.4.3). Scaled recharge for the other GMUs is shown in Table 6-15.

Table 6-15. Scaled recharge under for the other GMUs scenarios A, B and C

Code	Name	Recharge	Scaled recharge			
		A	B	Cdry	Cmid	Cwet
			GL/y			
N14	Billabong Creek Alluvium	12.3	9.1	7.5	12.0	14.4
N612	Western Murray Porous Rock	7.9	6.6	5.7	7.9	9.6
N802	Young Granite	2.3	1.9	1.8	2.3	2.7
N811	Lachlan Fold Belt	1086.7	906.3	851.4	1043.6	1284.1
A1	Australian Capital Territory	78.9	65.5	60.3	73.5	88.4
	Total	**1188.2**	**992.3**	**926.6**	**1139.3**	**1399.1**
	Percent change		-16%	-22%	-4%	18%

Note that Scenario D has the same scaling factors as Scenario C and therefore is not reported.

The ratio of current (2004/05) groundwater extraction to rainfall recharge is shown in Table 6-16 and Table 6-17. The ratio of extraction to recharge can be used as an indication of the potential level of stress within the aquifer. A New South Wales macro groundwater plan allocates 30 to 50 percent of recharge to environmental purposes (an E/R ratio of 0.3 to 0.5). Where the ratio is greater than 1.0 the groundwater resources of the GMU are being extracted at a rate greater than recharge is replenishing the groundwater.

The E/R ratio is never greater than 1.0 under any scenario. The E/R ratios are high under the dry scenarios for the Billabong Creek Alluvium GMU indicating potential issues for management of this GMU in a dry climate. However, Billabong Creek Alluvium GMU is connected with Billabong Creek and extraction of groundwater will cause surface water to recharge the aquifer and supplement total recharge.

Table 6-16. Comparison of current groundwater extraction with scaled rainfall recharge for the other GMUs under scenarios A, B and C

Code	Name	Current extraction 2004/05	E/R	Scaled E/R			
			A	B	Cdry	Cmid	Cwet
		GL/y					
N14	Billabong Creek Alluvium	5.7	0.46	0.63	0.77	0.48	0.40
N612	Western Murray Porous Rock	0.1	0.01	0.02	0.02	0.01	0.01
N802	Young Granite	0.7	0.31	0.39	0.41	0.31	0.27
N811	Lachlan Fold Belt	27.5	0.03	0.03	0.03	0.03	0.02
A1	Australian Capital Territory	0.5	0.01	0.01	0.01	0.01	0.01

Table 6-17. Comparison of future groundwater extraction with scaled rainfall recharge for the other GMUs under Scenario D

Code	Name	Future extraction (predicted)	Scaled E/R		
			Ddry	Dmid	Dwet
		GL/y			
N14	Billabong Creek Alluvium	7.2	0.96	0.60	0.50
N612	Western Murray Porous Rock	2.8	0.49	0.35	0.29
N802	Young Granite	1.1	0.61	0.46	0.40
N811	Lachlan Fold Belt	135.5	0.16	0.13	0.11
A1	Australian Capital Territory	1.0	0.02	0.01	0.01

6.6.3 Impact of extraction on streamflow

Stream impacts for the other GMUs are shown in Table 6-18. The following assumptions apply: the connectivity is the same as in MDBC (2007) and does not change with extraction; current groundwater extraction is equal to current entitlements and full stream impact has been realised; and extraction under Scenario D is the maximum likely extraction without plan revision. Future extraction is considered an upper limit as it will be limited by extraction rules under the macro groundwater sharing plan, 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, the full impact of current extraction will not have been fully realised, and connectivity factors are generally considered underestimates. It is difficult to distinguish impacts of less than 2 GL/year in converting GMU impacts to surface water catchments and ignoring these causes exacerbates underestimation.

Table 6-18. Surface–groundwater connectivity for the other GMUs showing an estimate of the volumetric impact of extraction on streamflow

Code	Name	Degree of connectivity	Impact of extraction on streamflow (2004/05)	Impact of extraction on streamflow (2030)	Time lag
		percent	GL/y		years
N14	Billabong Creek Alluvium	37%	2.1	2.7	1–10
N612	Western Murray Porous Rock	0%	0.0	0.0	>100
N802	Young Granite	25%	0.2	0.3	1–10
N811	Lachlan Fold Belt	30%	8.2	40.6	50–100
A1	Australian Capital Territory	100%	0.5	1.0	1–10
	Total		**11.1**	**44.6**	

Table 6-19 shows the total impact on the Murrumbidgee River when the stream impacts for the non-modelled areas are combined with those for the Mid-Murrumbidgee and Lower Murrumbidgee alluvium GMUs.

Table 6-19. Total impacts of groundwater development on streamflow of the Murrumbidgee under scenarios A, B, C, and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y							
Lower Murrumbidgee Alluvium GMU	53.0	54.6	58.1	60.2	65.2	59.9	60.0	64.5
Mid-Murrumbidgee Alluvium GMU	31.3	42.4	43.4	34.5	29.9	66.9	56.7	44.8
Other GMUs	11.1	11.1	11.1	11.1	11.1	44.6	44.6	44.6
Total impact	**95.4**	**108.1**	**112.6**	**105.8**	**106.2**	**169.4**	**161.3**	**153.9**

Of the above impacts, approximately 11 GL/year had been built into the current IQQM implementation. This implies that if this implementation is used, there may be approximately 84 GL/year underestimate under Scenario A, 95 GL/year under Scenario Cmid and 150 GL/year under Scenario Dmid. The river modelling in Chapter 4 has incorporated some, but not all of the above impacts. There are two reasons for this. The first is that the groundwater model was re-calibrated after the river modelling was undertaken using updated extraction figures. Secondly, the impact of the non-modelled areas occurred over a large area so that the impact over individual subcatchments was less than 2 GL/year. This is within the 'noise' of inflow data and hence was not used to modify the inflows. It should be noted that the river modelling has incorporated in the increase in flows to the river caused by surface water irrigation in the absence of groundwater development.

6.7 Conjunctive water use indicators

Groundwater can provide a secure water source during drier periods. Irrigators may elect to change from surface water to groundwater during years of low flow where such changes are feasible. Even without this, the lower surface water diversions in low flow years mean that groundwater forms a higher proportion of total diversions in those years. This return is estimated to be about 70 to 80 GL/year. Table 6-20 shows these ratios for years of lowest surface water diversions up to a year with average surface water diversions.

These results show that groundwater forms a minor source of water for the region as a whole under average flow years but is important in drier years, and occasionally would be the dominant source of water under the driest scenarios.

Table 6-20. Conjunctive water use indicators: ratio (as a percentage) of groundwater to total water diversion in the Murrumbidgee region in the one-, three- and five-year periods of lowest surface water diversions and the average year under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Lowest 1-year period	26%	47%	46%	27%	26%	51%	33%	30%
Lowest 3-year period	21%	29%	29%	22%	19%	34%	27%	22%
Lowest 5-year period	19%	27%	25%	20%	18%	30%	24%	22%
Average	17%	19%	19%	17%	16%	23%	21%	20%

6.8 Discussion

Lower Murrumbidgee Alluvium GMU

The modelling results indicate that the water balance is sustained through the large component of recharge coming from irrigation. The impact on the river is small. The main issue is whether the high component of irrigation recharge is likely to lead to salinisation of the groundwater resource in some areas. This is outside the scope of the current project. The current results indicate downward leakage through the aquifer sequence, a process which could cause such salinisation but other factors also need to occur for this to be significant.

Mid-Murrumbidgee Alluvium GMU

The modelling results indicate that the water balance is maintained through leakage from the river. The recent increase in groundwater development in this GMU coupled with good connectivity with the river means that river losses are high through these reaches and that the losses are not fully accounted for within the river planning model. However, the relatively high flows in the Murrumbidgee River may mean that the relative impact is not as high as for some of the more northern rivers.

Non-modelled areas

Results indicate that the level of development in the other GMUs is low except for the Billabong Creek Alluvium GMU. It is likely that stream recharge forms a significant part of the groundwater balance for this GMU, perhaps enabling the level of development to be sustained. Further information on groundwater balance is warranted to support this assumption and hence the level of development.

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7 Environment

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

- a summary
- an overview of the approach
- a presentation 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 (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 Murrumbidgee River is regulated by the Snowy Mountains Hydro-electric Scheme, Canberra's water supply system and several large storages that supply rural centres and major irrigation areas. The Water Sharing Plan (WSP) for the Murrumbidgee Regulated River Water Source (DIPNR, 2004) makes provisions for environmental water for the river downstream of Burrinjuck Dam. The Australian Capital Territory Environmental Flow Guidelines define environmental flows for a range of identified ecosystem types and for specific reaches within the territory's water supply catchments.
- The region contains several nationally and internationally important wetlands, including many upland sites. However, the major Murrumbidgee wetlands are on the middle and lower floodplains of the Murrumbidgee River. Some support large waterbird breeding events and an appreciable assemblage of rare, endangered and vulnerable species. The implications of climate change on water availability for the Mid Murrumbidgee Wetlands and the Lowbidgee Floodplain are assessed and reported.

7.1.2 Key messages

Mid Murrumbidgee Wetlands

- Water resource development has nearly doubled the average period between high flow events which inundate a large proportion of the Mid Murrumbidgee Wetlands (from 0.4 to nearly 0.8 years), and has more than tripled the maximum period between these events (from less than three to nearly ten years). The flooding volume per event has been slightly reduced, however, the change in period between high flow events means that the average annual flooding volume has been nearly halved. These changes are likely to have had serious adverse ecological consequences for these wetlands.
- Under a long-term continuation of the recent climate, the average period between high flows would more than double to be nearly two years and the average flooding volume per year would reduce by a further 69 percent to be only 16 percent of the without-development value.
- Under the best estimate 2030 climate the average period between high flows would increase by a further 29 percent and the average annual flooding volume would reduce by 32 percent. Further degradation of the wetlands would be likely. Under the dry extreme 2030 climate the average period between high flows would more than double and the average annual flooding volume would reduce by 65 percent. These changes would have serious ecological consequences. Under the wet extreme 2030 climate the average period between high flows would decrease by 17 percent and the average annual flooding volume would increase by 43 percent. This represents a return towards without-development flow conditions.

- Future additional farm dams, expansion of commercial plantation forestry and growth in groundwater extraction would cause small additional hydrologic impacts for the Mid Murrumbidgee Wetlands to those described above.

Lowbidgee Floodplain

- Water resource development more than tripled the average period between high flow events at Maude Weir that flood the Lowbidgee Floodplain (from 0.4 to 1.5 years) and has more than doubled the maximum period between high flow events (from 4 to 10.5 years). Although flood events are now larger on average, the increased period between events means the average annual flooding volume has been more than halved. It is likely these changes have adversely affected the wetlands of the Lowbidgee Floodplain but the effects are complicated by the high level of artificial manipulation of the water regime to and within this area.
- Under a long-term continuation of the recent climate, the average period between high flows would more than double to be 3.5 years and the maximum period between these events would increase by over 50 percent to be more than 16 years. The average flooding volume per year would reduce by 74 percent to be just 11 percent of the without-development value.
- Under the best estimate 2030 climate, the average period between high flows would increase by 16 percent and the average annual flooding volume would reduce by 33 percent. Under the dry extreme 2030 climate, the average period between high flows would nearly double and the average annual flooding volume would reduce by 71 percent. Under the wet extreme 2030 climate, the average period between flood events would decrease by 23 percent and the average annual flooding volume would increase by 41 percent. This would represent a return towards without-development flow conditions.
- Future additional farm dams, expansion of commercial plantation forestry and growth in groundwater extraction would cause small additional hydrologic impacts on the Lowbidgee Floodplain to those described above.

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 project 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 focuses on the specific rules for applying environmental water and the assessment of hydrologic indicators (defined by prior studies) for key environmental assets in the region. A broader description of the catchment, water resources and important environmental assets is provided in Chapter 2.

7.2.1 Summary of environmental flow rules

The WSP has the following environmental water rules:

- 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 1999/00 water use development and the management rules in the WSP (estimated to average 1925 GL/year over the long term). It is also estimated that this rule protects about 56 percent of the average annual flow over the long term for the environment

- until 1 July 2008, a minimum daily end-of-system flow of between 200 and 300 ML/day, depending on general security access licence allocation levels
- from 1 July 2008, a minimum daily end-of-system flow that is related to the 95th percentile natural daily flow
- transparent releases from Blowering Dam (up to 560 ML/day) and Burrinjuck Dam (up to 615 ML/day). (Transparent releases are 'when all dam inflows are released coincidentally with their occurrence')
- translucent releases from Burrinjuck Dam between April and October, when inflows exceed 615 ML/day. The proportion of inflow released is dependent on Burrinjuck storage level and an assessment of catchment condition (i.e., wet, medium and dry). Releases are subject to operational constraints. (Translucent releases are 'where a proportion of dam inflows are released coincidentally with their occurrence')
- an environmental water allowance of 50 GL/year subject to general security access licence allocation levels
- two other environmental water allowances that hold translucent releases not made due to operational constraints
- allowance for access licences to be committed for environmental purposes
- until July 2008, a minimum daily Balranald end-of-system flow of between 200 and 300 ML/day, depending on the general security access licence allocation levels
- from July 2008, the minimum daily Balranald end-of-system flow requirement is related to the 95th percentile natural daily flow.

The environmental assets assessed in this project are on the New South Wales portion of the Murrumbidgee River downstream of Burrinjuck Dam (Figure 7-1).

In the Australian Capital Territory, the Water Resources Act 2007 governs water management arrangements, which includes provisions for environmental flows (ACT Government, 2007). The Act requires the preparation of environmental flow guidelines which are used within the Australian Capital Territory strategy for sustainable water resource management (Environment ACT, 2004). The 2006 environmental flow guidelines (ACT Government, 2006) provide for the protection of particular components of the natural flow regime (base flows, riffle maintenance flows, pool maintenance flows, channel maintenance flows, groundwater abstraction limits and impoundment drawdown levels). Environmental flows have been established for a range of identified ecosystem types and for specific reaches within the Australian Capital Territory water supply catchments. The Guidelines set out flow requirements for non-drought conditions, as well as drought flows for Stage 1 and 2 water restrictions. Examples of the multiple specific environmental flow rules (as available for the modelling undertaken for this project) are provided below:

Base flow requirements include:

- maintenance of 75 percent of the 80th percentile of the monthly natural inflow, or the inflow, whichever is the lesser, below Corin and Bendora Dams
- maintenance of an average flow of 15 ML/day below Cotter Dam
- maintenance of an average flow of 10 ML/day or the natural inflow, whichever is the lesser, below Googong Dam
- maintenance of 80th percentile monthly flow November–May, and the 90th percentile monthly flow June–October inclusive, in the Murrumbidgee River.

Other flow requirements include:

- riffle maintenance flows of 150 ML/day for three consecutive days every two months below Corin and Bendora dams and 100 ML/day for one day every two months below Cotter and Googong dams and any impoundment on the Naas and Gudgenby rivers
- a pool maintenance flow of greater than 550 ML/day for two consecutive days between mid-July and mid-October below Corin and Bendora dams
- a channel maintenance flow – protection of 90 percent of the volume of events above the 80th percentile from abstraction
- groundwater abstraction limits to 10 percent of the long-term recharge.

All the Australian Capital Territory environmental flow requirements are represented in the river modelling for the Australian Capital Territory and are reflected in the results and analysis presented in Chapter 4. These environmental flow requirements are 'forced' in the model and so are met under all scenarios. They are therefore not reported on in this chapter.

7.2.2 Environmental assets and indicators

The Murrumbidgee region contains a total of 33 sites listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001) – see Chapter 2. There are two Ramsar sites within the region: one upland site and two lowland wetlands (Fivebough and Tuckerbil Swamps within the WSP area) that form a single Ramsar site. These two lowland wetlands are isolated from Murrumbidgee River flows and largely receive local inflow (irrigation drainage, stormwater or treated sewage discharge) (Environment Australia, 2001). The remaining nationally important wetlands include numerous small upland sites for which no investigations relating to environmental flow regimes have been undertaken. The two large lowland wetland complexes – the Mid Murrumbidgee Wetlands and the Lowbidgee Floodplain wetlands – have been assessed in this project. The following descriptions are from Environment Australia (2001) unless otherwise cited.

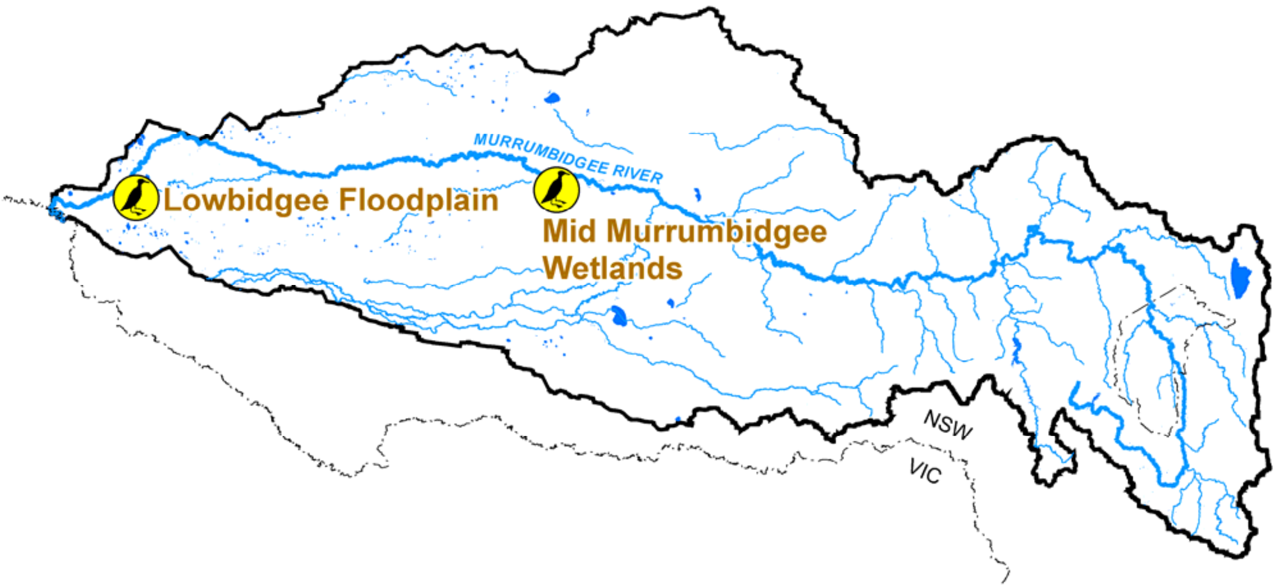

Figure 7-1. Location map of assessed environmental assets

Mid Murrumbidgee Wetlands (NSW052)

The Mid Murrumbidgee Wetlands are an assemblage of lagoons and billabongs along the Murrumbidgee River from Narrandera to Carrathool and include Bulgari Lagoon, Currawananna Lagoon, McKennas Lagoon and Sunshower Lagoon. There is no prescribed geographic area, as their area varies greatly with flooding. The wetlands are on the floodplain and receive flows from the river mostly during winter and spring floods.

River Red Gum (*Eucalyptus camaldulensis*) forest and woodlands dominate the vegetation of the area with Black Box (*E. largiflorens*) woodland being more marginal on the floodplain. The lagoons and billabongs have open water habitat with aquatic plants such as Spike Rush (*Juncus* spp and/or *Eleocharis* spp), Garland Lily (*Calostemma purpureum*) and Blanket Fern (*Pleuosorus rutiflolius*).

Many species of waterbird are recorded on the lagoons and billabongs (Briggs et al., 1994). Resident species that are listed as endangered at the state level include the Bush Stone-curlew (*Burhinus grallarius*). There are several species listed as vulnerable including the Freckled Duck *(Stictonetta naevosa)*, Blue-billed Duck *(Oxyura australis)* and Brolga *(Grus rubicundus).* Other notable resident fauna includes the Koala *(Phascolarctus cinereus).*

Land tenure is a mixture of state forest, nature reserves (for example, Narrandera Nature Reserve), crown reserves and freehold. Land uses include grazing, forestry, recreation and nature conservation.

Hardwick et al. (2001) describe commence-to-flow thresholds for billabongs and lagoons at several locations on the middle section of the Murrumbidgee Riveras between 12 and 29 GL/day. The Narrandera State Forest (a substantial wetland area) floods at 26.8 GL/day at the Narrandera gauge, and this indicator was selected for assessment in this project.

Lowbidgee Floodplain (NSW021)

The Lowbidgee Floodplain is around the lower Murrumbidgee River downstream of Maude and covers some 200,000 ha. The broader Lowbidgee is sub-divided into the Nimmie-Pollen-Caira system near Maude Weir and the Redbank-Yanga system further downstream (Kingsford and Thomas, 2001). The floodplain receives floods overbank or via controlled diversions from Maude and Redbank weirs (Kingsford and Thomas, 2001). This is most often during winter and spring. The Nimmie-Pollen-Caira system also has a large number of water control structures.

The vegetation of the Nimmie-Pollen-Caira system is predominantly extensive areas of Lignum (*Muelhlenbeckia florulenta*). The Redbank-Yanga portion is covered by River Red Gum (*E. camaldulensis*) forest and woodlands with Black Box (*E. largiflorens*) on the floodplain margins. A wide range of fauna are found on the floodplain and both portions are known to be used extensively for waterbird breeding. Kingsford and Thomas (2001) cite major reductions in the incidence and numbers of waterbirds breeding between 1983 and 1999 caused by clearing of Lignum in the Nimmie-Pollen-Caira system. Extensive use of the area by Indigenous people is evident.

Land tenure is mostly freehold, although recently the New South Wales Government purchased much of the Redbank-Yanga portion (over 31,000 ha) and made it a national park in 2007 (DECC, 2007). Land uses include grazing, cropping, irrigation (particularly for the Nimmie-Pollen-Caira system), nature conservation and forestry.

The Murrumbidgee River decreases in channel capacity in a downstream direction from a channel capacity of 35 GL/day at Hay, 20 GL/day at Maude Weir and 11 GL/day at Redbank Weir (Kingsford and Thomas, 2001). Overbank flows into the Lowbidgee Floodplain occurs at 20 GL/day (at Maude), although controlled diversions from both Maude and Redbank weirs can occur at much lower flow levels. The availability of these controlled diversions is subject to fairly complicated rules and therefore is not suitable to establish an indicator for this project. The 20 GL/day flow at Maude Weir was therefore used for assessment in this project.

Table 7-1. Definition of environmental indicators

Name	Description
Mid Murrumbidgee Wetlands	
Average period between high flow events	Average period (years) between flows exceeding 26.8 GL/day at Narrandera gauge
Maximum period between high flow events	Maximum period (years) between flows exceeding 26.8 GL/day at Narrandera gauge
Average flooding volume per year	Average annual volume above 26.8 GL/day at Narrandera gauge
Average flooding volume per event	Average event volume above 26.8 GL/day at Narrandera gauge
Lowbidgee Floodplain	
Average period between high flow events	Average period (years) between flows exceeding 20 GL/day at Maude Weir
Maximum period between high flow events	Maximum period (years) between flows exceeding 20 GL/day at Maude Weir
Average flooding volume per year	Average annual volume above 20 GL/day at Maude Weir
Average flooding volume per event	Average event volume above 20 GL/day at Maude Weir

7.3 Results

The projected changes in the selected environmental indicators are listed for the various scenarios in Table 7-2. These were assessed using scenario outputs from the Murrumbidgee river model (Chapter 4).

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

	P	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Mid Murrumbidgee Wetlands	years		percent change from Scenario A						
Average period between high flow events	0.4	0.8	150%	113%	29%	-17%	123%	28%	-15%
Maximum period between high flow events	2.8	9.7	12%	10%	0%	-40%	10%	0%	-40%
	GL								
Average flooding volume per year	1246	652	-69%	-65%	-32%	43%	-66%	-35%	40%
Average flooding volume per event	544	525	-27%	-27%	-14%	20%	-26%	-17%	21%
Lowbidgee Floodplain	years								
Average period between high flow events	0.4	1.5	133%	94%	16%	-23%	129%	18%	-24%
Maximum period between high flow events	4.0	10.5	54%	53%	0%	-8%	53%	4%	-8%
	GL								
Average high flow volume per year	1169	509	-74%	-71%	-33%	41%	-73%	-36%	38%
Average high flow volume per event	562	785	-38%	-45%	-23%	10%	-39%	-25%	7%

7.4 Discussion of key findings

Mid Murrumbidgee Wetlands

Water resource development has nearly doubled the average period between high flow events which inundate a large proportion of the Mid Murrumbidgee Wetlands from 0.4 to 0.8 years, and has more than tripled the maximum period between events from 2.8 to 9.7 years. The flooding volume per event has only been slightly reduced (4 percent), however, the change in period between events means that the average annual flooding volume has been nearly halved. This assessment is consistent with that of Frazier and Page (2006) who report a 40 percent reduction in the duration and frequency of wetland inundation for an area covering the billabongs due to water resources development. These changes are likely to have had serious adverse ecological consequences for these wetlands.

Under Scenario B the average period between high flows would more than double to be nearly two years and the maximum period between events would increase slightly to be nearly 11 years. Average flooding volumes per event would reduce by a further 27 percent. The average flooding volume per year would reduce by a further 69 percent (relative to Scenario A) to be only 16 percent of the without-development value. Overall, the recent climate conditions indicate less frequent flooding but with similar event volumes than under the dry extreme 2030 conditions (see below).

Under Scenario Cmid the average period between high flows to the billabongs would increase by a further 29 percent but the maximum period between events would not be affected. The event and annual flooding volumes of these high flows would reduce substantially by 14 percent and 32 percent, respectively. Further degradation of the wetlands would be likely.

Under Scenario Cdry the average period between high flow events would increase by 113 percent (to once in over 1.6 years on average). The maximum period between the high flow events would increase by 10 percent. Substantial reductions in event flooding volume (27 percent) and the annual excess volume (65 percent) of high flow events would also occur – very similar to Scenario B conditions. These changes would be very likely to have serious ecological consequences.

Under Scenario Cwet, the average period between high flow events would decrease by 17 percent. The maximum period between high flow events would decrease by 40 percent. The event and annual flooding volumes of these high flows would increase substantially by 20 percent and 43 percent, respectively. This represents a return towards without-development flow conditions.

Projected future catchment and groundwater development would have only small additional effects on the periods between and volumes of these high flow events.

Lowbidgee Floodplain

Water resource development more than tripled the average period between high flow events at Maude Weir that flood the Lowbidgee Floodplain (from 0.4 to 1.5 years) and has more than doubled the maximum period between high flow events (from 4 to 10.5 years). Although the average flooding volume per event has increased by 40 percent (562 to 785 GL), the annual excess flooding volume has been more than halved from 1169 to 509 GL. Kingsford and Thomas (2001) also note substantial reductions in the annual volume of flows to this area of the river due to water resources development. It is likely these changes have adversely affected the wetlands of the Lowbidgee but the effects are complicated by the high level of artificial manipulation of the water regime to and within this area. This manipulation confounds the ecological consequences of climate change impacts.

Under Scenario B the average period between high flows would more than double to be 3.5 years and the maximum period between these events would increase by over 50 percent to be more than 16 years. Flood volumes per event would reduce by 38 percent and the flooding volume per year would reduce by 74 percent, relative to Scenario A. The annual flood volume would then be just 11 percent of the without-development value. Overall, the recent climate conditions indicate less frequent flooding but with similar event volumes compared to the dry extreme 2030 climate conditions (see below).

Under Scenario Cmid the average period between high flows would increase by 16 percent but there would be no increase in the maximum period between these events. The excess event volume of these events would reduce by 23 percent and annual excess volume would reduce by 33 percent.

Under Scenario Cdry the average period between high flows would increase by 94 percent and the maximum period would increase by 53 percent. The excess event volume per event would reduce by 45 percent and the annual excess flood volume would reduce by 71 percent. Under Scenario Cwet the average period between high flows would decrease by 23 percent and the maximum period between events would decrease by 8 percent, leading to a 41 percent increase in the average annual flood volume.

Projected future catchment and groundwater development would cause small additional hydrologic impacts to those described above.

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					
4100013	825	596	1306	18	3%	0%	-22%	-51%	-2%	-16%	6%	18%
4100014	272	571	1306	39	7%	0%	-22%	-44%	-2%	-11%	7%	15%
4100015	137	570	1314	37	6%	0%	-22%	-43%	-2%	-11%	6%	14%
4100016	248	629	1309	20	3%	0%	-22%	-51%	-2%	-17%	6%	19%
4100017	321	772	1282	98	13%	1%	-21%	-53%	-2%	-20%	6%	17%
4100041	1406	726	1287	75	10%	2%	-13%	-39%	-2%	-19%	6%	18%
4100061	167	908	1264	165	18%	1%	-12%	-27%	-3%	-9%	6%	14%
4100081	1524	768	1233	131	17%	4%	-12%	-27%	-2%	-11%	6%	13%
4100240	989	1066	1159	261	24%	5%	-12%	-25%	-2%	-8%	6%	14%
4100250	2149	645	1290	55	8%	2%	-12%	-35%	-2%	-17%	6%	18%
4100260	1237	639	1221	61	10%	2%	-12%	-28%	-2%	-10%	6%	14%
4100321	264	1206	1133	490	41%	3%	-13%	-22%	-3%	-8%	6%	10%
4100331	1427	793	1108	55	7%	2%	-14%	-43%	-2%	-14%	6%	20%
4100380	387	1046	1214	211	20%	2%	-12%	-26%	-3%	-9%	6%	14%
4100391	383	849	1261	141	17%	1%	-14%	-39%	-3%	-18%	6%	15%
4100430	565	858	1254	158	18%	2%	-21%	-39%	-3%	-9%	6%	13%
4100440	1061	628	1302	40	6%	1%	-21%	-45%	-2%	-13%	6%	15%
4100450	844	583	1303	17	3%	0%	-22%	-51%	-2%	-15%	6%	17%
4100470	1645	812	1261	119	15%	4%	-20%	-42%	-3%	-13%	6%	15%
4100480	552	644	1281	58	9%	1%	-21%	-44%	-3%	-12%	6%	14%
4100501	894	514	1138	48	9%	1%	-15%	-27%	-1%	-3%	4%	9%
4100570	662	1146	1157	395	34%	6%	-12%	-23%	-3%	-8%	6%	12%
4100590	277	1096	1212	280	26%	2%	-19%	-36%	-3%	-9%	6%	13%
4100610	146	1009	1230	237	24%	1%	-21%	-38%	-3%	-9%	6%	13%
4100620	676	688	1098	114	17%	2%	-15%	-24%	-2%	-4%	3%	4%
4100670	211	875	1101	165	19%	1%	-15%	-26%	-1%	-5%	6%	13%
4100710	116	868	1255	146	17%	0%	-12%	-36%	-3%	-18%	6%	16%
4100721	684	1149	1134	424	37%	6%	-13%	-24%	-3%	-9%	6%	11%
4100760	213	718	1119	70	10%	0%	-15%	-29%	-1%	-8%	6%	15%
4100770	87	847	1095	118	14%	0%	-15%	-27%	-1%	-7%	6%	15%
4100910	2658	653	1280	60	9%	3%	-19%	-42%	-3%	-12%	6%	14%
4101021	273	1055	1204	249	24%	1%	-13%	-26%	-3%	-9%	6%	14%
4101030	1147	533	1321	4	1%	0%	-22%	-71%	-2%	-22%	6%	38%
4101070	186	821	1226	155	19%	1%	-12%	-27%	-2%	-11%	6%	14%
4101301	55650	395	1361	15	4%	18%	-22%	-43%	-3%	-9%	7%	16%
4101410	193	703	1135	35	5%	0%	-15%	-27%	-1%	-9%	6%	16%
4101761	363	685	1257	89	13%	1%	-12%	-29%	-2%	-12%	6%	14%
4105421	95	1550	1060	1043	67%	2%	-13%	-15%	-3%	-3%	6%	9%
4105430	467	1201	1094	662	55%	7%	-14%	-17%	-3%	-4%	6%	10%
4105451	60	1385	1090	893	64%	1%	-13%	-15%	-3%	-3%	6%	9%
4105710	248	1504	1041	989	66%	5%	-13%	-15%	-3%	-3%	6%	9%
4107001	1	903	1187	120	13%	0%	-12%	-28%	-2%	-9%	6%	16%
4107041	190	903	1187	120	13%	0%	-12%	-28%	-2%	-9%	6%	16%
4107050	492	715	1154	80	11%	1%	-13%	-29%	-2%	-10%	6%	14%

		Scenario A					Scenario Cdry		Scenario Cmid		Scenario Cwet	
4107130	228	877	1156	114	13%	1%	-12%	-30%	-2%	-9%	6%	15%
4107171	92	1040	1132	267	26%	1%	-12%	-24%	-2%	-7%	6%	13%
4107291	135	641	1189	52	8%	0%	-12%	-30%	-2%	-11%	6%	14%
4107310	672	893	1112	84	9%	1%	-14%	-42%	-2%	-13%	6%	19%
4107381	304	669	1199	46	7%	0%	-12%	-29%	-2%	-7%	6%	14%
4107420	199	1045	1111	271	26%	1%	-14%	-27%	-2%	-7%	6%	13%
4107450	28	671	1182	45	7%	0%	-12%	-28%	-2%	-7%	6%	14%
4107480	898	797	1122	47	6%	1%	-14%	-24%	-2%	-9%	6%	17%
4107563	68	632	1219	38	6%	0%	-12%	-27%	-2%	-7%	6%	14%
4107564	157	612	1207	35	6%	0%	-12%	-28%	-2%	-7%	6%	13%
4107601	22	595	1198	31	5%	0%	-12%	-27%	-1%	-6%	6%	13%
4107611	1005	643	1141	54	8%	1%	-15%	-29%	-1%	-7%	6%	14%
4107750	68	626	1193	58	9%	0%	-12%	-28%	-2%	-9%	6%	14%
4107900	122	665	1175	47	7%	0%	-12%	-29%	-2%	-8%	6%	14%
4110020	943	678	1183	64	9%	1%	-12%	-29%	-2%	-11%	6%	14%
	87331	**530**	**1308**	**54**	**10%**	**100%**	**-18%**	**-31%**	**-2%**	**-9%**	**6%**	**13%**

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		
4100013	18	0	396	0.5	-52%	-18%	16%
4100014	39	0	95	0.4	-45%	-12%	13%
4100015	37	0	78	0.6	-45%	-13%	12%
4100016	20	0	102	0.4	-52%	-19%	17%
4100017	98	0	96	0.3	-53%	-20%	17%
4100041	75	0	600	0.4	-40%	-20%	17%
4100061	165	0	30	0.2	-27%	-10%	13%
4100081	131	5434	613	0.4	-30%	-14%	10%
4100240	261	1816	89	0.1	-26%	-9%	12%
4100250	55	0	1019	0.5	-36%	-18%	17%
4100260	61	0	614	0.5	-29%	-11%	13%
4100321	490	0	48	0.2	-22%	-8%	10%
4100331	55	0	456	0.3	-43%	-15%	19%
4100380	211	0	110	0.3	-26%	-10%	14%
4100391	141	0	82	0.2	-39%	-18%	15%
4100430	158	0	119	0.2	-39%	-10%	13%
4100440	40	0	429	0.4	-46%	-15%	14%
4100450	17	0	377	0.4	-52%	-16%	14%
4100470	119	0	781	0.5	-42%	-14%	14%
4100480	58	0	334	0.6	-45%	-13%	13%
4100501	48	0	228	0.3	-27%	-4%	8%
4100570	395	0	120	0.2	-23%	-8%	12%
4100590	280	0	50	0.2	-36%	-9%	13%
4100610	237	0	27	0.2	-38%	-9%	13%
4100620	114	0	155	0.2	-24%	-4%	3%
4100670	165	0	49	0.2	-26%	-5%	13%
4100710	146	0	26	0.2	-36%	-18%	16%
4100721	424	403	122	0.2	-24%	-9%	10%
4100760	70	0	50	0.2	-29%	-8%	14%
4100770	118	0	20	0.2	-27%	-7%	14%
4100910	60	0	1247	0.5	-43%	-13%	13%
4101021	249	1578	50	0.2	-28%	-12%	10%
4101030	4	0	556	0.5	-72%	-23%	35%
4101070	155	0	71	0.4	-27%	-11%	13%

Modelling catchment	A runoff	Plantations increase	Farm dam increase		Ddry runoff	Dmid runoff	Dwet runoff
4101301	15	0	36679	0.7	-45%	-12%	12%
4101410	35	0	53	0.3	-28%	-10%	14%
4101761	89	0	193	0.5	-30%	-13%	13%
4105421	1043	0	17	0.2	-15%	-3%	9%
4105430	662	0	136	0.3	-17%	-4%	9%
4105451	893	0	11	0.2	-15%	-3%	9%
4105710	989	0	41	0.2	-15%	-3%	9%
4107001	120	0	0	0.0	-28%	-9%	16%
4107041	120	1043	0	0.0	-30%	-11%	13%
4107050	80	0	172	0.3	-30%	-11%	13%
4107130	114	3388	0	0.0	-34%	-14%	8%
4107171	267	0	0	0.0	-24%	-7%	13%
4107291	52	0	21	0.2	-31%	-11%	13%
4107310	84	0	2	0.0	-42%	-13%	19%
4107381	46	1212	3	0.0	-31%	-10%	10%
4107420	271	0	1	0.0	-27%	-7%	13%
4107450	45	0	0	0.0	-28%	-7%	14%
4107480	47	0	257	0.3	-25%	-10%	16%
4107563	38	0	0	0.0	-27%	-7%	14%
4107564	35	0	0	0.0	-28%	-7%	12%
4107601	31	0	7	0.3	-28%	-8%	11%
4107611	54	0	247	0.2	-30%	-8%	13%
4107750	58	0	0	0.0	-28%	-9%	14%
4107900	47	0	25	0.2	-29%	-8%	13%
4110020	64	2126	460	0.5	-31%	-14%	10%
	54	**17000**	**47562**	**0.5**	**-32%**	**-10%**	**12%**

Appendix B River modelling reach mass balances

Murrumbidgee Irrigation Area

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Effluent return (into Main Canal and Sturt Canal from Murrumbidgee River)	1061.2	-10%	4%	0%	-8%	3%	-1%	-9%
Sub-total	**1061.2**	**-10%**	**4%**	**0%**	**-8%**	**3%**	**-1%**	**-9%**
Diversions								
Licensed private diversions								
General security	505.8	-14%	7%	1%	-10%	7%	0%	-12%
Supplementary flow	43.8	-1%	-7%	-5%	-9%	-8%	-5%	-10%
Stock and domestic	7.3	0%	0%	0%	0%	0%	0%	0%
High security	245.6	-1%	1%	0%	-2%	0%	0%	-2%
Conveyance	239.0	-11%	1%	-1%	-9%	1%	-2%	-10%
Town water supply	19.7	0%	0%	0%	0%	0%	0%	0%
Sub-total	**1061.3**	**-10%**	**4%**	**0%**	**-8%**	**3%**	**-1%**	**-9%**

4100341

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	147.2	-39%	14%	-12%	-42%	13%	-13%	-43%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Effluent return	914.4	-25%	9%	-6%	-22%	8%	-7%	-23%
Irrigation returns	88.0	-23%	9%	-4%	-26%	8%	-5%	-27%
River groundwater gains	10.0	10%	2%	3%	1%	2%	3%	1%
Sub-total	**1159.7**	**-26%**	**9%**	**-6%**	**-25%**	**8%**	**-7%**	**-26%**
Diversions								
Licensed private diversions								
General security	409.6	-25%	7%	-3%	-21%	6%	-4%	-22%
Supplementary flow	32.4	-35%	5%	-12%	-39%	4%	-12%	-42%
Stock and domestic	9.4	-1%	0%	0%	-1%	0%	0%	-1%
High security	8.6	-2%	1%	0%	-2%	0%	0%	-2%
Conveyance (Coleambally Irrigation Area)	125.9	-6%	1%	-1%	-5%	1%	-1%	-5%
Town water supply	1.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**587.0**	**-21%**	**6%**	**-3%**	**-18%**	**5%**	**-4%**	**-19%**
Outflows								
End of catchment flows	328.6	-32%	13%	-11%	-34%	11%	-12%	-35%
Subcatchment effluent	57.8	-37%	11%	-12%	-39%	9%	-13%	-40%
River groundwater loss	0.3	-54%	148%	-22%	-53%	140%	-23%	-55%
Irrigation supply losses	4.0	7%	-20%	3%	10%	-15%	6%	6%
River reach evaporation	25.5	7%	3%	4%	13%	3%	4%	13%
Sub-total	**416.2**	**-30%**	**12%**	**-10%**	**-31%**	**10%**	**-11%**	**-32%**
Unattributed fluxes								
River unattributed loss	156.5	-33%	17%	-11%	-34%	16%	-12%	-35%

4101301

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	1415.3	-47%	22%	-18%	-45%	20%	-20%	-47%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Effluent return	229.0	-37%	12%	-10%	-40%	10%	-13%	-42%
River groundwater gains	2.7	45%	-12%	13%	27%	-11%	14%	28%
Sub-total	**1647.0**	**-46%**	**20%**	**-17%**	**-44%**	**18%**	**-19%**	**-46%**
Diversions								
Licensed private diversions								
General security	8.8	-3%	4%	4%	4%	4%	4%	2%
Supplementary flow	1.6	-34%	14%	-7%	-36%	13%	-9%	-38%
Stock and domestic	0.8	0%	0%	0%	0%	0%	0%	0%
High security	4.7	-1%	1%	0%	-2%	0%	0%	-2%
Town water supply	1.2	0%	0%	0%	0%	0%	0%	0%
Sub-total	**17.0**	**-5%**	**4%**	**1%**	**-2%**	**3%**	**1%**	**-3%**
Outflows								
End of catchment flows	1151.9	-50%	23%	-19%	-47%	21%	-21%	-49%
Net evaporation river storage	4.8	-14%	15%	-1%	-11%	14%	-2%	-12%
River reach evaporation	14.4	11%	7%	6%	15%	7%	7%	16%
Net inflow into the Nimmie-Caira system in Lowbidgee	192.8	-33%	10%	-9%	-36%	8%	-11%	-38%
Net inflow into the Redbank Forest system in Lowbidgee	173.0	-42%	15%	-12%	-43%	13%	-15%	-44%
Sub-total	**1537.0**	**-46%**	**20%**	**-17%**	**-45%**	**18%**	**-19%**	**-46%**
Unattributed fluxes								
River unattributed loss	92.6	-47%	26%	-21%	-45%	24%	-22%	-46%

4100401

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	1751.3	-45%	20%	-16%	-43%	17%	-18%	-44%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
River groundwater gains	6.1	3%	2%	2%	-6%	2%	2%	-6%
Sub-total	**1757.4**	**-44%**	**19%**	**-16%**	**-43%**	**17%**	**-18%**	**-44%**
Diversions								
Licensed private diversions								
General security	56.4	-32%	5%	-5%	-26%	4%	-7%	-28%
Supplementary flow	9.2	-61%	15%	-24%	-69%	14%	-27%	-70%
Stock and domestic	11.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**76.6**	**-31%**	**6%**	**-7%**	**-27%**	**5%**	**-8%**	**-29%**
Outflows								
End of catchment flows	1415.3	-47%	22%	-18%	-45%	20%	-20%	-47%
Subcatchment effluent	229.0	-37%	12%	-10%	-40%	10%	-13%	-42%
Net evaporation river storage	5.0	-13%	14%	-1%	-8%	13%	-2%	-9%
River reach evaporation	7.8	6%	4%	4%	12%	3%	4%	12%
Sub-total	**1657.1**	**-46%**	**20%**	**-17%**	**-44%**	**18%**	**-19%**	**-45%**
Unattributed fluxes								
River unattributed loss	23.7	0%	0%	0%	0%	0%	0%	0%

4100361

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	2089.3	-43%	19%	-15%	-41%	17%	-17%	-43%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
River groundwater gains	15.4	26%	-8%	9%	20%	-7%	9%	20%
Sub-total	**2104.6**	**-43%**	**18%**	**-15%**	**-41%**	**16%**	**-17%**	**-42%**
Diversions								
Licensed private diversions								
General security	176.2	-32%	7%	-5%	-27%	6%	-7%	-29%
Supplementary flow	19.9	-55%	19%	-22%	-65%	18%	-25%	-68%
Stock and domestic	7.1	0%	0%	0%	0%	0%	0%	0%
High security	1.5	-2%	1%	0%	-2%	0%	0%	-2%
Town water supply	2.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**204.6**	**-32%**	**9%**	**-6%**	**-28%**	**8%**	**-7%**	**-30%**
Outflows								
End of catchment flows	1751.3	-45%	20%	-16%	-43%	17%	-18%	-44%
Net evaporation river storage	7.9	4%	7%	4%	8%	6%	3%	7%
River reach evaporation	22.9	3%	2%	6%	19%	3%	6%	19%
Sub-total	**1782.1**	**-44%**	**19%**	**-16%**	**-42%**	**17%**	**-18%**	**-43%**
Unattributed fluxes								
River unattributed loss	115.9	-46%	23%	-17%	-44%	21%	-19%	-45%

4100211

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	3265.2	-37%	15%	-12%	-34%	14%	-14%	-36%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Effluent return	11.3	-16%	5%	-2%	-15%	5%	-3%	-16%
River groundwater gains	0.1	2505%	-100%	780%	2389%	-100%	823%	2420%
Sub-total	**3276.6**	**-37%**	**15%**	**-12%**	**-34%**	**14%**	**-13%**	**-35%**
Diversions								
Licensed private diversions								
General security	15.9	-10%	4%	2%	-4%	4%	1%	-6%
Supplementary flow	0.7	-25%	0%	-12%	-32%	-4%	-14%	-29%
Stock and domestic	0.3	0%	0%	0%	0%	0%	0%	0%
High security	0.2	-2%	1%	0%	-2%	0%	0%	-2%
Town water supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**17.2**	**-10%**	**4%**	**1%**	**-5%**	**3%**	**0%**	**-6%**
Outflows								
End of catchment flows	2089.3	-43%	19%	-15%	-41%	17%	-17%	-43%
Subcatchment effluent (to Murrumbidgee Irrigation Area, Coleambally Irrigation Area and Yanco Creek)	1058.8	-24%	8%	-5%	-21%	7%	-6%	-22%
River groundwater loss	3.4	9%	7%	2%	23%	6%	2%	22%
Net evaporation river storage	7.8	-3%	9%	2%	1%	8%	1%	0%
River reach evaporation	9.0	9%	2%	6%	17%	2%	6%	17%
Sub-total	**3168.2**	**-37%**	**15%**	**-12%**	**-34%**	**13%**	**-13%**	**-35%**
Unattributed fluxes								
River unattributed loss	91.0	-42%	22%	-17%	-39%	20%	-18%	-41%

4100051

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	4260.8	-30%	13%	-9%	-28%	12%	-10%	-29%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
River groundwater gains	0.3	-100%	-11%	-100%	-100%	-100%	-100%	-100%
Sub-total	**4261.1**	**-30%**	**13%**	**-9%**	**-28%**	**12%**	**-10%**	**-29%**
Diversions								
Licensed private diversions								
General security	33.7	-26%	8%	-4%	-21%	6%	-5%	-23%
Supplementary	2.4	18%	-18%	2%	24%	-17%	3%	27%
Sub-total	**36.1**	**-23%**	**6%**	**-3%**	**-18%**	**5%**	**-5%**	**-20%**
Outflows								
End of catchment flows	3265.2	-37%	15%	-12%	-34%	14%	-14%	-36%
Subcatchment effluent (to Murrumbidgee Irrigation Area)	875.9	-8%	4%	0%	-7%	3%	0%	-7%
River groundwater loss	1.7	413%	-42%	106%	463%	1026%	1518%	1745%
Net evaporation public storages	0.0	-300%	70%	-92%	-111%	49%	-63%	-284%
Net evaporation wetlands	0.1	-43%	20%	-11%	-37%	16%	-15%	-41%
River reach evaporation	19.3	8%	2%	5%	18%	2%	5%	18%
Sub-total	**4162.2**	**-30%**	**13%**	**-9%**	**-28%**	**12%**	**-10%**	**-29%**
Unattributed fluxes								
River unattributed loss	60.4	-43%	24%	-14%	-39%	22%	-16%	-40%

4100011

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	4166.7	-30%	13%	-9%	-27%	12%	-9%	-28%
Indirectly gauged	183.7	-43%	17%	-18%	-51%	16%	-19%	-51%
Sub-total	**4350.4**	**-30%**	**13%**	**-9%**	**-28%**	**12%**	**-10%**	**-29%**
Diversions								
Licensed private diversions								
General security	8.6	-6%	3%	2%	-2%	3%	2%	-3%
Supplementary flow	0.1	61%	-18%	10%	90%	-25%	11%	91%
Stock and domestic	0.3	0%	0%	0%	0%	0%	0%	0%
High security	0.4	-2%	1%	0%	-2%	0%	0%	-2%
Sub-total	**11.6**	**-4%**	**2%**	**2%**	**0%**	**2%**	**1%**	**-1%**
Outflows								
End of catchment flows	4203.2	-31%	13%	-9%	-28%	12%	-10%	-29%
River groundwater loss	24.3	8%	-2%	2%	9%	49%	57%	67%
River reach evaporation	9.3	4%	3%	6%	20%	3%	6%	20%
Sub-total	**4236.8**	**-30%**	**13%**	**-9%**	**-28%**	**12%**	**-10%**	**-28%**
Unattributed fluxes								
River unattributed loss	102.0	-40%	19%	-14%	-38%	18%	-15%	-39%

4100391

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	2047.3	-22%	10%	-6%	-19%	10%	-6%	-19%
Indirectly gauged	132.3	-41%	15%	-18%	-39%	15%	-18%	-39%
Sub-total	**2179.6**	**-23%**	**10%**	**-6%**	**-20%**	**10%**	**-6%**	**-20%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	2116.2	-24%	10%	-6%	-21%	10%	-6%	-21%
Unattributed fluxes								
River unattributed loss	63.1	-6%	2%	-1%	-5%	2%	-1%	-5%

4100061

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Storage volume								
Public storages								
Blowering Dam	-7.7	46%	-11%	5%	47%	-13%	8%	50%
Inflows								
Subcatchments								
Directly gauged	1896.7	-21%	9%	-5%	-18%	10%	-5%	-18%
Indirectly gauged	63.1	-35%	14%	-9%	-27%	13%	-10%	-27%
Sub-total	**1959.8**	**-21%**	**10%**	**-5%**	**-18%**	**10%**	**-5%**	**-18%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Town water supply	1.6	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	1941.0	-21%	10%	-5%	-18%	10%	-5%	-18%
Net evaporation public storages	5.6	24%	-1%	22%	54%	-2%	20%	51%
Sub-total	**1946.6**	**-21%**	**10%**	**-5%**	**-18%**	**10%**	**-5%**	**-18%**
Unattributed fluxes								
River unattributed loss	19.0	0%	0%	0%	0%	0%	0%	0%

4100041

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Storage volume								
Public storages								
Burrinjuck Dam	-5.5	34%	-3%	6%	35%	-5%	8%	38%
Inflows								
Subcatchments								
Directly gauged	3656.6	-28%	12%	-8%	-25%	12%	-8%	-25%
Indirectly gauged	193.0	-46%	18%	-19%	-39%	17%	-20%	-40%
Sub-total	**3849.5**	**-29%**	**12%**	**-9%**	**-25%**	**12%**	**-9%**	**-26%**
Diversions								
Licensed private diversions								
General security	6.2	-12%	8%	1%	-5%	7%	0%	-7%
Town water supply	5.1	0%	0%	0%	0%	0%	0%	0%
Sub-total	**11.3**	**-6%**	**5%**	**1%**	**-3%**	**4%**	**0%**	**-4%**
Outflows								
End of catchment flows	3803.4	-29%	13%	-9%	-26%	12%	-9%	-26%
Net evaporation public storages	-2.2	-154%	50%	-77%	-223%	48%	-76%	-218%
River reach evaporation	4.7	14%	-3%	6%	21%	-3%	6%	21%
Sub-total	**3805.8**	**-29%**	**13%**	**-9%**	**-26%**	**12%**	**-9%**	**-26%**
Unattributed fluxes								
River unattributed loss	41.1	-5%	1%	-1%	-4%	1%	-1%	-4%

4100081 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	1134.8	-33%	15%	-9%	-30%	14%	-10%	-31%
Indirectly gauged	143.6	-35%	13%	-11%	-27%	10%	-14%	-30%
Urban returns	30.4	0%	0%	0%	0%	0%	0%	0%
Sub-total	**1308.8**	**-32%**	**14%**	**-9%**	**-29%**	**13%**	**-11%**	**-30%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	1308.8	-32%	14%	-9%	-29%	13%	-11%	-30%
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

4101761 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	110.5	-34%	14%	-11%	-28%	13%	-12%	-29%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**110.5**	**-34%**	**14%**	**-11%**	**-28%**	**13%**	**-12%**	**-29%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	110.5	-34%	14%	-11%	-28%	13%	-12%	-29%
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

4107561 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	134.7	-35%	19%	-11%	-32%	18%	-12%	-33%
Indirectly gauged	17.2	-32%	13%	-7%	-28%	13%	-7%	-28%
Urban returns	2.9	0%	0%	0%	0%	0%	0%	0%
Sub-total	**154.8**	**-34%**	**18%**	**-10%**	**-31%**	**17%**	**-11%**	**-32%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	150.5	-36%	18%	-11%	-33%	17%	-12%	-33%
Net evaporation - public storages	3.9	15%	2%	8%	26%	2%	8%	26%
Sub-total	**154.4**	**-34%**	**18%**	**-11%**	**-31%**	**17%**	**-11%**	**-32%**
Unattributed fluxes								
River unattributed loss	0.4	-2%	7%	6%	11%	7%	6%	11%

4107291 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	108.2	-35%	20%	-12%	-33%	19%	-13%	-34%
Indirectly gauged	10.9	-34%	14%	-11%	-30%	13%	-11%	-31%
Sub-total	**119.1**	**-35%**	**19%**	**-12%**	**-33%**	**18%**	**-13%**	**-33%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	118.9	-35%	19%	-12%	-33%	18%	-13%	-34%
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

4107381 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	548.7	-33%	15%	-9%	-33%	14%	-10%	-34%
Indirectly gauged	29.8	-32%	14%	-7%	-29%	10%	-10%	-31%
Sub-total	**578.5**	**-33%**	**15%**	**-9%**	**-33%**	**13%**	**-10%**	**-34%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	577.9	-33%	15%	-9%	-33%	13%	-10%	-34%
Unattributed fluxes								
River unattributed loss	0.6	21%	1%	8%	29%	1%	9%	30%

4107611 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	324.7	-30%	13%	-8%	-32%	13%	-9%	-32%
Indirectly gauged	45.0	-28%	14%	-7%	-29%	13%	-8%	-30%
Sub-total	**369.7**	**-30%**	**13%**	**-8%**	**-31%**	**13%**	**-9%**	**-32%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	369.1	-30%	13%	-8%	-31%	13%	-9%	-32%
Unattributed fluxes								
River unattributed loss	0.6	21%	1%	9%	31%	1%	9%	31%

4100501 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	270.7	-31%	13%	-9%	-32%	13%	-9%	-33%
Indirectly gauged	22.9	-24%	9%	-3%	-27%	8%	-4%	-27%
Sub-total	**293.5**	**-30%**	**13%**	**-8%**	**-32%**	**12%**	**-9%**	**-32%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	293.1	-30%	13%	-8%	-32%	12%	-9%	-33%
Unattributed fluxes								
River unattributed loss	0.4	12%	2%	6%	26%	2%	6%	26%

4100331 (Upper Murrumbidgee model)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Inflows								
Subcatchments								
Directly gauged	11.7	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	134.3	-39%	20%	-14%	-43%	19%	-15%	-43%
Sub-total	**146.0**	**-35%**	**18%**	**-13%**	**-39%**	**18%**	**-13%**	**-40%**
Diversions								
Licensed private diversions								
Regulated	0.0	0%	0%	0%	0%	0%	0%	0%
Outflows								
End of catchment flows	146.0	-35%	18%	-13%	-39%	18%	-13%	-40%
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

Canberra supply

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895							
Model end date	Jun-2006							
	GL/y	percent change from Scenario A						
Storage volume								
Public storages								
Corin Dam	-0.1	108%	-50%	-1%	112%	-50%	18%	107%
Bendora Dam	0.0	0%	0%	0%	0%	0%	0%	0%
Googong Dam	-0.3	90%	-22%	34%	92%	-20%	22%	99%
Cotter Dam	0.0	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	227.3	-28%	15%	-8%	-26%	14%	-9%	-26%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Pumped diversion from Murrumbidgee River	0.3	424%	-57%	62%	364%	-57%	66%	364%
Sub-total	**227.3**	**-27%**	**15%**	**-8%**	**-25%**	**14%**	**-9%**	**-26%**
Diversions								
Canberra water supply	57.4	4%	1%	1%	3%	1%	1%	3%
Outflows								
End of catchment flows	167.6	-39%	20%	-12%	-36%	19%	-13%	-36%
Net evaporation Public storages	3.1	41%	0%	12%	42%	0%	12%	42%
Sub-total	**170.7**	**-38%**	**19%**	**-11%**	**-34%**	**18%**	**-12%**	**-35%**
Unattributed fluxes								
River unattributed loss	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 projected 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.

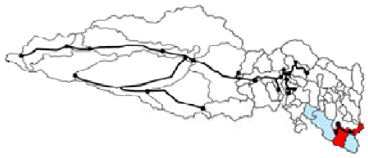
Table C-1. Explanation of components of the uncertainty assessments

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	410050 Murrumbidgee River @ Billilingra	Reach 1
Upstream gauge	410033 Murrumbidgee River @ Mittagang Crossing	

Reach length (km)	30.8
Area (km^2)	3675
Outflow/inflow ratio	1.76
Net gaining reach	



Land use	ha	%
Dryland	367,500	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

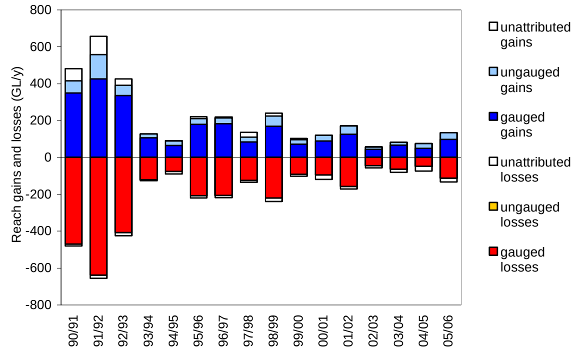
This is a strongly gaining reach.

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains and no adjustment of SIMHYD estimates was required. There are no recorded diversions and ungauged losses are small.

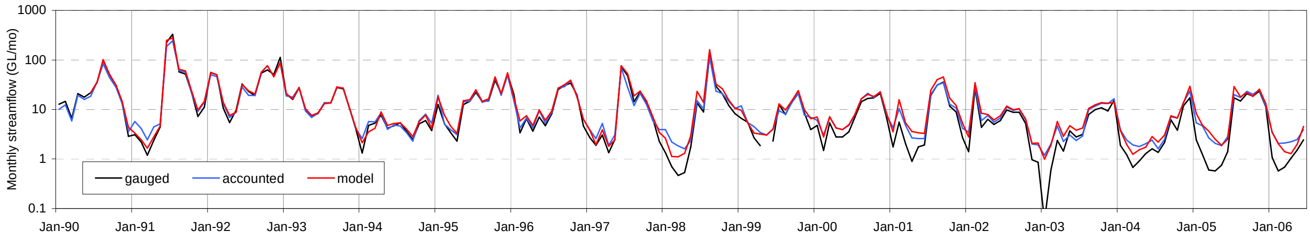
Baseline model performance is excellent. Accounting also explains observed flows very well.

The projected changes are much greater than river model uncertainty, with the exception of the medium climate change scenarios.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.73	0.93	0.83
Attributed	0.92	0.93	0.92
Fraction of variance			
Gauged	0.86	1.00	0.93
Attributed	0.95	1.00	0.98



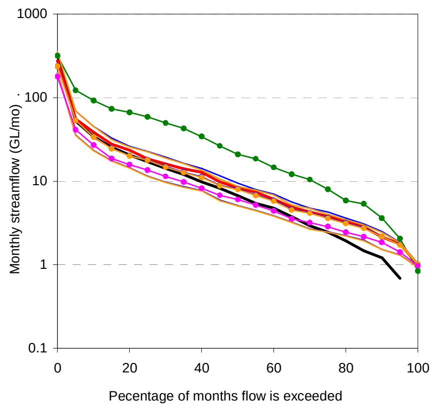
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	**-0.65**	**-0.57**	-0.27	-0.11	
Tributary inflows	**-0.90**	**-0.84**	-0.02	-0.40	
Main gauge outflows	**-0.94**	**-0.76**	-0.05	-0.28	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.94**	**-0.74**	-0.07	-0.41	



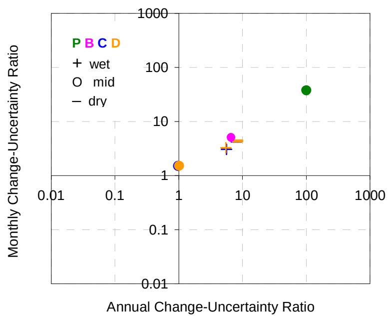
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	118	110	8
Tributary inflows	76	42	33
Local inflows	21	40	-18
Unattributed gains and noise	-	17	-17
Losses	GL/y	GL/y	GL/y
Main stem outflows	214	193	21
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	15	-15

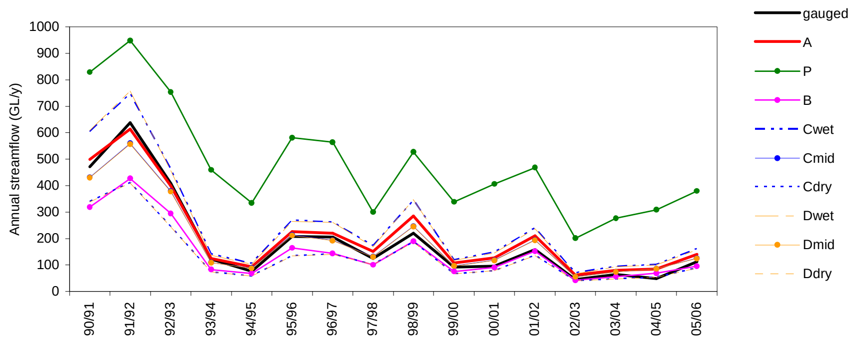
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.97	0.95
Log-normalised	-	-
Ranked	0.95	0.96
Low flows only	<0	<0
High flows only	0.95	0.90
Annual		
Normal	0.97	0.97
Log-normalised	0.91	0.95
Ranked	0.98	0.95

Definitions:
- low flows (flows<10% percentile) : 1.2 GL/mo
- high flows (flows>90% percentile) : 34.0 GL/mo



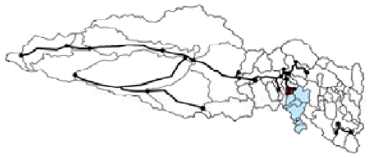
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	100.0	6.6	5.6	1.0	8.0	5.5	1.0	8.3
Monthly streamflow	37.9	5.1	3.1	1.5	4.3	3.3	1.5	4.4





Downstream gauge	410006 Tumut River @ Tumut	Reach 2
Upstream gauge	410073 Tumut River @ Oddys Bridge	

Reach length (km)	17.2
Area (km^2)	2474
Outflow/inflow ratio	1.17
Net gaining reach	



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

Almost all inflows are gauged. Estimated local runoff are small and explains most of the ungauged gains but adjustment was required. There are no recorded diversions and ungauged losses are small.

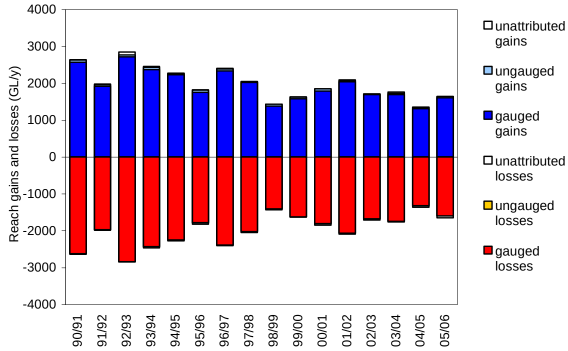
Baseline model performance is good. Accounting also explains observed flows extremely well.

Despite good model perfromance, the projected changes are close to river model uncertainty for the medium and wet climate change scenarios.

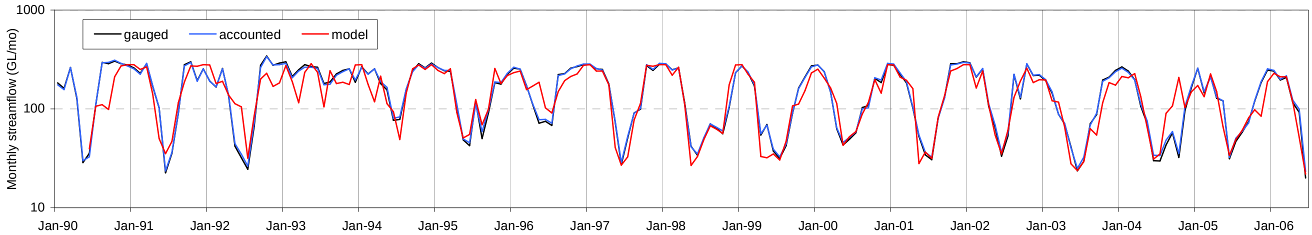
Land use	ha	%
Dryland	247,400	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

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



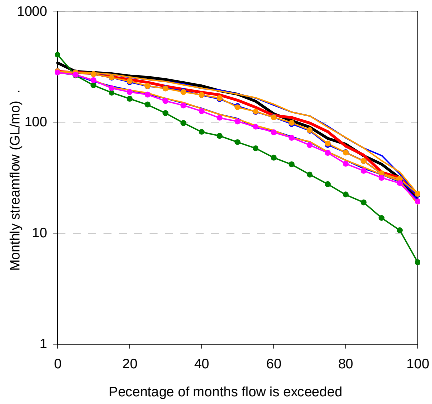
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.09	-0.08	-0.12	-0.12	
Tributary inflows	**-0.71**	**-0.56**	-0.31	-0.42	
Main gauge outflows	-0.30	-0.29	-0.02	-0.01	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.65**	**-0.52**	-0.34	-0.43	Adjusted -57.8%



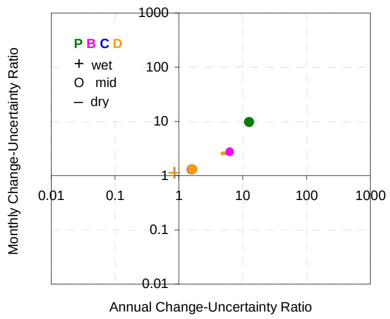
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1569	1689	-119
Tributary inflows	247	250	-4
Local inflows	54	42	13
Unattributed gains and noise	-	18	-18
Losses	GL/y	GL/y	GL/y
Main stem outflows	1849	1972	-123
Distributary outflows	0	0	0
Net diversions	2	0	2
River flux to groundwater	0	-	0
River and floodplain losses	0	-1	1
Unspecified losses	19	-	19
Unattributed losses and noise	-	27	-27

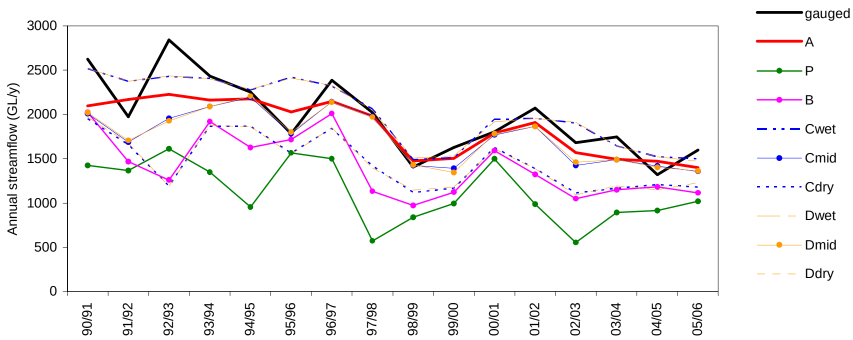
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.75	1.00
Log-normalised	0.79	1.00
Ranked	0.73	1.00
Low flows only	<0	0.83
High flows only	<0	0.73
Annual		
Normal	0.62	1.00
Log-normalised	0.67	0.99
Ranked	0.75	0.99

Definitions:
- low flows (flows<10% percentile) : 41.7 GL/mo
- high flows (flows>90% percentile) : 280.2 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	12.6	6.3	0.9	1.6	5.6	0.8	1.6	5.6
Monthly streamflow	9.8	2.7	1.1	1.3	2.6	1.1	1.3	2.6



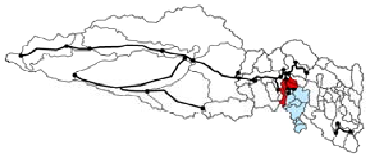


Downstream gauge	**4100391 Tumut River @ Brungle Bridge**	**Reach 3**
Upstream gauge	**410006 Tumut River @ Tumut**	

Reach length (km)	24.8
Area (km^2)	2568
Outflow/inflow ratio	1.07
Net gaining reach	

Land use	ha	%
Dryland	256,800	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006



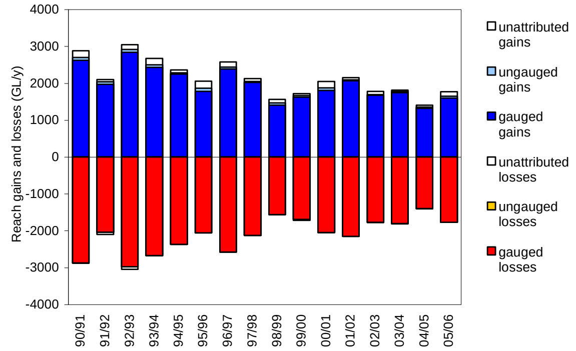
This is a slightly gaining reach. Flows are dominated by regulated main stem inflows from upstream.

Most all inflows are gauged. Estimated local runoff explains most of the ungauged gains without any adjustment. There are no recorded diversions. Ungauged losses are a small component of the overall water balance.

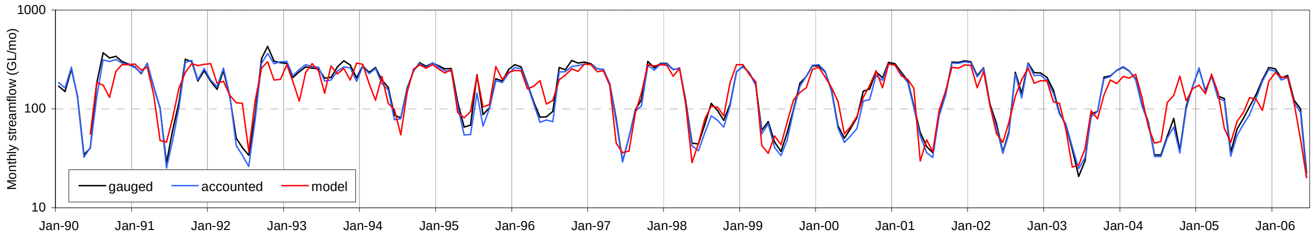
Baseline model performance is good. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the wet and medium climate change scenarios.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.93	0.99	0.96
Attributed	0.95	0.99	0.97
Fraction of variance			
Gauged	0.97	1.00	0.99
Attributed	0.99	1.00	0.99



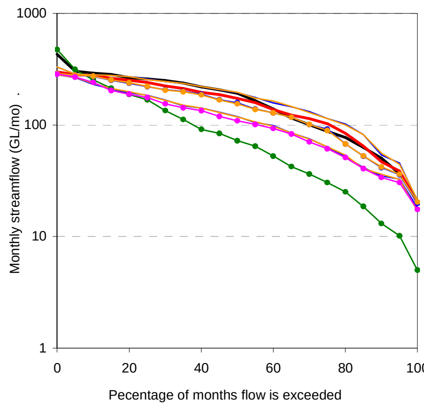
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.05	-0.02	-0.25	-0.25	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.22	-0.12	-0.17	-0.17	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.88**	**-0.65**	-0.18	-0.22	



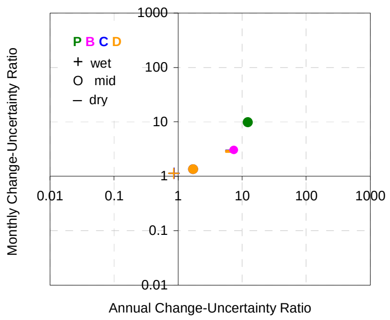
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1849	1972	-123
Tributary inflows	95	0	95
Local inflows	118	51	66
Unattributed gains and noise	-	106	-106
Losses	GL/y	GL/y	GL/y
Main stem outflows	1999	2117	-118
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	62	-	62
Unattributed losses and noise	-	13	-13

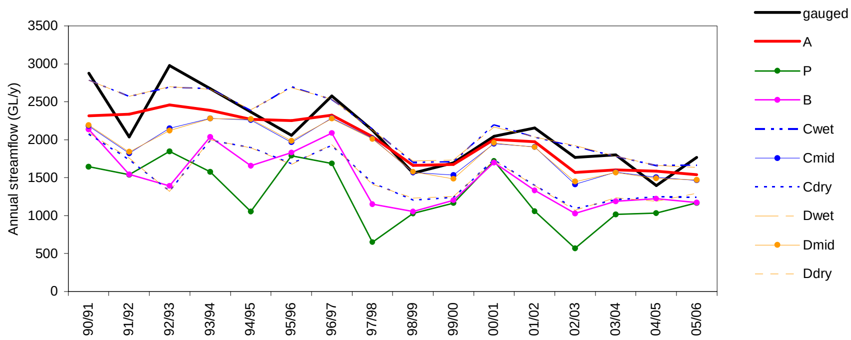
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.75	0.98
Log-normalised	0.79	0.98
Ranked	0.73	0.98
Low flows only	<0	0.67
High flows only	<0	0.40
Annual		
Normal	0.67	0.94
Log-normalised	0.70	0.94
Ranked	0.64	0.97

Definitions:
- low flows (flows<10% percentile) : 50.2 GL/mo
- high flows (flows>90% percentile) : 291.8 GL/mo



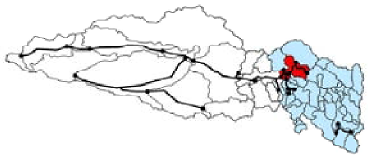
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	12.3	7.4	0.9	1.7	6.7	0.9	1.7	6.7
Monthly streamflow	9.8	3.0	1.1	1.3	2.9	1.1	1.3	2.8





Downstream gauge	410004 Murrumbidgee River @ Gundagai	Reach 4
Upstream gauge	410008 Murrumbidgee River @ BD/S Burrinjuck Dam	

Reach length (km)	76
Area (km^2)	22044
Outflow/inflow ratio	3.43
Net gaining reach	



This is a strongly gaining reach. Flows are dominated by tributary inflows from the Tumut River and upstream.

Most inflows are gauged. Estimated local runoff explains most of the ungauged gains but strong adjustment was required. There are no recorded diversions and ungauged losses are relatively small.

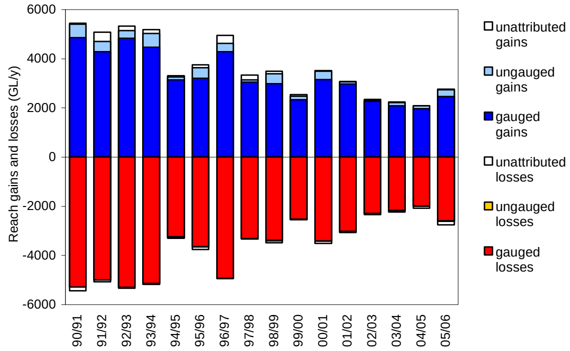
Baseline model performance is very good. Accounting explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the wet climate change scenario.

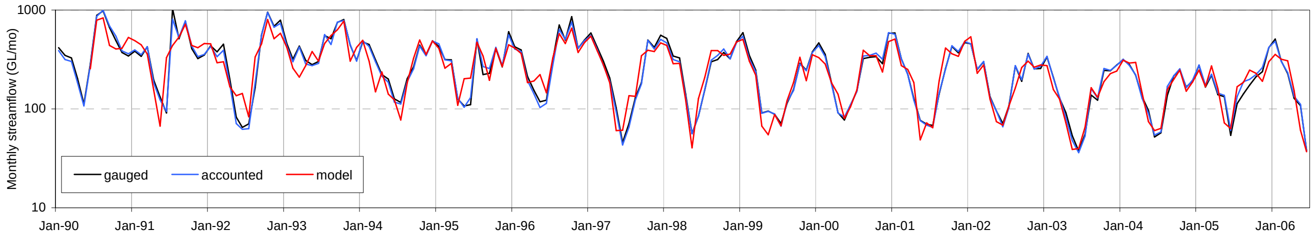
Land use	ha	%
Dryland	2,204,400	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.90	0.98	0.94
Attributed	0.97	0.98	0.98
Fraction of variance			
Gauged	0.96	1.00	0.98
Attributed	0.99	1.00	0.99



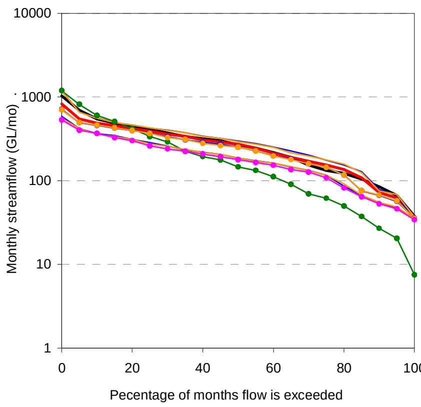
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.70	-0.46	-0.05	-0.06	
Tributary inflows	-0.28	-0.25	-0.12	-0.11	
Main gauge outflows	-0.69	-0.49	-0.02	-0.01	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.77	-0.67	-0.18	-0.33	Adjusted 260.0%



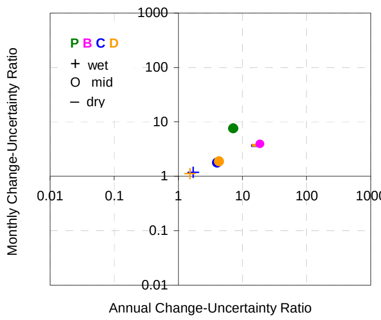
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1084	1044	39
Tributary inflows	2204	2227	-23
Local inflows	168	270	-103
Unattributed gains and noise	-	110	-110
Losses	GL/y	GL/y	GL/y
Main stem outflows	3402	3581	-179
Distributary outflows	0	0	0
Net diversions	12	10	1
River flux to groundwater	0	-	0
River and floodplain losses	4	0	4
Unspecified losses	41	-	41
Unattributed losses and noise	-	61	-61

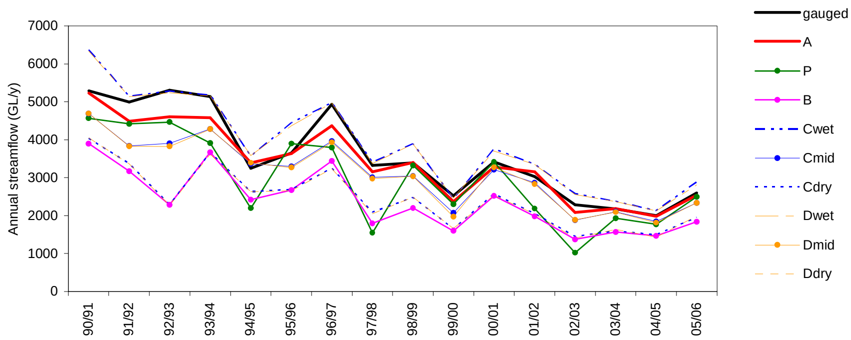
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.82	0.98
Log-normalised	0.84	0.99
Ranked	0.84	0.99
Low flows only	<0	0.89
High flows only	0.05	0.88
Annual		
Normal	0.93	0.99
Log-normalised	0.95	0.99
Ranked	0.95	0.99

Definitions:
- low flows (flows<10% percentile) : 84.5 GL/mo
- high flows (flows>90% percentile) : 545.4 GL/mo



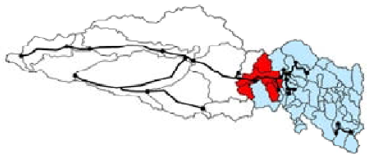
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	7.2	18.7	1.7	4.0	16.8	1.5	4.3	17.2
Monthly streamflow	7.5	3.9	1.2	1.8	3.7	1.1	1.9	3.7





Downstream gauge	410001 Murrumbidgee River @ Wagga Wagga	Reach 5
Upstream gauge	410004 Murrumbidgee River @ Gundagai	

Reach length (km)	117.8
Area (km²)	27875
Outflow/inflow ratio	1.07
Net gaining reach	



This is a slightly 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 strong upwards adjustment was required. There are some recorded diversions and ungauged losses and small river and floodplain losses.

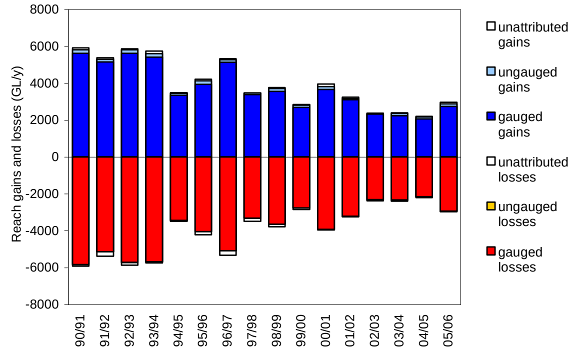
Baseline model performance is very good. Accounting explains observed flows extremely well.

The projected changes are generally greater than river model uncertainty.

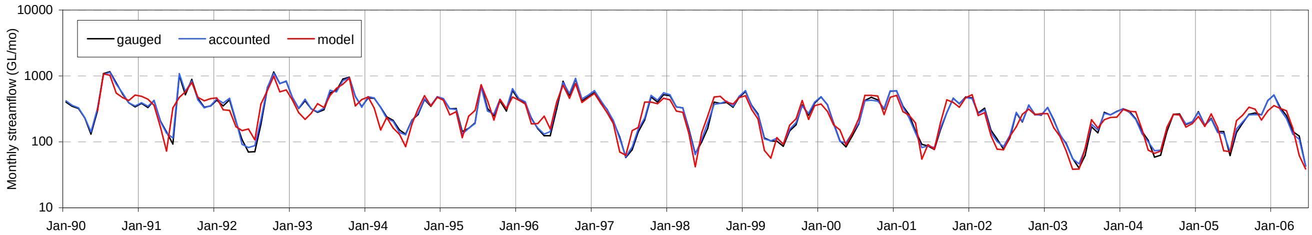
Land use	ha	%
Dryland	2,785,714	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	1,786	0
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.95	0.97	0.96
Attributed	0.98	0.98	0.98
Fraction of variance			
Gauged	0.99	1.00	0.99
Attributed	1.00	1.00	1.00



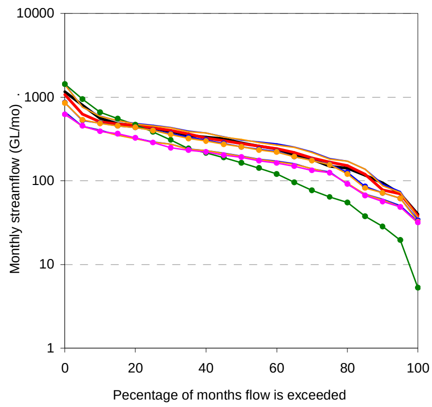
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.38	-0.01	-0.39	-0.41	
Tributary inflows	-0.81	-0.27	-0.09	-0.01	
Main gauge outflows	-0.52	-0.10	-0.29	-0.35	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.72	-0.35	-0.06	-0.07	Adjusted 446.8%



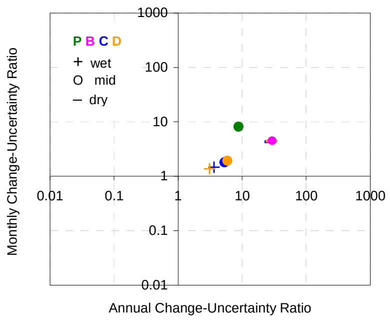
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	3402	3581	-179
Tributary inflows	295	172	123
Local inflows	149	136	13
Unattributed gains and noise	-	64	-64
Losses	GL/y	GL/y	GL/y
Main stem outflows	3711	3847	-136
Distributary outflows	0	0	0
Net diversions	12	7	5
River flux to groundwater	24	-	24
River and floodplain losses	7	1	6
Unspecified losses	93	-	93
Unattributed losses and noise	-	98	-98

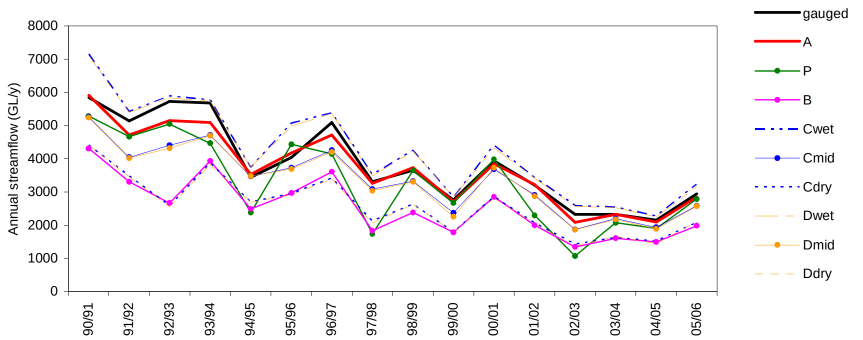
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.86	0.99
Log-normalised	0.84	0.99
Ranked	0.84	0.99
Low flows only	<0	0.56
High flows only	0.44	0.97
Annual		
Normal	0.95	0.99
Log-normalised	0.97	1.00
Ranked	0.99	0.99

Definitions:
- low flows (flows<10% percentile) : 94.5 GL/mo
- high flows (flows>90% percentile) : 558.9 GL/mo



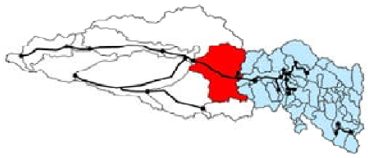
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	8.8	29.4	3.6	5.3	27.6	3.1	5.9	28.7
Monthly streamflow	8.1	4.5	1.5	1.8	4.3	1.4	1.9	4.4





Downstream gauge	410005 Murrumbidgee River @ Narrandera	Reach 6
Upstream gauge	410001 Murrumbidgee River @ Wagga Wagga	

Reach length (km)	120.8
Area (km^2)	36417
Outflow/inflow ratio	0.76
Net losing reach	



Land use	ha	%
Dryland	3,622,490	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	19,210	1
Open water*	-	-

* averages for 1990–2006

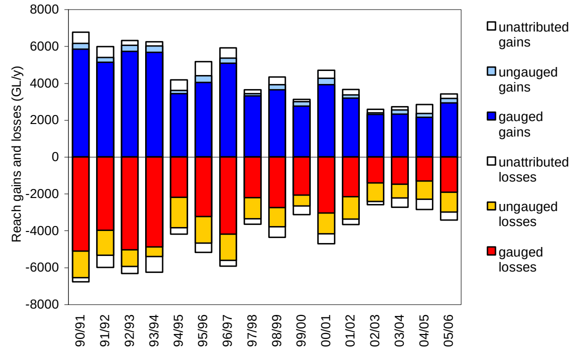
This is a losing reach. Flows are dominated by inflows from upstream and bulk diversions.

Most of the inflows are gauged. Estimated local runoff explains some of the ungauged gains but a downward adjustment of model esimates was required. There are large diversions. Unattributed ungauged gains and losses are considerable, which may be due to difficulties in disaggregating annual diversion records.

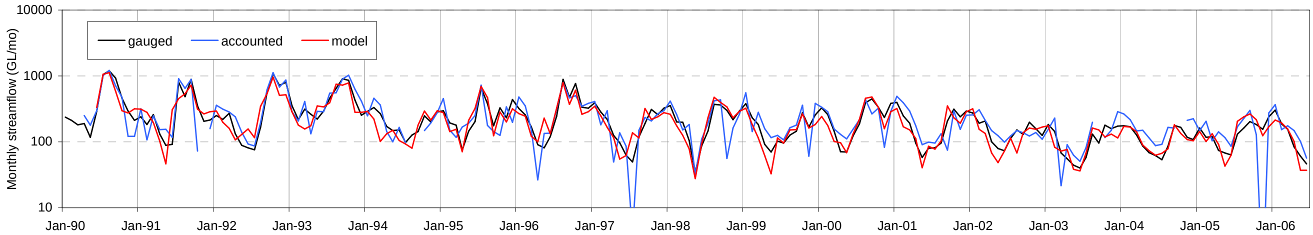
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are greater than river model uncertainty, except for the wet climate change scenarios.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.86	0.65	0.76
Attributed	0.92	0.90	0.91
Fraction of variance			
Gauged	0.92	0.86	0.89
Attributed	0.93	0.97	0.95



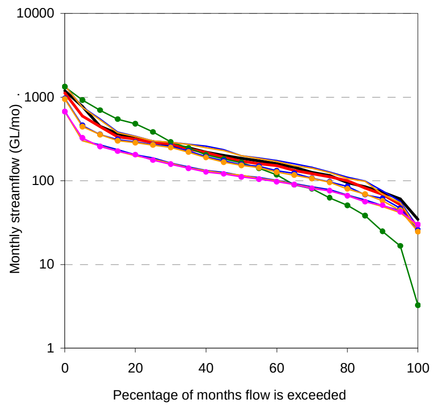
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.25	-0.05	-0.38	**-0.59**	
Tributary inflows	-0.40	-0.41	-0.21	-0.24	
Main gauge outflows	-0.38	-0.12	-0.10	-0.42	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.24	-0.23	-0.26	-0.26	Adjusted -77.3%



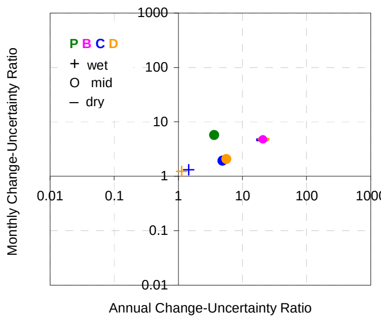
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	3711	3847	-136
Tributary inflows	29	2	27
Local inflows	0	250	-250
Unattributed gains and noise	-	381	-381
Losses	GL/y	GL/y	GL/y
Main stem outflows	2730	2931	-201
Distributary outflows	919	0	919
Net diversions	37	1074	-1037
River flux to groundwater	1	-	1
River and floodplain losses	17	32	-15
Unspecified losses	34	-	34
Unattributed losses and noise	-	441	-441
	2	0	2

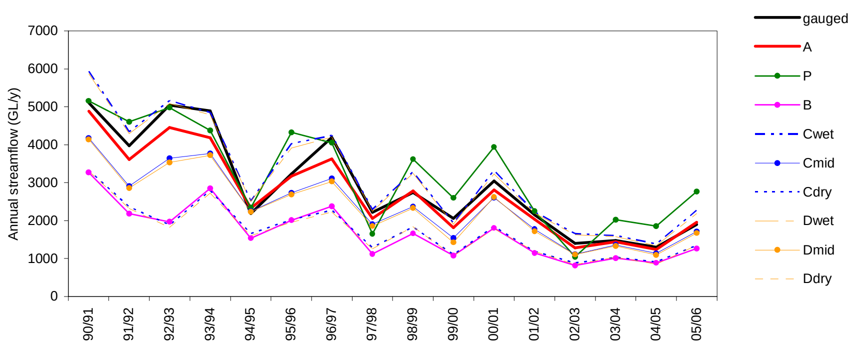
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.86	0.80
Log-normalised	0.80	#NUM!
Ranked	0.76	0.56
Low flows only	<0	<0
High flows only	0.46	0.74
Annual		
Normal	0.94	0.96
Log-normalised	0.96	0.96
Ranked	0.99	0.91

Definitions:
- low flows (flows<10% percentile) : 73.0 GL/mo
- high flows (flows>90% percentile) : 446.9 GL/mo



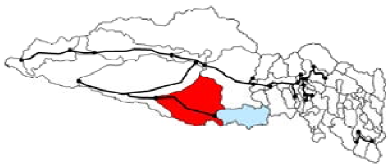
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.6	20.9	1.4	4.9	20.2	1.1	5.6	21.3
Monthly streamflow	5.7	4.7	1.3	1.9	4.6	1.2	2.1	4.8





Downstream gauge	410016 Billabong Creek @ Jerilderie	Reach 7
Upstream gauge	410091 Billabong Creek @ Walbundrie	

Reach length (km)	133.5	
Area (km^2)	9125	
Outflow/inflow ratio	1.73	
Net gaining reach		



This is a strongly gaining reach. Flows are dominated by inflows from upstream, but local inflows are also considerable.

About half of inflows are gauged. Estimated local runoff explains most of the ungauged gains but a downward adjustment was required. Recorded diversions and estimated river and wetland losses are relatively small.

The hydrology of this reach was not modelled by the river model.

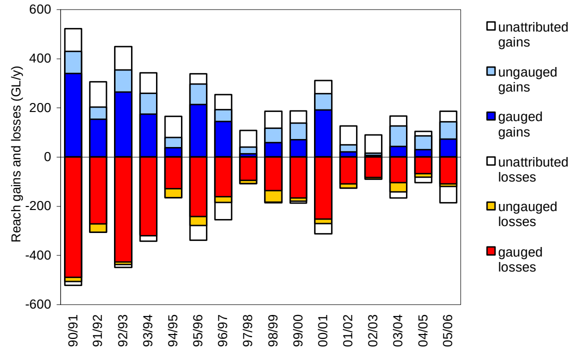
Accounting explains observed flows well, although the apparently relatively high baseflows were not explained by the accounting (alternatively there may have been gauging error).

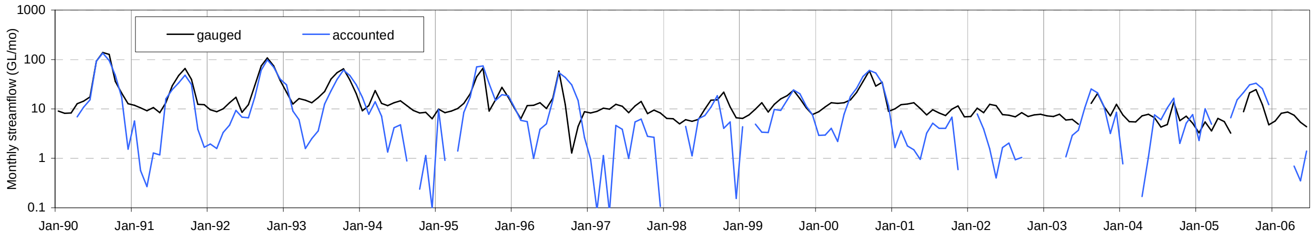
Land use	ha	%
Dryland	893,686	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	18,814	2
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.48	0.82	0.65
Attributed	0.73	0.91	0.82
Fraction of variance			
Gauged	0.94	0.70	0.82
Attributed	0.97	0.96	0.96

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.06	-0.01	-0.72	-0.37	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.57	-0.49	-0.30	-0.20	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.01	-0.09	-0.48	-0.36	Adjusted -48.1%

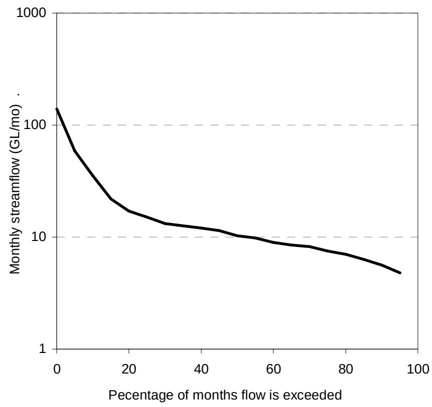




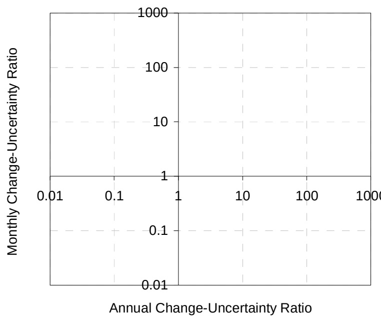
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	115	-115
Tributary inflows	0	0	0
Local inflows	0	60	-60
Unattributed gains and noise	-	66	-66
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	198	-198
Distributary outflows	0	0	0
Net diversions	0	10	-10
River flux to groundwater	0	-	0
River and floodplain losses	0	11	-11
Unspecified losses	0	-	0
Unattributed losses and noise	-	22	-22

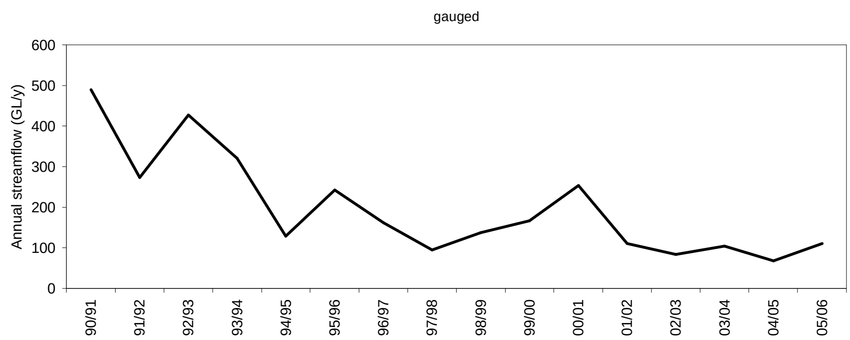
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.79
Log-normalised	-	-
Ranked	<0	0.28
Low flows only	<0	<0
High flows only	<0	0.95
Annual		
Normal	<0	0.76
Log-normalised	-	-
Ranked	<0	0.71

Definitions:
- low flows (flows<10% percentile) : 5.6 GL/mo
- high flows (flows>90% percentile) : 35.5 GL/mo



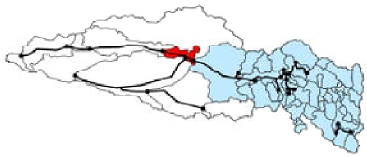
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow								
Monthly streamflow								





Downstream gauge	410021 Murrumbidgee River @ Darlington Point	Reach 8
Upstream gauge	410005 Murrumbidgee River @ Narrandera	

Reach length (km)	117.9
Area (km^2)	37552
Outflow/inflow ratio	0.60
Net losing reach	



This is a strongly losing reach. Flows are dominated by inflows from upstream. Almost all inflows are gauged. Estimated local runoff explains little of the ungauged gains. There are large recorded diversions, which appear to be divided up differently in the water accounts and river model, as between distributary flows and diversions respectively. Ungauged losses are considerable, and some of these can be attributed to river and wetland losses.

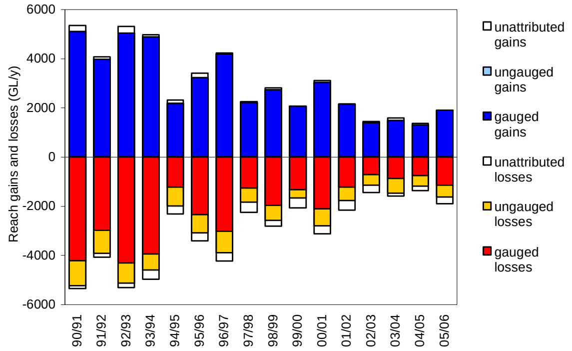
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are much greater than river model uncertainty, except for the wet cliamte change scenario.

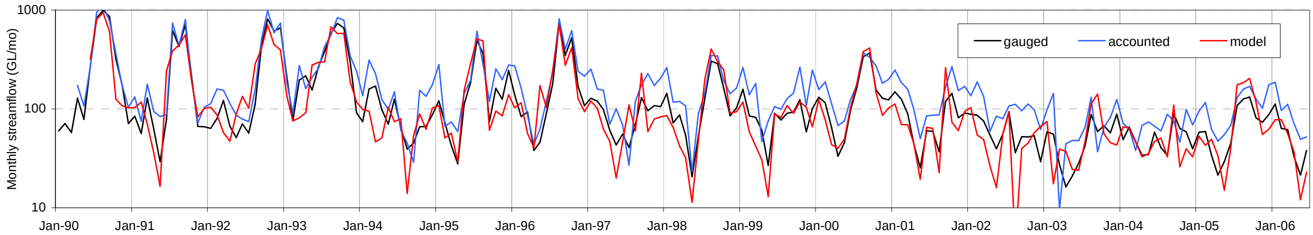
Land use	ha	%
Dryland	3,740,394	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	14,806	0
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.97	0.69	0.83
Attributed	0.97	0.91	0.94
Fraction of variance			
Gauged	0.99	0.94	0.96
Attributed	0.99	0.98	0.99



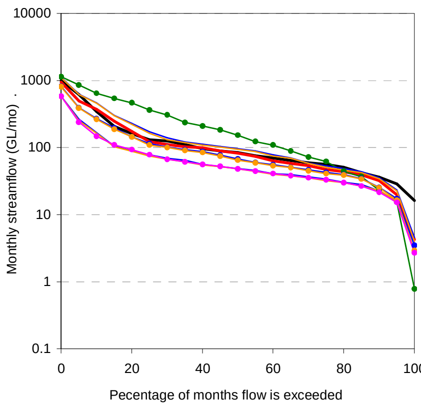
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.13	-0.02	-0.34	-0.62	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.23	-0.13	-0.05	-0.26	
Distributary outflows	-0.17	-0.02	-0.26	-0.54	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.05	-0.11	-0.16	-0.21	



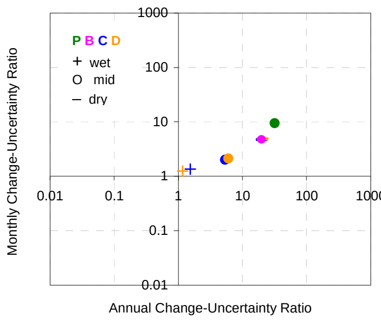
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	2730	2931	-201
Tributary inflows	0	0	0
Local inflows	11	2	9
Unattributed gains and noise	-	92	-92
Losses	GL/y	GL/y	GL/y
Main stem outflows	1627	1744	-117
Distributary outflows	1017	345	672
Net diversions	18	519	-501
River flux to groundwater	3	-	3
River and floodplain losses	16	139	-124
Unspecified losses	59	-	59
Unattributed losses and noise	-	277	-277
	0	0	0

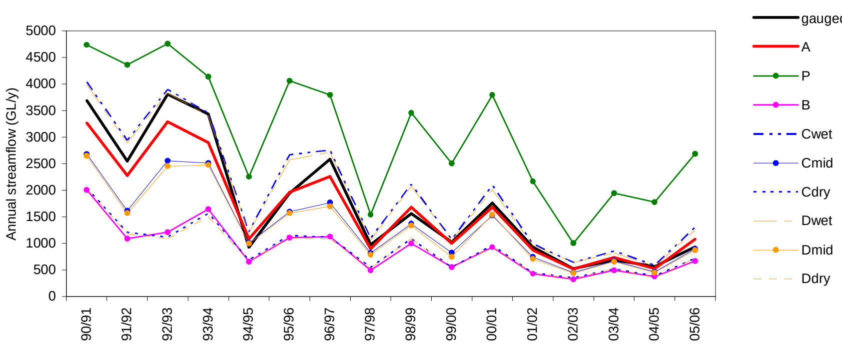
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.88	0.88
Log-normalised	0.69	0.66
Ranked	0.64	0.84
Low flows only	<0	<0
High flows only	0.53	0.78
Annual		
Normal	0.95	0.75
Log-normalised	0.97	0.67
Ranked	0.92	0.96

Definitions:
- low flows (flows<10% percentile) : 36.0 GL/mo
- high flows (flows>90% percentile) : 345.9 GL/mo



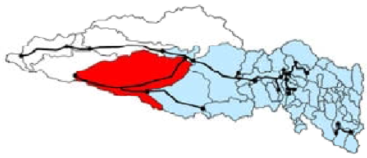
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	31.7	19.8	1.5	5.3	19.8	1.2	6.0	20.6
Monthly streamflow	9.4	4.8	1.4	2.0	4.7	1.2	2.1	4.8





Downstream gauge	410134 Billabong Creek @ Darlot	Reach 9
Upstream gauge	410016 Billabong Creek @ Jerilderie	

Reach length (km)	309.7
Area (km^2)	59115
Outflow/inflow ratio	1.39
Net gaining reach	



Land use	ha	%
Dryland	5,862,148	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	49,352	1
Open water*	-	-

* averages for 1990–2006

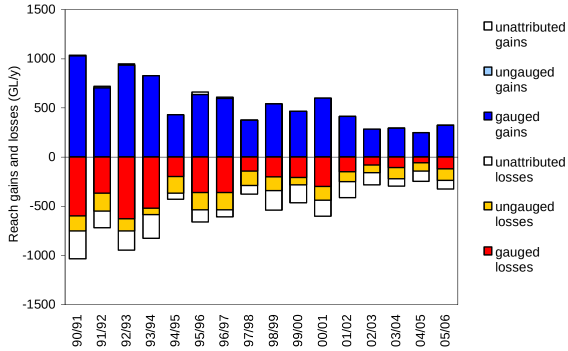
This is a gaining reach. There are differences between the river model and the accounts in the way that distributaries and diversions are treated.

Most inflows are gauged. Estimated local runoff does not explain ungauged gains and was adjusted to zero. Accounts could not be closed well; mainly because the fate of tributary inflows from the Murrumbidgee could not be accounted for. Recorded diversions are modest, but there is a difference in control volume between the river model and accounts.

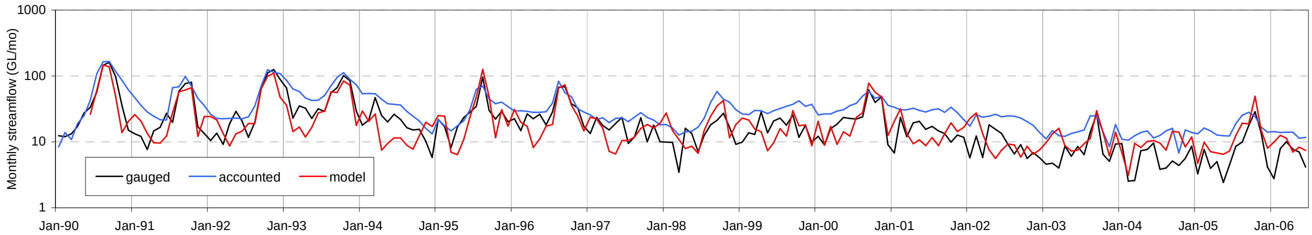
Baseline model performance is good. Accounting explains observed flows reasonably well, but does not explain recent reductions in baseflow.

The projected changes are greater than river model uncertainty, except for the wet climate change scenario.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.99	0.50	0.75
Attributed	0.99	0.73	0.86
Fraction of variance			
Gauged	1.00	0.70	0.85
Attributed	1.00	0.93	0.96



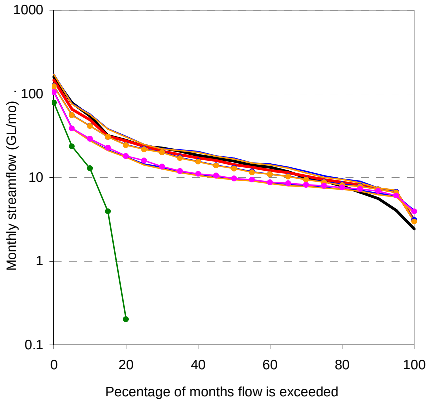
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.08	-0.17	**-0.65**	-0.13	
Tributary inflows	-0.03	-0.13	**-0.87**	**-0.70**	
Main gauge outflows	-0.34	-0.26	-0.36	-0.09	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.01	-0.04	-0.30	-0.01	Adjusted -100.0%



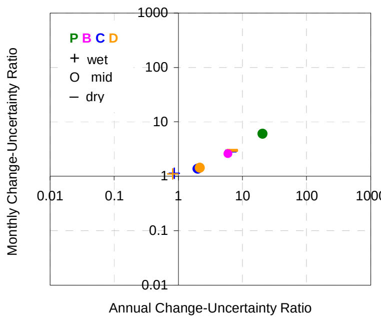
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	112	198	-86
Tributary inflows	866	345	520
Local inflows	0	0	0
Unattributed gains and noise	-	5	-5
Losses	GL/y	GL/y	GL/y
Main stem outflows	266	275	-9
Distributary outflows	46	0	46
Net diversions	519	42	478
River flux to groundwater	-10	-	-10
River and floodplain losses	29	86	-56
Unspecified losses	127	-	127
Unattributed losses and noise	-	146	-146

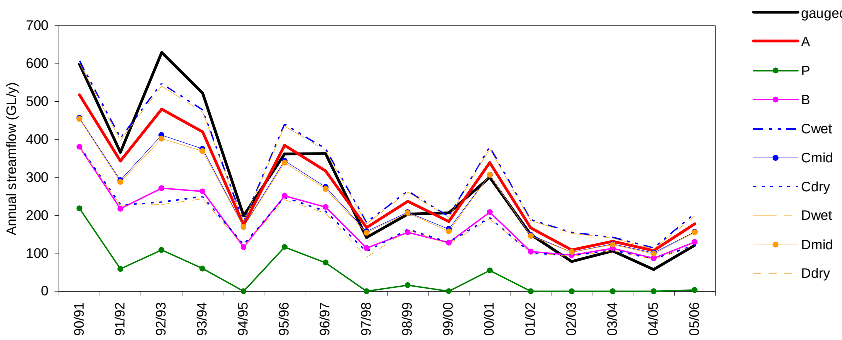
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.83	0.60
Log-normalised	0.56	0.24
Ranked	0.26	0.62
Low flows only	<0	<0
High flows only	0.55	0.58
Annual		
Normal	0.89	0.24
Log-normalised	0.88	0.37
Ranked	0.92	0.95

Definitions:
- low flows (flows<10% percentile) : 5.6 GL/mo
- high flows (flows>90% percentile) : 54.4 GL/mo



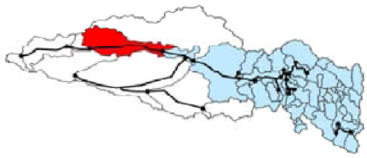
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	20.6	5.9	0.9	2.0	6.6	0.8	2.2	6.9
Monthly streamflow	6.0	2.6	1.1	1.4	2.9	1.1	1.4	3.0





Downstream gauge	410136 Murrumbidgee River @ D/S Hay Weir	Reach 10
Upstream gauge	410021 Murrumbidgee River @ @ Darlington Point	

Reach length (km)	165.6
Area (km^2)	42696
Outflow/inflow ratio	0.78
Net losing reach	



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

Most of the inflows are gauged. Estimated local runoff explains none of the ungauged gains and was adjusted to zero. There are considerable recorded diversions and ungauged losses .

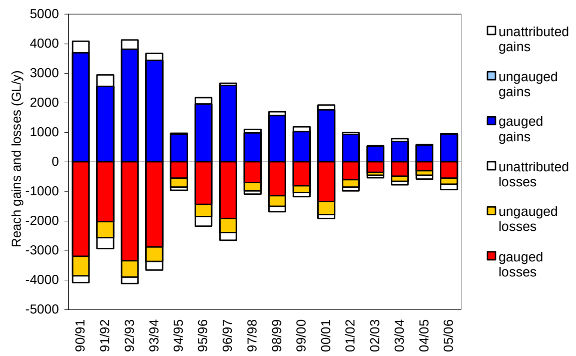
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are greater than river model uncertainty in all cases.

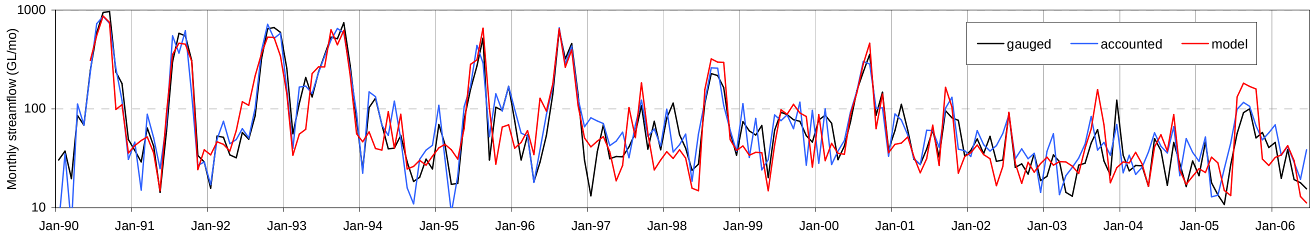
Land use	ha	%
Dryland	4,245,017	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	24,583	1
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.92	0.72	0.82
Attributed	0.92	0.90	0.91
Fraction of variance			
Gauged	0.97	0.95	0.96
Attributed	0.97	0.98	0.97



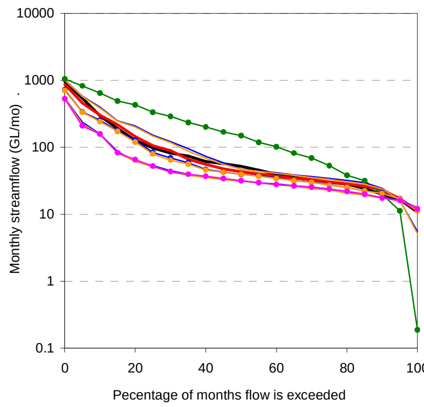
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.31	-0.21	**-0.57**	**-0.51**	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.50**	-0.33	-0.32	-0.14	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.02	-0.09	-0.31	-0.10	Adjusted -100.0%



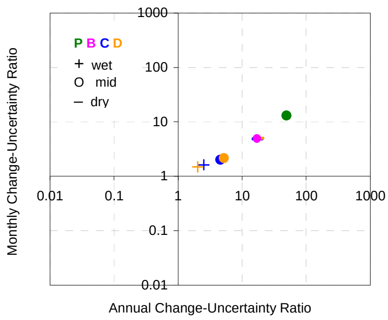
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1627	1744	-117
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	153	-153
Losses	GL/y	GL/y	GL/y
Main stem outflows	1327	1359	-32
Distributary outflows	0	0	0
Net diversions	206	220	-14
River flux to groundwater	-15	-	-15
River and floodplain losses	28	131	-103
Unspecified losses	82	-	82
Unattributed losses and noise	-	188	-188
	0	0	0

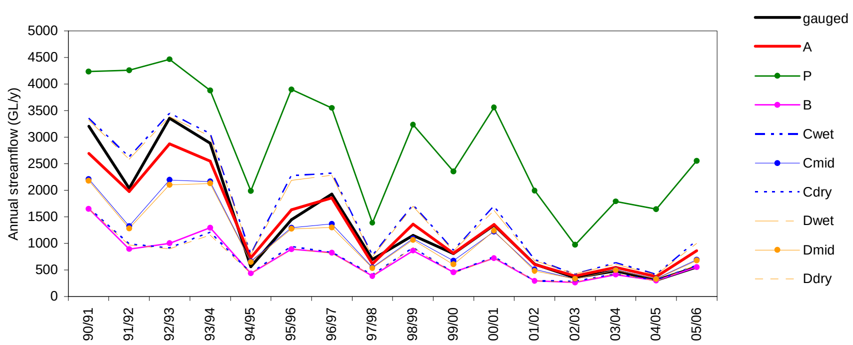
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.89	0.91
Log-normalised	0.73	0.82
Ranked	0.55	0.72
Low flows only	<0	<0
High flows only	0.67	0.53
Annual		
Normal	0.95	0.99
Log-normalised	0.95	0.97
Ranked	0.92	0.95

Definitions:
- low flows (flows<10% percentile) : 19.8 GL/mo
- high flows (flows>90% percentile) : 295.5 GL/mo



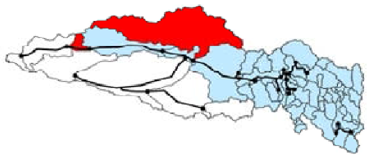
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	49.2	17.1	2.5	4.6	17.3	2.0	5.2	18.0
Monthly streamflow	13.0	4.9	1.6	2.0	4.9	1.5	2.2	5.0





Downstream gauge	410140 Murrumbidgee River @ D/S Maude Weir	Reach 11
Upstream gauge	410136 Murrumbidgee River @ D/S Hay Weir	

Reach length (km)	60.4
Area (km^2)	56544
Outflow/inflow ratio	0.76
Net losing reach	



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

ALmost all inflows are gauged. Estimated local runoff does not explain any of the ungauged gains and was adjusted to zero. There are recorded diversions. Ungauged losses are considerable and partly correspond to distributary (effluent) outflows in the river model.

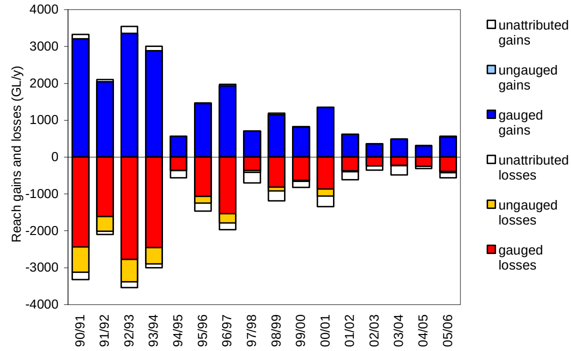
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are greater than river model uncertainty.

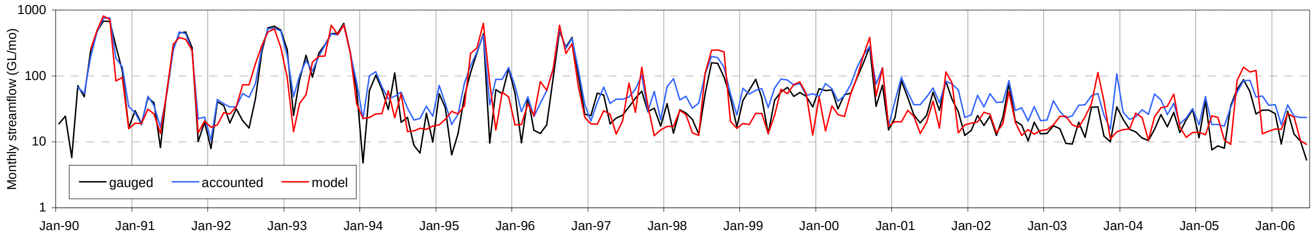
Land use	ha	%
Dryland	5,621,837	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	32,563	1
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.97	0.73	0.85
Attributed	0.97	0.87	0.92
Fraction of variance			
Gauged	1.00	0.94	0.97
Attributed	1.00	0.99	0.99



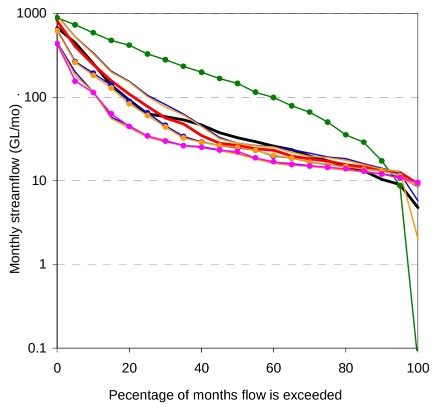
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.03	-0.07	**-0.87**	**-0.71**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.05	-0.14	**-0.79**	-0.44	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.01	-0.06	-0.30	-0.38	Adjusted -100.0%



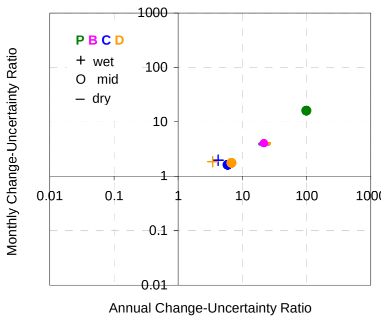
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1327	1359	-32
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	39	-39
Losses	GL/y	GL/y	GL/y
Main stem outflows	1032	1027	6
Distributary outflows	187	0	187
Net diversions	77	74	3
River flux to groundwater	-6	-	-6
River and floodplain losses	13	110	-98
Unspecified losses	24	-	24
Unattributed losses and noise	-	186	-186
	0	0	0

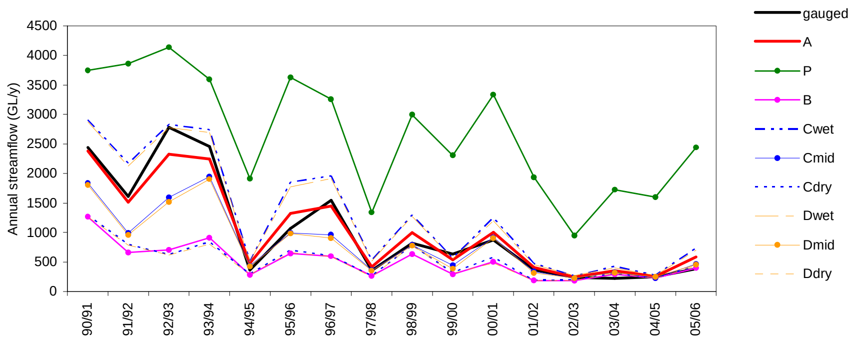
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.86	0.97
Log-normalised	0.65	0.76
Ranked	0.40	0.82
Low flows only	<0	<0
High flows only	0.95	0.92
Annual		
Normal	0.96	0.96
Log-normalised	0.94	0.83
Ranked	0.94	0.91

Definitions:
- low flows (flows<10% percentile) : 10.3 GL/mo
- high flows (flows>90% percentile) : 251.3 GL/mo



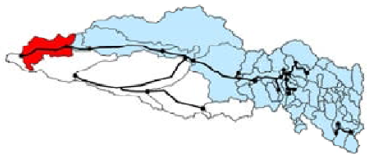
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	99.3	21.7	4.2	5.9	21.8	3.4	6.8	22.7
Monthly streamflow	16.0	4.0	2.0	1.6	3.9	1.8	1.8	4.0





Downstream gauge	410130 Murrumbidgee River @ D/S Balnarald Weir	Reach 12
Upstream gauge	410140 Murrumbidgee River @ D/S Maude Weir	

Reach length (km)	102.5
Area (km^2)	60195
Outflow/inflow ratio	0.79
Net losing reach	



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

Most inflows are gauged. Estimated local runoff does not explain any of the ungauged gains and was adjusted to zero. Recorded diversions are modest, but ungauged losses are large.

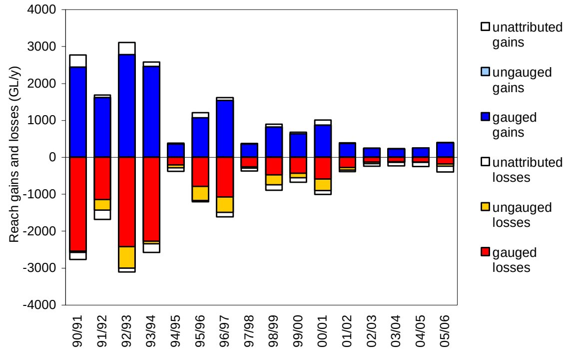
Baseline model performance is good. Accounting explains observed flows very well.

The projected changes are greater than river model uncertainty.

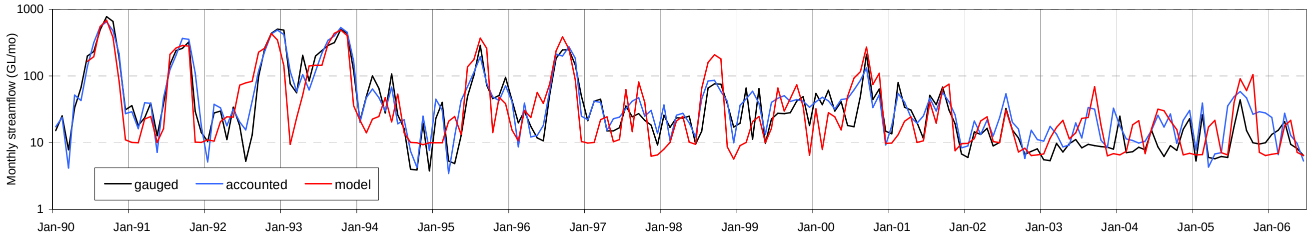
Land use	ha	%
Dryland	5,922,577	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	96,923	2
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.92	0.73	0.83
Attributed	0.92	0.89	0.91
Fraction of variance			
Gauged	0.98	0.82	0.90
Attributed	0.98	0.99	0.98



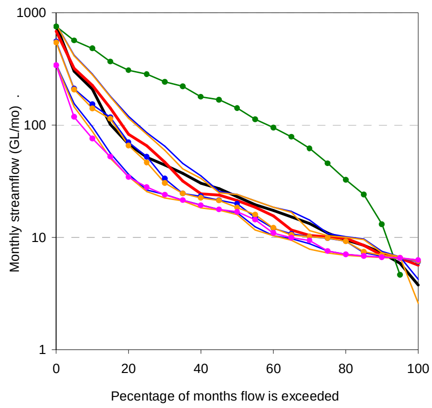
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.21	-0.03	**-0.76**	**-0.58**	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.59**	-0.34	-0.42	-0.21	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.00	-0.09	-0.39	-0.47	Adjusted -100.0%



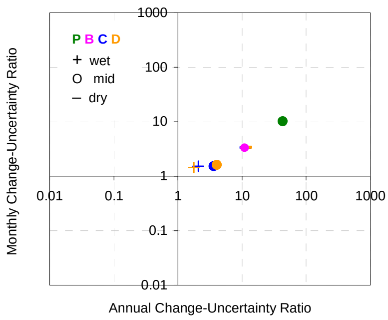
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1032	1027	6
Tributary inflows	187	0	187
Local inflows	0	0	0
Unattributed gains and noise	-	87	-87
Losses	GL/y	GL/y	GL/y
Main stem outflows	817	816	1
Distributary outflows	0	0	0
Net diversions	18	18	0
River flux to groundwater	-3	-	-3
River and floodplain losses	330	158	172
Unspecified losses	63	-	63
Unattributed losses and noise	-	122	-122

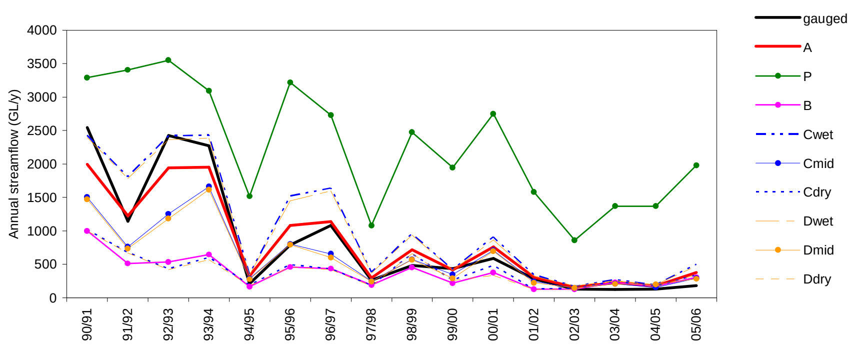
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.79	0.94
Log-normalised	0.49	0.81
Ranked	0.25	0.75
Low flows only	<0	<0
High flows only	0.40	0.78
Annual		
Normal	0.92	0.98
Log-normalised	0.90	0.92
Ranked	0.92	0.93

Definitions:
- low flows (flows<10% percentile) : 7.2 GL/mo
- high flows (flows>90% percentile) : 208.7 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	43.0	10.9	2.1	3.6	11.2	1.8	4.0	11.6
Monthly streamflow	10.2	3.3	1.5	1.5	3.3	1.4	1.6	3.4





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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.