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Water Availability in the Murray

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

July 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: Mouth of the Murray River with Lake Alexandrina and the Coorong, South Australia. Courtesy of the Murray-Darling Basin Commission.

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 Murray region. This is the last of the 18 regions that comprise the MDB to be reported on from the project. 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 Murray region straddles southern New South Wales, northern Victoria and south-eastern South Australia and represents 19.5 percent of the total area of the MDB. The region is based around the Murray River and lower Darling River below Menindee and extends the full length of the Murray to the Southern Ocean. It receives inflows from the Barwon-Darling, Murrumbidgee, Ovens, Goulburn-Broken, Campaspe and Loddon-Avoca regions. The population is 309,000 or 16 percent of the MDB total, concentrated in the centres of Albury-Wodonga, Echuca, Swan Hill, Mildura, Renmark, Murray Bridge and Goolwa. While this report is primarily for the Murray region as defined above, because this region is strongly affected by inflows from upstream regions (including the Barwon-Darling and its tributaries, the Murrumbidgee and several Victorian regions), in places results are presented for the entire MDB. In these cases, results relate to aggregated hydrologic assessments to Wentworth on the Murray River based on the linked surface water modelling. Comparisons and contrasts between the 18 regions considered in the project will be reported in a report for the MDB.

The dominant land use in the Murray region is dryland pasture used for livestock grazing. Dryland cropping is also a major enterprise and slightly more than 22 percent of the region is covered with native vegetation. There are 539,900 ha of irrigated cropping within the region. Major irrigated enterprises include: rice in southern New South Wales, pastures, hay production and horticulture in northern Victoria and horticulture in the Sunraysia and Riverland regions of the lower Murray. Over 95 percent of the irrigation water used was sourced from surface water diversions in 2000. There are around 53,000 ha of commercial forestry plantations in upper Murray.

The region includes some large and important wetlands along the Murray River, the lower Darling River, the Great Darling Anabranch and the Edward Wakool system. A number of the wetlands are listed as sites of international importance under the Ramsar convention including: Barmah Forest; Gunbower Forest; Hattah-Kulkyne Lakes; the Riverland wetland complex; and the Coorong, and Lakes Alexandrina and Albert. Several sites are 'Icon Sites' under the Murray-Darling Basin Commission's Living Murray Initiative. In addition, there are large areas of floodplain and River Red Gum forest along the major rivers and along the smaller tributaries such as Billabong Creek in New South Wales and Broken Creek in Victoria. The environmental assessment provided in this report relates to the Icon Sites and to the lower Darling River and associated anabranch lakes; the latter are collectively listed as a wetland of national importance.

The region uses over 36 percent of the surface water diverted for irrigation and urban use in the MDB and around 14 percent of groundwater used in the MDB. The Murray and lower Darling river system is highly regulated. Hume Dam located on the Murray River and Dartmouth Dam on the Mitta Mitta River are the major water storages in the region. The river system is supplemented with water from the Snowy Mountains Hydro-electric Scheme, Menindee Lakes on the lower Darling River and Lake Victoria in south-western New South Wales.

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 average annual rainfall and modelled runoff for the entire Murray region are 340 mm and 24 mm respectively. Rainfall is fairly uniform throughout the year while runoff is highest in winter and spring. The region generates 16.5 percent of total MDB runoff.

Current average surface water availability for the MDB aggregated to Wentworth on the Murray River is 14,493 GL/year. For the Murray region, current average surface water availability is 11,162 GL/year because availability is reduced by water use in upstream regions. Of this, the Murray region contributes 5211 GL/year (or 47 percent) on average, with the remainder of the water being contributed by upstream regions. About one-tenth of the Murray region contribution is an inter-basin transfer from the Snowy Mountains Hydro-electric Scheme into the upper Murray.

Current average surface water use across the MDB reduces streamflow at Wentworth by 7422 GL/year. On average, an additional 673 GL/year is diverted downstream of Wentworth. Combined, these give a total 'effective use' across the MDB of 8095 GL/year which is an extremely high 56 percent of the average available MDB water. Average surface water use within the Murray region is 4045 GL/year or half of the total 'effective use' for the MDB. The relative level of surface water use for the Murray region is therefore a high 36 percent.

Flows in the Murray River are highly regulated. Dartmouth and Hume dams both regulate 87 percent of their total inflow. In the Murray system, New South Wales general security water, Victorian water and South Australian water are all highly used: 79 percent of the allocated New South Wales general security water is used; 87 percent of the Victorian combined high and low reliability water shares (including delivery losses) is used; and 81 percent of the South Australian allocated water is used.

The end-of-system flow of the Murray River has been significantly reduced by water resource development. The average annual end-of-system flow under without-development conditions (but including Snowy Mountains Hydro-electric Scheme contributions) is 12,233 GL/year and this has been reduced by 61 percent to 4733 GL/year on average as a result of water resource development. The higher relative level of use (compared to the 56 percent level of use quoted above) is a result of lower water availability at the Murray mouth due to evaporative losses from the lower river and the Lower Lakes. Cease-to-flow conditions occur at the Murray River mouth 1 percent of the time under without-development conditions; under current development conditions flow ceases 40 percent of the time. In spite of these changes in end-of-system flow conditions, the average (and minimum) areal extent of the Lower Lakes has increased 6 percent due to construction of the barrages across the river mouth. Under the historical climate and current development levels in the Lower Lakes never fall below mean sea level.

Total groundwater extraction in the Murray region for 2004/05 is estimated at 233 GL and represents 13.5 percent of groundwater use in the MDB. Current groundwater extraction is 5 percent of total water use within the region and around 8 percent of total water use in years of lowest surface water diversion. The majority (83 percent) was from the Katunga Water Supply Protection Area (WSPA), Lower and Upper Murray Alluvium and South Australia–Victoria Border Zone groundwater management units (GMUs). The eventual total net streamflow loss to groundwater across the entire Murray region as a result of the current level of groundwater extraction is estimated to be 101 GL/year. This is comprised of 73 GL/year of streamflow loss from both rivers and drains across the modelled Southern Riverine Plains area (from upstream of Yarrawonga to downstream of Swan Hill) and 28 GL/year of streamflow loss across non-modelled GMUs.

Groundwater modelling indicates that current groundwater extraction (166 GL/year) across the entire Murray region portion of the Southern Riverine Plains model area represents 84 percent of total diffuse recharge or 45 percent of combined diffuse and river recharge. About one quarter of the extraction in the modelled area within the region is outside the Lower Murray Alluvium and Katunga WSPA GMUs. For the Lower Murray Alluvium GMU (parts of which lie outside the Murray region), modelling indicates that current extraction – which is roughly equivalent to the long-term average extraction limit (LTAEL) – represents 29 percent of total groundwater recharge. This is a low level of development which can be supported by the existing distribution of bores. Total recharge exceeds extraction in all years. Leakage from the more saline Shepparton Formation to deeper aquifers is 109 GL/year and is a large component of the water balance and thus represents a salinisation risk for the deeper aquifers which are primary aquifers used for irrigation. For the Katunga WSPA GMU which is entirely within the Murray region, modelling indicates that current extraction represents 42 percent of total groundwater recharge. This is a moderate level of development which can be supported by the existing distribution of bores. Total recharge exceeds extraction for 100 percent of the time. Under a long-term continuation of the recent climate there would be no change in recharge and under the best estimate 2030 climate the water balance would remain unchanged. The modelling indicates that although current extraction is less than half the LTAEL, this level of extraction represents the maximum yield of the GMU under current extraction rules.

Simple water balance analyses for the 20 lower priority GMUs indicate that total current extraction outside of the Southern Riverine Plains model area is 67 GL/year. Several of the GMUs in the Mallee region have either been recharged thousands of years ago or modern recharge is associated with high salinity. For the eight lower priority GMUs where rainfall recharge is significant, current extraction is less than one-fifth of recharge. However, in the Upper Murray Alluvium GMU extraction is nearly eight times the rainfall recharge.

For the major wetlands and floodplain forests along the Murray River, water resource development in the Murray region and in the upstream contributing regions has approximately doubled the average period between significant inundation events (to at least 3.5 years). Flood volumes have also been greatly reduced such that the average annual flood volume is now less than a quarter, and in some cases only a fifth, of the volume under without-development conditions.

For the Lower Lakes, Coorong and Murray Mouth, water resource development has increased the average period between the flood events required to flush the river mouth and help sustain the lake and estuarine ecosystems from 1.2 years to 2.2 years. Flood volumes have also been greatly reduced such that the average annual flood volume is only a fifth of the volume under without-development conditions.

For the Darling Anabranch Lakes, water resource development has more than trebled the average period between events that flood the lakes, from once in less than three years on average to once in more than eight years on average. Flood volumes have also been greatly reduced such that the average annual flood volume is only a fifth of the volume under without-development conditions.

In all the above cases, the hydrological changes resulting from water resource development have been major, and are associated with the significant declines that have been observed in these flood-dependent ecosystems.

Recent climate and current development (Scenario B)

The average annual rainfall and modelled runoff over the ten-year period 1997 to 2006 in the Murray region are 8 and 21 percent lower respectively than the long-term (1895 to 2006) average values.

Under a long-term continuation of the recent (1997 to 2006) climate and current water sharing arrangements, average surface water availability for the MDB would decrease by 27 percent and for the Murray region would decrease by 30 percent. End-of-system flows at the barrages would decrease by 50 percent, and the volume of water diverted for use within the region would decrease by 13 percent. New South Wales and Victorian diversions in the region would, on average, decrease by 21 and 7 percent respectively. Diversions in South Australia would reduce by 12 percent; Adelaide and rural town water supply would be unaffected under this or any 2030 climate scenario. Impacts on region diversion volumes would be far greater in dry years: the lowest 1-year diversion volume would be reduced by 60 percent. The relative level of use for the MDB would increase from 56 to 66 percent and for the Murray region would increase from 36 to 45 percent. The minimum area of the Lower Lakes (occurring at a level of 0.2 m above mean sea level) would be about 1000 ha less than the minimum under the historical climate.

The annual flow in the Murray system at the South Australian border for 2007/08 has been lower than would have ever occurred under the historical climate at the current level of development. Annual flows this low would not occur under the best estimate or wet extreme 2030 climate, but would occur in 1 percent of the years under a continuation of the recent climate or in 4 percent of the years under the dry extreme 2030 climate. During the extreme low flow period of 2007/08, South Australian irrigation allocations were lower than modelled because of simplifying assumptions in the modelling. The modelling results reported here have been adjusted to account for this. However, the adjusted results assume accurate implementation of the current South Australian irrigation allocation practices during low flow periods. During the recent drought, South Australian irrigation allocations have sometimes been higher than the current practice would recommend due to optimistic expectations of cross-border flows, and have thus been closer to the unadjusted modelled allocations. This could also happen in future dry periods, in which case South Australian diversions would be considerably higher than reported and the minimum levels in the Lower Lakes would be considerably lower than reported, under this and under other drier future climate scenarios.

Under a long-term continuation of the recent (1997 to 2006) climate, total recharge to the Lower Murray Alluvium GMU would fall by 12 percent but would still exceed extraction, while for the Katunga WSPA GMU recharge would be unaffected. For the lower priority GMUs there would generally be only minor changes to the ratios of extraction to recharge.

A long-term continuation of the climate of the last ten years (1997 to 2006) would cause additional significant hydrological change for the Icon Sites. The average period between assessed beneficial floods would in all cases be then close to three times the period under without-development conditions under the historical climate. Flood magnitudes would also decline significantly such that average annual flood volumes would, for all Icon Sites, be 5 percent or less of the without-development volumes. As the recent climate in the Darling Basin has not been significantly different to the historical climate, a long-term continuation of this climate would have no consequences for the Darling Anabranch Lakes.

Future climate and current development (Scenario C)

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Murray region is more likely to decrease than increase. About three-quarters of the modelling results show a decrease in runoff and about one-quarter of the results show an increase in runoff for the region. Under the best estimate (median) 2030 climate average annual runoff within the region would be reduced by 10 percent. The extreme estimates (from the high global warming scenario) range from a 37 percent reduction to a 7 percent increase in average annual runoff. The results from the low global warming scenario range from a 12 percent reduction to a 2 percent increase in average annual runoff for the region.

Under the best estimate 2030 climate average surface water availability for the MDB would fall by 12 percent and for the Murray region would fall by 14 percent. Total diversion volumes in the region would fall by 4 percent and end-of-system flows would fall by 24 percent. Diversion impacts would differ between water products. New South Wales and Victorian diversions in the region would, on average, decrease by 8 and 1 percent respectively. New South Wales general security water use in the region would be decreased by 9 percent, supplementary access would be decreased by 14 percent and high security town water supplies would not be impacted. Diversions in South Australia would fall by 3 percent. Impacts on region diversion volumes would be far greater in dry years: the lowest 1-year diversion volume would be reduced by 14 percent. The relative level of use for the MDB would increase from 56 to 60 percent and for the Murray region would increase from 36 to 40 percent.

Under the wet extreme 2030 climate average surface water availability for the MDB and Murray Region would increase by 7 percent. End-of-system flows would increase by 20 percent. Diversions in New South Wales would, on average, increase by 2 percent while total Victorian and South Australian diversions would be essentially unaffected.

Under the dry extreme 2030 climate average surface water availability for the MDB would fall by 37 percent and in the Murray region would fall by 41 percent. Total diversions in the region would fall by 23 percent and end of system flows would fall by 69 percent. Average New South Wales and Victorian diversions in the region would decrease by 32 and 18 percent respectively. Diversions in South Australia would fall by 30 percent. Impacts on total diversion volumes for the region would be far greater in dry years: the lowest 1-year diversion volume would be reduced by 64 percent. The minimum area of the Lower Lakes (occurring at a level 0.05 m above mean sea level) would be around 2000 ha lower than the minimum under the historical climate.

The best estimate 2030 climate would have little effect on groundwater recharge and thus groundwater balances would be largely unaffected. The dry extreme 2030 climate would have a broadly similar effect as a continuation of the recent climate in terms of impact on groundwater recharge.

The best estimate 2030 climate, while less severe than a continuation of the recent climate, would still lead to significant increases in the average period between beneficial floods for all assessed environmental sites. These increases, combined with reduced flood sizes, would mean that average annual flood volumes would be between 8 to12 percent of the without-development volumes (under historical climate, except for the Darling Anabranch Lakes where average annual volumes would be 15 percent of the without-development volumes). These hydrologic changes would have very serious consequences for the ecosystem health of all sites.

The wet extreme 2030 climate would lead to little change in flood frequency for the assessed environmental sites. However, flood events would be somewhat larger – except in the case of the Gunbower-Koondrook-Perricoota Forest, where event size would fall slightly. These hydrological changes would not be expected to have additional impacts on the assessed sites. The dry extreme 2030 climate would cause hydrological changes slightly more severe than a long-term continuation of the recent climate. Hence the average period between floods would be three or more times the average period under without-development conditions (under the historical climate) and average annual flood volumes would be only 1 or 2 percent of without-development volumes, except for the Darling Anabranch Lakes where average annual flood volumes would be 10 percent of the without-development volumes.

Future climate and future development (Scenario D)

The area of commercial forestry plantations in the Murray region is projected to increase by 33,000 ha (62 percent) by 2030. It is assumed that the projected increase would be concentrated in a small number of subcatchments and the impacts would be significant in these areas, however, the impact on average annual runoff across the entire region would be negligible. Farm dam storage capacity is projected to increase by 10,900 ML (12 percent) by 2030. These additional farm dams would decrease average annual runoff across the Murray region by less than 1 percent. The best estimate of the combined impact of climate change and development is an 11 percent reduction in average annual runoff. Extreme estimates (due to climate change uncertainty) range from a 38 percent reduction to a 6 percent increase.

Projected future regional development (additional groundwater extraction, farm dams and commercial forestry plantations) would reduce inflows by 146 GL/year; of this 90 GL/year would be due to future development in upstream regions, 29 GL/year would be due to future farm dams in the region, 19 GL/year would be due to commercial forestry plantations in the region and about 8 GL/year would be due to future groundwater extraction in the region. Future development alone would cause a 2 percent decrease in average annual streamflow at Wentworth, a 1 percent increase in cease-to-flow periods and a 0.5 percent decrease in average surface water diversions.

Groundwater extraction from the Lower Murray Alluvium and Katunga WSPA GMUs is not projected to increase. Extraction in the region for the modelled area of the Southern Riverine Plains is projected to increase from 166 GL/year to 193 GL/year on average due to increased in extraction in lower priority GMUs. Groundwater extraction across the 20 lower priority GMUs outside of the Southern Riverine Plains model area is projected to increase more than seven-fold to 508 GL/year meaning total groundwater extraction in the region at 2030 would be 701 GL/year on average. Groundwater extraction would then represent 15 percent of total future water use on average and 24 percent in years of lowest surface water use. At these future extraction levels and under the best estimate 2030 climate, extraction would be less than half of the rainfall recharge volume for all but the Upper Murray Alluvium GMU where extraction would be over ten times the rainfall recharge. Neither the current nor the projected future level of extraction from the Upper Murray Alluvium GMU are likely to be sustainable.

Of the future developments considered, the increases in groundwater extraction would have noticeable impacts on the hydrology of some of the Icon Sites. The groundwater levels under Barmah-Millewa and Gunbower-Koondrook-Perricoota forests would be expected to fall by up to one metre. This is in addition to reductions in groundwater levels of a similar magnitude under these forests due to the current levels of groundwater extraction.

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 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 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 the states. There is uncertainty both as to how landholders will respond to existing and new policies and how governments may set their future policies.

The river models for the Murray are well suited to the purposes of this project and are able to reproduce observed streamflow patterns in most of the system very well. The models provides strong evidence of changes in flow pattern due to prior development in the regulated part of the system. The models provides strong evidence of a change in flows under best estimate or dry extreme 2030 climates, but the projected changes under a wet extreme 2030 climate are the same order of magnitude as river model uncertainty. Uncertainties associated with forestry, further groundwater extraction and farm dam development are all small when compared to climate scenario uncertainty and internal model uncertainty. Some caution is warranted in interpreting predictions of absolute as well as relative changes in flow patterns and average flows in the Murray between the offtakes of the Edward system and Barmah, the Edward-Wakool system itself and the Great Darling Anabranch.

The assessments for the Lower Murray Alluvium GMU (NSW) and the Katunga WSPA GMU (Victoria) used a groundwater model that covers a much broader area across multiple regions (the Southern Riverine Plains groundwater model). Assessments for the remaining lower priority GMUs were based on simpler water balance analyses. However, the Upper Murray groundwater model was used to determine stream loss to groundwater in relevant lower priority areas.

The Southern Riverine Plains groundwater model was run in a without-development calibration. The model was developed for this project and while it has been peer-reviewed, it has not received widespread scrutiny. Monitoring and extraction data are not as good as for some other regions. Lateral flows from outside the model area are small. The model was assessed as thorough and hence is adequate for providing information on water availability in the context of this project, but less reliable for local management requirements. The model reached dynamic equilibrium under all scenarios. The level of reliability of predictions could be improved to very thorough by recognising the importance of the Lower Murray Alluvium and Katunga WSPA GMUs as groundwater resources and the requirement for a more robust water allocation model for future decisions.

The streamflow impacts from groundwater extraction in the non-modelled areas are reliant on the value of the 'connectivity factor'. For the fractured rock areas, a value of 30 percent has been used. For such steep terrain, this is considered low, but is consistent with that used for other regions representing a wider range of terrain. A value of 80 percent has been used for the alluvial fill, consistent with those inferred from modelling studies for similar hydrogeological units.

There is considerable uncertainty in the groundwater development projections in the lower priority GMUs but the estimates do show their importance. 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).

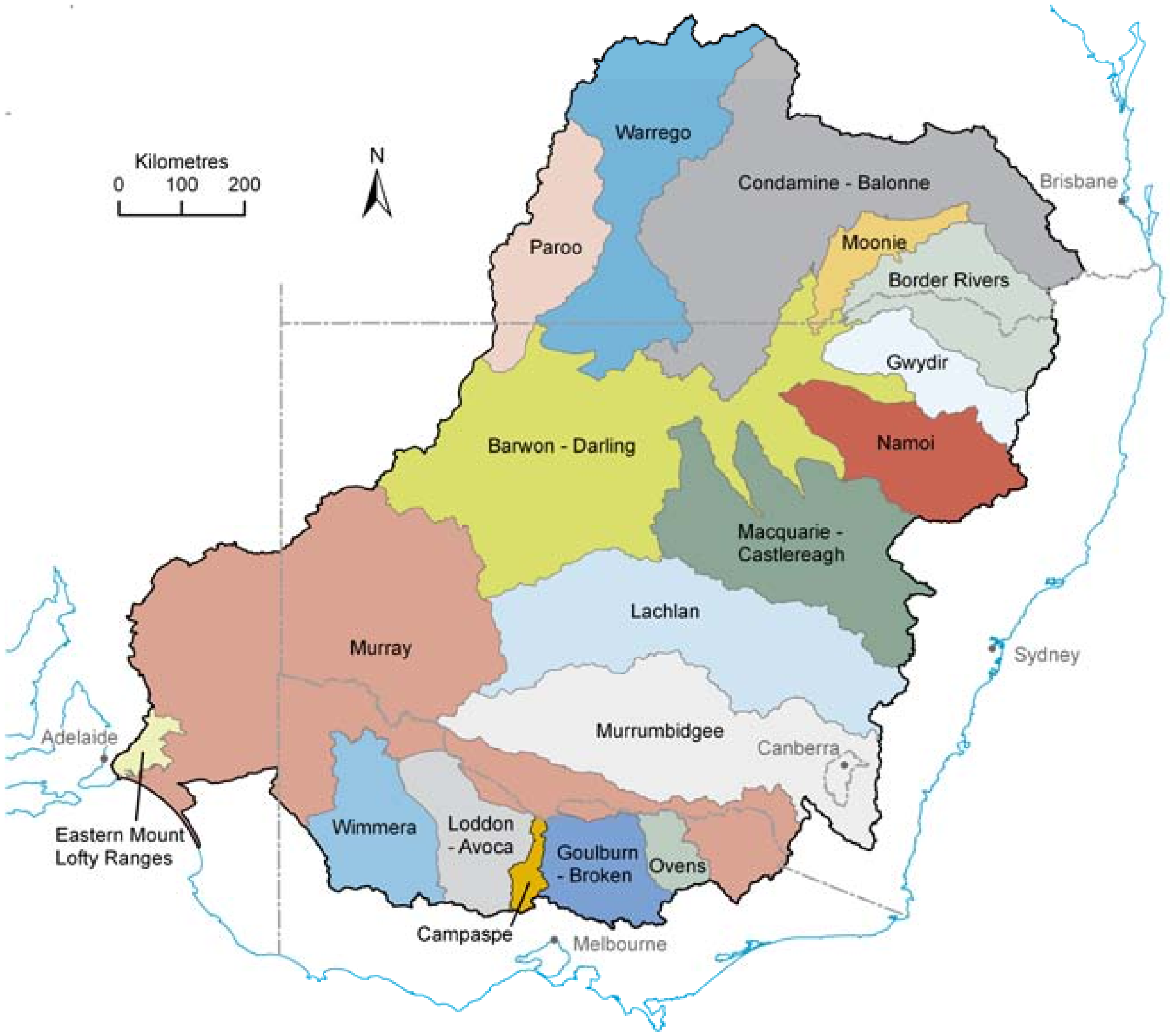

Figure 1-1. Region by region map of the Murray-Darling Basin

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.

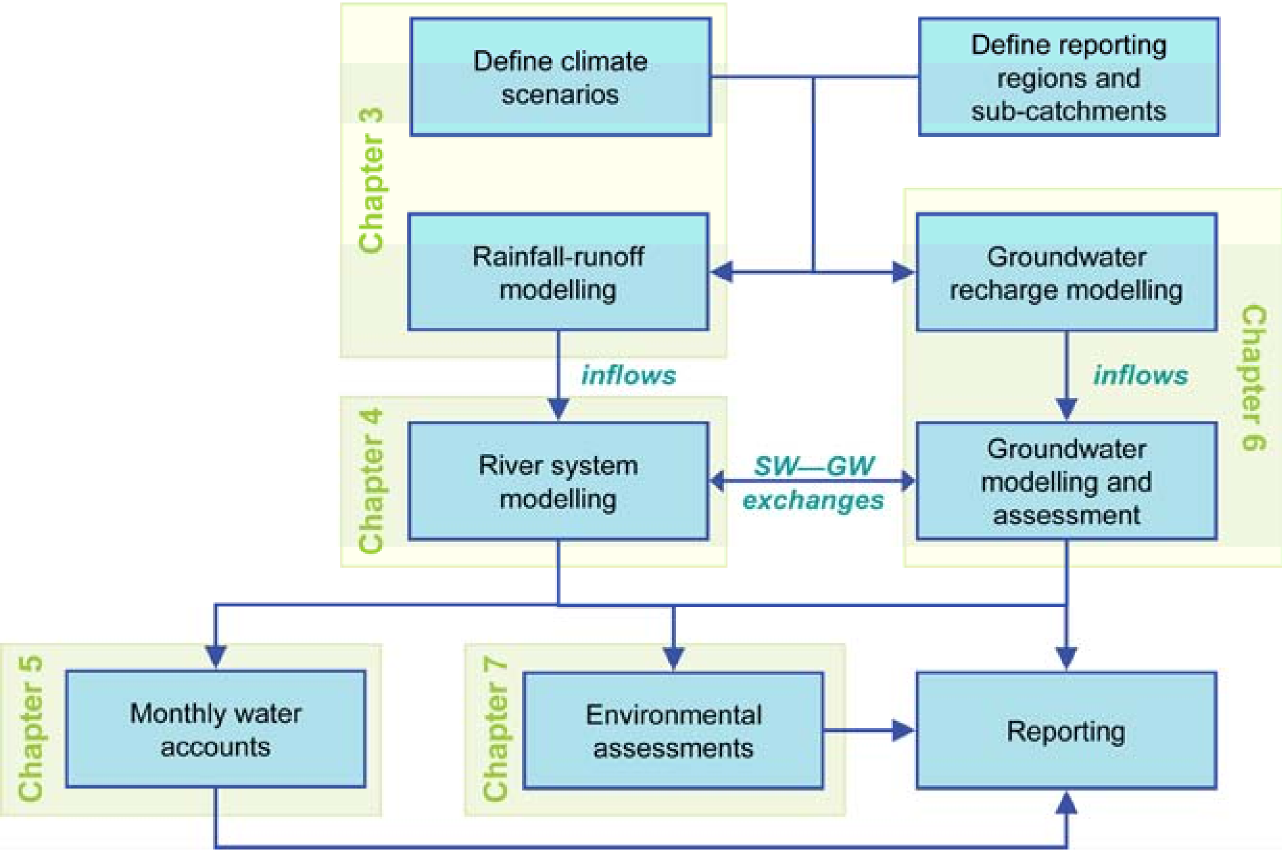

Figure 1-2. Methodological framework for the Murray-Darling Basin Sustainable Yields Project

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; New South Wales Government, 2000; Victoria Government, 1989; South Australia Government, 2004). Data on the current extent of farm dams is taken from the 2007 Geosciences Australia 'Man-made Hydrology' GIS coverage (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	Monthly 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 Hydro model: purpose built by Snowy Hydro Limited to guide the planning and operation of the SMHS.	Snowy Mountains Hydro-electric Scheme

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

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

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

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

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

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

1.5.1 Surface–groundwater interactions

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

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

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

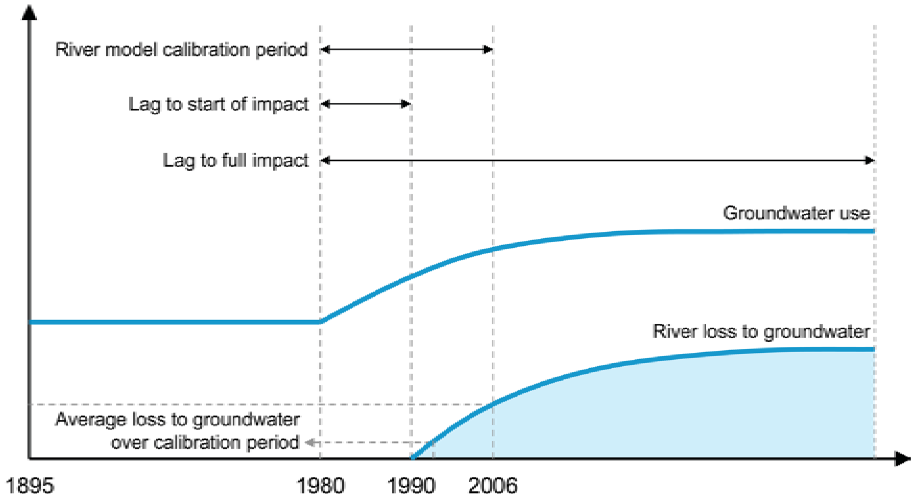

Figure 1-3. Timeline of groundwater use and resultant impact on river

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

1.6 Monthly water accounts

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

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

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

1.6.1 Wetland and irrigation water use

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

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

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

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

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

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

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

1.6.2 Calculation and attribution of apparent ungauged gains and losses

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

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

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

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

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

The water accounting model includes the following components:

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

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

1.7 Groundwater modelling

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

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

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

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

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

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

1.8 Environmental assessment

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

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

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

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

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

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

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2 Overview of the region

The Murray region straddles southern New South Wales, northern Victoria and south-eastern South Australia and represents 19.5 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the Murray River and lower Darling River below Menindee and extends the full length of the Murray to the southern Ocean. The population is 309,000 or 16 percent of the MDB total, concentrated in the centres of Albury-Wodonga, Echuca, Swan Hill, Mildura, Renmark, Murray Bridge and Goolwa.

While this report is primarily for the Murray region as defined above, because this region is strongly affected by inflows from upstream regions (including the Barwon-Darling and its tributaries, the Murrumbidgee and several Victorian regions), in places results are presented for the entire MDB. In these cases, results relate to aggregated hydrological assessments to Wentworth on the Murray River based on the linked surface water modelling; see Chapter 4 for further explanation. This distinction is analogous to the distinction made between the Darling Basin and the Barwon-Darling in the project report for the Barwon-Darling region (CSIRO, 2008a). Comparisons and contrasts between the 18 regions considered in the project will be reported in a report for the entire MDB (CSIRO, 2008b). Descriptions of the other regions which comprise the MDB are provided in the project's report for each region.

The dominant land use is dryland pasture used for livestock grazing. Dryland cropping is also a major enterprise and slightly more than 22 percent of the region is covered with native vegetation. There are 539,900 ha of irrigated cropping within the region. Major irrigated enterprises include: rice in southern New South Wales; pastures, hay production and horticulture in northern Victoria; and horticulture in the Sunraysia and Riverland regions of the lower Murray. Over 95 percent of the irrigation water used in 2000 was sourced from surface water diversions. The area of commercial forestry plantations in the region is about 10 percent of the irrigated cropping area and is limited to the upper Murray catchment. The region contains a number of wetlands of national and international (Ramsar-listed) importance including the Barmah-Millewa Forest; the Gunbower Forest; the Koondrook-Perricoota Forests; the Kerang Lakes; the Chowilla floodplain; and the Coorong and Lakes Alexandrina and Albert Wetland.

The region uses over 36 percent of the surface water diverted for irrigation and urban use and over 11 percent of groundwater used in the MDB. The Murray and lower Darling river system is highly regulated. Hume Dam located on the Murray River and Dartmouth Dam on the Mitta Mitta River are the major water storages in the region. The river system is supplemented with water stored in the Snowy Mountains Hydro-electric Scheme, Menindee Lakes on the lower Darling River and Lake Victoria in south-western New South Wales.

This chapter summarises the Murray region's biophysical features including rainfall, topography, land use and the environmental assets of significance. It outlines the institutional arrangements for the region's natural resources and presents key features of the surface and groundwater resources of the region including historical water use.

2.1 The region

The Murray region is located predominantly in New South Wales and South Australia and covers 207,667 km^2 or 19.5 percent of the MDB. It is bounded to the east by the Great Dividing Range, to the north by the Murrumbidgee, Lachlan and Barwon-Darling regions, to the south by the Loddon-Avoca, Campaspe, Goulburn-Broken and Ovens regions and forms the western edge of the MDB. The region ends at the river mouth. The topography varies from steep to gently undulating hills, low relief floodplains and flat plains.

Major water resources in the Murray region include the Murray 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 are associated with these water resources including: on-farm water storage; Dartmouth Dam on the Mitta Mitta River and Hume Dam in the headwaters of the Murray River; Lake Mulwala on the Murray River; Menindee Lakes on the lower Darling River; Lake Victoria on Rufus River; and Lake Alexandrina and Lake Albert on the lower Murray.

The average annual rainfall for the region is 340 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 between May and October and between

November and April. 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 average annual rainfall over the ten-year period 1997 to 2006 is around 8 percent lower but not statistically different, than the long-term average values (Figure 2-1).

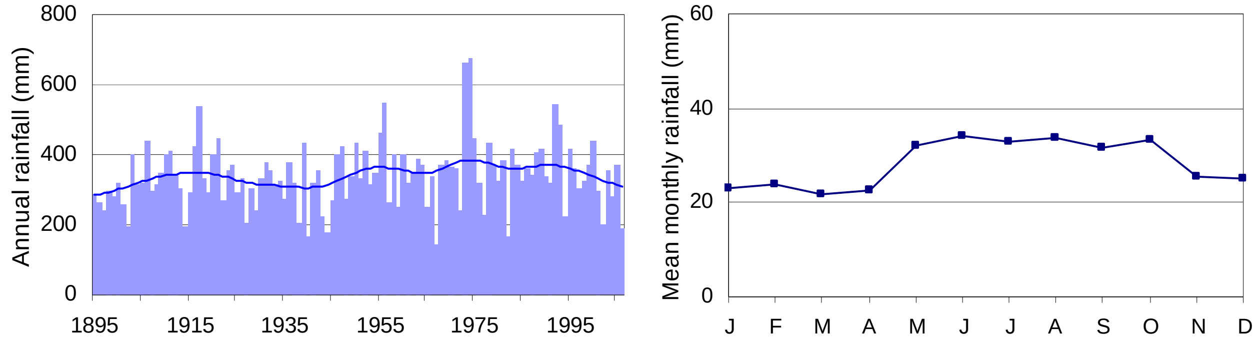

Figure 2-1. 1895–2006 annual and monthly rainfall averaged over the region. The curve on the annual graph shows the low frequency variability.

The Murray region contributes about 16.5 percent of the total runoff in the MDB. The average annual modelled runoff over the region for the 111-year period is 24 mm and is highest in the winter and early spring. The average annual modelled runoff over the 10-year period 1997 to 2006 was 21 percent lower than the long-term average values. The runoff estimates for the eastern half of the Murray region (where most of the runoff is produced) are relatively good because there are many gauged catchments from which to estimate the model parameter values.

The regional population is approximately 309,000 or 16 percent of the MDB total. The larger urban centres include Albury-Wodonga and Yarrawonga to the east, Deniliquin, Echuca and Swan Hill in the central section and Mildura, Renmark and Murray Bridge in the west. The dominant land use is dryland pasture used for broadacre grazing. Dryland cropping is a major enterprise and around 22 percent of the region is covered with native vegetation. There were 539,900 ha of irrigated cropping within the region in 2000. The major enterprises were pasture and hay production particularly for the dairy industry in northern Victoria, cereal grain production including rice in southern New South Wales and vineyards and orchards in the Sunraysia and Riverland areas of the lower Murray.

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. 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 Murray region

Land use	Area		
	percent		ha
Dryland crops	6.9		1,441,100
Dryland pasture	65.0		13,474,900
Irrigated crops	2.6		539,900
Cereals		*21.9*	*118,400*
Horticulture		*2.5*	*13,400*
Orchards		*5.4*	*28,900*
Pasture and hay		*60.5*	*326,600*
Vine fruits		*9.7*	*52,600*
Native vegetation	22.5		4,662,500
Plantation forests	0.3		53,300
Urban	0.2		48,200
Water	2.5		526,100
Total	**100.0**		**20,746,000**

Source: BRS, 2005.

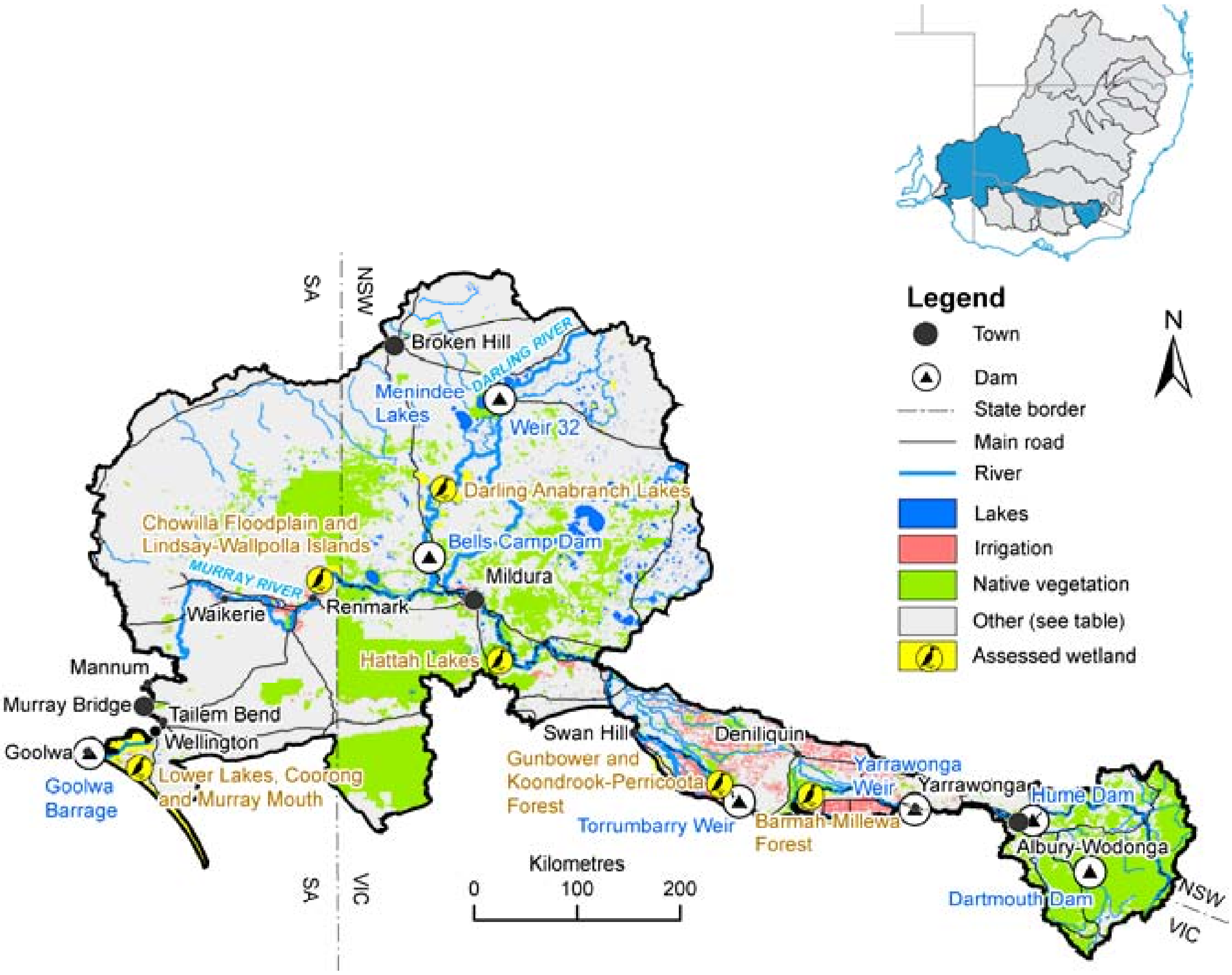

Figure 2-2. Map of dominant land uses of the Murray region with inset showing the region's location within the Murray-Darling Basin. The assets shown are only those assessed in the project (Chapter 7) and fall within the region. A full list of key assets associated with the region is at Table 2-2

There are two regional catchment plans within the New South Wales portion of the region. The Murray Catchment Action Plan (CAP) and the Lower Murray Darling CAP provide strategies for managing natural resources in the region (MCMA, 2007 and LMDCMA, 2006). These plans are statutory documents; they were prepared under the Catchment Management Authorities Act 2003 (NSW Government, 2003) and are approved for a term of ten years. Their purpose is to provide strategic direction for investment in natural resource management for the New South Wales Murray and Lower Murray-Darling Catchments through education, planning and partnership development (MCMA, 2007). The Murray and Lower Murray Darling catchment management authorities (CMAs) have identified community, biodiversity, water and land assets as the investment focus and have assigned targets, actions and ways to monitor progress toward improvement. The plans build on the planning and activity already undertaken including the Murray and Lower Murray Darling Catchment Blueprints (DLWC, 2002 and 2003), vegetation management plans and water sharing plans.

Four 30-year Murray Land and Water Management Plans, covering the entire irrigated area of Murray Irrigation Limited's area of operations, were finalised in 1995. The plans detail a long-term strategy to improve natural resource management of the irrigated area and involve works and measures at a farm and district level to improve: water use efficiency, drainage to minimise groundwater recharge, protection and enhancement of native vegetation, landholder education, research and development, incentive schemes and detailed monitoring and reporting (Murray Irrigation Limited, 2004). These plans provide a mechanism for implementation of the Murray CAP within the mid Murray.

The Murray region within northern Victoria is covered by the North East, Goulburn Broken, North Central, and Mallee CMAs. The CMAs were established in 1997 under the Catchment and Land Protection Act 1994 (Victorian Government, 1994) to achieve effective integration and delivery of land and water management programs in this area of Victoria.

The North East CMA region includes the Murray valley upstream of Barmah, the North Central CMA region includes the region downstream of Echuca to Nyah and the Mallee CMA includes the Sunraysia region from Robinvale to the South Australian border.

Each Victorian CMA has developed a regional catchment strategy which is an integrated framework for land and water management in the catchment. The strategies prepared in 2003 were the primary integrated planning framework for land, water and biodiversity for the period 2003 to 2007. They are overarching strategic documents that support several action plans. They provide a mechanism to deliver a coordinated approach to catchment management and achieve the vision, priorities and objectives of the community. The CMAs coordinate and monitor the implementation of their respective strategy.

Each strategy takes an assets-based approach to natural resource management, examining how the respective catchment's key natural resource assets can be enhanced and how the threats they face can be addressed. Human or social assets are identified as well as the primary natural resource assets of the region. The assets considered include management of water resources, waterways and wetlands to protect high priority water and biodiversity assets while maintaining sustainable economic use of the region's water assets.

Water and land resources within South Australia are managed under the South Australia Natural Resource Management Act 2004 (South Australian Government, 2004). The Act provides the framework for the integrated use and management of the state's natural resources. A natural resource management board is responsible for providing an integrated response to water, soil, biodiversity, pest plant and animal control. A key function of the board is the development of plans that will assist in the development of better management and conservation of the region's natural resources. Two types of plans are prepared, a Natural Resource Management Plan and Water Allocation Plans.

The natural resource management plan is a 10-year strategic plan and includes a 3-year business plan detailing the resources needed to implement the plan. The plan is required to include:

- information on the natural resources and their state and condition; environmental, social, economic and practical considerations relating to their use, management, conservation, protection, improvement and where relevant their rehabilitation; and management of pest species of animals and plants
- information about the issues surrounding the management of natural resources at the regional and local level and specifically about methods for improvement of natural resources and their conservation, use or management, action plans for proper stormwater management and flood mitigation, arrangements for management of wetlands, estuaries and marine resources.

2.2 Environmental description

Due to its geographic extent, the environmental characteristics of the Murray region range from alpine to arid and inland to coastal. The range of features can best be described by outlining the major bioregions and significant wetlands.

2.2.1 Bioregions

The Murray region traverses a number of bioregions and landscapes covering a range of geology, landform, altitude and climate. Within South Australia the landscapes of the Murray River catchment can be divided into five distinct units: the river corridor, the Coorong and Lower Lakes, the Eastern Mount Lofty Ranges and Murray Plains, the Murray Mallee east of the river, and the pastoral South Olary Plains to the river's north. The eastern slopes of the Eastern Mount Lofty Ranges are steep and fall away to the broad Murray Plains and eventually to the river itself. The major vegetation groups within this landscape are mallee, woodlands and chenopod shrub lands (RMCWMB, 2003). Most of these are subregions of the Murray Darling Depression bioregion (ANRA, 2008).

The major bioregions upstream of the South Australian border include the Australian Alps, Highlands-Northern Fall, Northern Inland Slopes, South Western Slopes, Riverina, Murray Fans, Murray Mallee, Murray Darling Depression and Murray Scroll Belt (DSE, 2007a and DECC, 2008) as described in more detail below.

The Australian Alps bioregion encompasses the headwaters of the Murray River and consists of a series of high plateaus and peaks along the Great Dividing Range. The vegetation associated with the sub-alpine plateaus is Sub-alpine

Woodland, Treeless Sub-alpine Mosaic and Sub-alpine Grassland ecosystems. The upper slopes and areas generally surrounding sub-alpine areas are dominated by Montane Dry Woodland, Montane Damp Forest, Montane Wet Forest and Montane Grassy Woodland ecosystems.

The Highlands-Northern Fall bioregion in Victoria are the northerly aspect of the Great Dividing Range and have moderate to steep slopes, high plateaus and alluvial flats along the main valleys. The vegetation is a mosaic of Herb-rich Foothill Forest and Shrubby Dry ecosystems dominating large areas of lower slopes, Montane Dry Woodland and Heathy Dry Forest ecosystems on the upper slopes and plateau, and Grassy Dry Forest and Valley Grassy Forest ecosystems associated with major river valleys.

The Victorian Northern Inland Slopes bioregion consists of foothill slopes and minor ranges separated by river valleys that drain northward from the High Country to the Murray River. It is a mixed complex of granitic and metamorphic rocks that protrudes through and is surrounded by the Riverine Plain. The vegetation is dominated by: Grassy Dry Forest, Box Ironbark Forest, Granitic Hills Woodland, Heathy Dry Forest, and Shrubby Dry Forest ecosystems on the less fertile hills; Herb-rich Foothill Forest ecosystems on the more fertile hills and outwash; and Grassy Woodland, Valley Grassy Forest, Plains Grassy Woodland, Floodplain Riparian Woodland and Riverine Grassy Woodland/Riverine Sedgy Forest/Wetland Mosaic ecosystems on the fertile plains and watercourses.

The New South Wales South Western Slopes bioregion is an extensive area of foothills and isolated ranges comprising the lower inland slopes of the Great Dividing Range extending from north of Cowra through southern New South Wales. The bioregion extends from Albury in the south and Holbrook and Culcairn in the northeast of the region. In the higher rainfall eastern hill country, woodlands and open woodlands of White Box (*Eucalyptus albens*) are dominant. To the west and north these give way to vegetation communities dominated by Grey Box (*Eucalyptus microcarpa*) and White Cypress Pine (*Callitris glaucophylla*). Valley flats are dominated by Rough-barked Apple (*Angophora floribunda*), with River Oak (*Casuarina cunninghammia*) found along eastern streams and River Red Gum (*Eucalyptus camaldulensis*) lining the larger central and western streams.

The Riverina bioregion lies in southwest New South Wales, and central-north Victoria. It extends from Ivanhoe in the Murray Darling Depression bioregion south to Bendigo, and from Narrandera in the east to Balranald in the west. The Riverina bioregion is characterised by a flat to gently undulating landscape on recent unconsolidated sediments and evidence of former stream channels and wide floodplain areas associated with major river systems and prior streams. The vegetation is dominated by Plains Grassy Woodland, Plains Grassland, Pine Box Woodland/Riverina Plains Grassy Woodland Mosaic, Riverine Grassy Woodland/Riverine Sedgy Forest/Wetland Mosaic, Plains Grassy Woodland/Gilgai Plains Woodland/Wetland Mosaic, Grassy Woodland and Wetland Formation ecosystems. This bioregion has been cleared heavily and used extensively for irrigated and dryland cropping and grazing.

The Murray Fans bioregion is characterised by a flat to gently undulating landscape on recent unconsolidated sediments with evidence of former stream channels, braided old river meanders and palaeochannels and broad floodplain areas associated with major river systems and prior streams (known as braided/anastomosing streams). The vegetation is a mosaic of Plains Grassy Woodland, Pine Box Woodland, Riverina Plains Grassy Woodland and Riverina Grassy Woodland ecosystems. It lies adjacent to the Murray River in northern Victoria near Echuca and Torumbarry.

The Murray Mallee bioregion located in north-western Victoria is typified by calcareous material in the form of broad undulating sandy plains that is often associated with linear, west-east aligned, low sand dunes with intervening heavier textured swales developed from Cainozoic deposits of alluvial, aeolian and swampy deposits. The vegetation is dominated by East/West-Dune Mallee with some Chenopod Mallee and Shallow-Sand Mallee. The mallee plains, drainage lines and groundwater discharge landscapes are dispersed with salt lakes and gypsum flats, with lunettes developed on the eastern margins of the related lakes. The vegetation is dominated by Gypseous Plains Shrubland, Saline Shrubland (Raak), Plains Grassland and Drainage-line Grassy Woodland.

The Murray Darling Depression bioregion lies in the southwest corner of New South Wales and extends into Victoria and South Australia. The landscape is characterised by dunefields, sandplains and undulating plains of brown calcareous soils. There is very little structured drainage but numerous lakes, swamps and depressions are present, some of which are driven by saline groundwater. Soils and vegetation differ according to the landform. On the dunefields red, brown and yellow calcareous sands occur with more clayey materials in the swales. On sandplains the soil tends to be heavier with brown gradational or texture contrast profiles, and mallee is found only on sandy rises. Lakes and depressions all have clay floors. The more saline lakes have grey cracking clays and carry chenopods. Salt lake floors carry little vegetation. Lunettes comprise varying soils from clean sands, brown clayey sands, mixed sand to clay. The dunes support diverse

Mallee (*Eucalyptus sp*.) communities with mixed shrubs and Porcupine Grass (*Triodia pungens*). Belah (*Casuarina pauper*), Rosewood (*Heterodendrum oleifolium*) and Variable Spear Grass (*Stipa variabilis*) occupy the swales. Lakes and depressions all have clay floors, and vegetation relates to the presence or absence of salt and gypsum.

The Murray Scroll Belt bioregion, found in far north-west Victoria, is an entrenched river valley and associated floodplain and lake complexes of numerous oxbow lakes, billabongs, ephemeral lakes, swamps and active meander belts. The Murray River forms a narrow valley where fluvial processes predominate within an otherwise aeolian-dominated landscape. Alluvium deposits from the Cainozoic period gave rise to the red brown earths, cracking clays and texture contrast soils (Dermosols, Vertosols, Chromosols and Sodosols) that support Alluvial-Plain Shrubland, Riverine Grassy Chenopod Woodland and Riverine Grassy Forest ecosystems.

2.2.2 Significant wetlands

The Murray region includes some large and important wetlands along the Murray River, the lower Darling River, the Great Darling Anabranch and the Edward-Wakool system. A number of the wetlands are listed as sites of international importance under the Ramsar convention (see Table 2.2) including: Barmah Forest; Gunbower Forest; Hattah-Kulkyne Lakes; the Riverland wetland complex; and the Coorong, and Lakes Alexandrina and Albert Wetland. Several sites are 'Icon Sites' under the Murray-Darling Basin Commission's Living Murray Initiative (MDBC, 2008). In addition to these wetlands there are large areas of floodplain and River Red Gum forest along the major rivers and along the smaller tributaries such as Billabong Creek in New South Wales and Broken Creek in Victoria.

For the Murray region, assessments are provided in Chapter 7 for several Living Murray Initiative Icon Sites and for one additional site listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). A short description of these assessment sites is given below with additional details in Chapter 7.

Barmah-Millewa Forest

The Barmah-Millewa Forest located upstream of Echuca is the largest River Red Gum forest in Australia. It covers approximately 66,000 ha of floodplain. It provides a diverse range of wetland environments and supports large breeding colonies of waterbirds such as Egrets (*Ardea spp*), Ibis (*Threskiornis spp*) and Rufous Heron (*Nycticorax caledonicus*). The forest also has diverse plant associations, supports rare and threatened plant species, and provides habitat and food sources for native fish (MDBC, 2006a).

Gunbower-Koondrook-Perricoota Forest

The Gunbower-Koondrook-Perricoota Forest, located downstream of Torrumbarry Weir is the second largest River Red Gum forest in Australia, covering some 50,000 ha. The Koondrook-Perricoota Forests in New South Wales cover approximately 30,000 ha. The wetland complex is an important breeding area for waterbirds such as the Rufous Heron *(Nycticorax caledonicus)* and the Intermediate Egret *(Ardea intermedia)*. It also provides habitat for other rare or threatened species (MDBC, 2006b).

Hattah Lakes

The Hattah Lakes are located downstream of Robinvale and are made up of 17 intermittent and perennial freshwater lakes, 12 of which are internationally important wetlands under the Ramsar Convention. The lakes are also part of the Hattah-Kulkyne National Park Biosphere Reserve. Most of the lakes fill from flows in the Murray River via Chalka Creek (MDBC, 2006c). The varied inundation conditions at the lakes provide for a wide diversity of plants and animals. The lakes can provide feeding and breeding areas for many waterbirds and native fish.

Chowilla Floodplain and Lindsay-Wallpolla Islands

The combined Chowilla Floodplain and Lindsay-Wallpolla Islands is a broad floodplain mostly located in South Australia but it also covers an area in New South Wales and Victoria. The Chowilla Floodplain is part of the internationally important Riverland wetland (recognised under the Ramsar Convention) and is listed on the national and state directories of important wetlands. The Chowilla and Lindsay-Wallpolla Islands are the main wetland areas. The Chowilla Floodplain has 28 plant species of state significance, four animal species of national significance and 23 animal species of state significance. Lindsay-Wallpolla Islands have two plant species of national significance and 51 of state significance, 27 animal species of national significance and 37 of state significance. There are five species of waterbirds protected under international migratory bird agreements (MDBC, 2006d).

Lower Lakes, Coorong and Murray Mouth

The Lower Lakes, Coorong and Murray Mouth are at the terminus of the Murray River in South Australia. The area includes the Coorong, and Lakes Alexandrina and Albert Wetland that is listed as internationally important under the Ramsar Convention and is important for breeding and feeding of many species of waterbirds and native fish. The Lower Lakes are isolated from the Murray Mouth and the Coorong by barrages constructed in the 1920s. The Coorong is a 140 km long wetland that runs parallel with the coast and covers 660 km^2. The Coorong has three distinct sections: the Murray estuary, incorporating the Murray Mouth and connection with the southern ocean; the north lagoon; and the south lagoon. The area provides habitat for over 85 species of waterbirds and supports over half of the waterbirds found in South Australia. It is ranked within the top six waterbird sites in Australia, based on the diversity and abundance of species (MDBC, 2006e).

Lower Darling River and associated Darling Anabranch Lakes

The Darling Anabranch Lakes are located on the Great Anabranch of the lower Darling River. The wetland covers 269,000 ha and includes 14 lakes, the associated river channel and marginal vegetation (Environment Australia, 2001). The Anabranch is a former channel of the Darling River that receives floodwater from the lower Darling River. The upstream lakes receive floodwater and fill before the lakes at the downstream end of the Anabranch. The Anabranch until recently had also received a replenishment release from Menindee Lakes but this water was restricted to the Anabranch channel and low-lying floodplain areas upstream of block-bank structures. The anabranch also receives a share of off-allocation releases from Menindee Lakes.

The vegetation surrounding the lakes is dominated by Black Box, Nitre Goosefoot and Lignum. Several species of native fish have also been recorded including Golden Perch, Murray Cod and Bony Bream. The lakes provide habitat for many species and large numbers of waterbirds. The lakes have particular importance for Indigenous occupation and there are many sites and artefacts particularly in the lake lunettes.

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

Site Code	Directory of Important Wetlands in Australia name	Area(1)	Ramsar sites
		ha	
NSW002	Kosciusko Alpine Fens, Bogs and Lakes	30	none
NSW010	Menindee Lakes	45,000	none
NSW012	Talyawalka Anabranch & Teryawynia Creek	highly variable	none
NSW020	Darling Anabranch Lakes	269,000	none
NSW040	Lake Cowal/Wilbertroy Wetlands *	20,500	none
NSW046	Koondrook-Perricoota Forests	31,150	yes(9)
NSW051	Merrowie Creek (Cuba Dam to Chillichil Swamp)	2,500	none
NSW053	Millewa Forest #	33,636	yes(2)
NSW055	Wakool-Tullakool Evaporation Basins	2,100	none
NSW056	Werai Forest	11,234	none
SA039	Banrock Swamp Wetland Complex	1,220	yes(8)
SA040	Gurra Lakes Wetland Complex	660	none
SA041	Irwin Flat	50	none
SA042	Loch Luna Wetland Complex	1,905	none
SA043	Loveday Swamps	479	none
SA044	Lower Murray Swamps	155	none
SA046	Noora Evaporation Lakes	500	none
SA047	Pike-Mundic Wetland Complex	up to 6,700	none
SA048	Riverland Wetland Complex	30,600	yes(7)
SA049	Spectacle Lakes	427	none

Site Code	Directory of Important Wetlands in Australia name	Area[1]	Ramsar sites
SA050	Stockyard Plain	305	none
SA051	Swan Reach Wetland Complex	250	none
SA063	The Coorong, Lake Alexandrina & Lake Albert	140,500	yes[6]
SA069	Murray Bridge Army Training Area Wetlands	71	none
VIC002	Davies Plain	no details	none
VIC004	Belsar Island	2,521	none
VIC005	Beveridge Island	1,018	none
VIC007	Hattah Lakes	1,018	yes[4]
VIC009	Heywoods Lake	228	none
VIC010	Kings Billabong Wetlands	502	none
VIC014	Lake Ranfurly	265	none
VIC016	Lake Wallawalla	828	none
VIC017	Lindsay Island	15,000	none
VIC018	Major Mitchell Lagoon	9	none
VIC022	Pink Lakes	393	none
VIC023	Raak Plain	550	none
VIC025	Wallpolla Island	9,200	none
VIC026	Wargan Basins (Meridian Lakes)	690	none
VIC032	Lake Hume	18,465	none
VIC033	Ryan's Lagoon	60	none
VIC034	Barmah-Millewa Forest #	29,500	yes[2]
VIC036	Broken Creek #	2,500	none
VIC037	Cemetery Swamp	89	yes[5]
VIC039	Fosters Swamp	219	yes[5]
VIC040	Gunbower Island	19,500	yes[3]
VIC041	Hird's Swamp	344	yes[5]
VIC042	Johnson's Swamp	411	yes[5]
VIC044	Kow Swamp ##	2,724	none
VIC046	Lake Charm	520	yes[5]
VIC047	Lake Cullen ##	632	yes[5]
VIC048	Lake Kelly & Stevensons Swamp	320	yes[5]
VIC049	Lake William	96	yes[5]
VIC050	Little Lake Charm, Kangaroo Lake & Racecourse Lake	1,332	yes[5]
VIC052	Lower Goulburn River Floodplain #	13,000	none
VIC053	Muckatah Depression #	2,909	none
VIC057	Third, Middle and Reedy Lakes	598	yes[5]
VIC058	Town Swamp	90	yes[5]
VIC059	Tragowel Swamp (McPhails Swamp)	262	none
VIC089	Lake Dartmouth	5,990	none
VIC123	Cardross Lakes	293	none
VIC131	Avoca Floodway (Tutchewop Plains)	484	none
VIC143	Mitta Mitta River **	2,320	none
VIC144	Ovens River ***	3,750	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.
[2] Barmah Forest Ramsar site, 28,515 ha.
[3] Gunbower Forest Ramsar site, 19,931 ha.
[4] Hattah-Kulkyne Lakes Ramsar site, 955 ha.
[5] Kerang Wetlands Ramsar site, 9,419 ha
[6] The Coorong, and Lakes Alexandrina and Albert Wetland, South Australia, Ramsar site, 140,500 ha.
[7] Riverland Ramsar site, 30,600 ha.
[8] Banrock Station Wetland Complex Ramsar site, 1375 ha.
[9] NSW Central Murray State Forests Ramsar site, 84,028 ha.
* Total wetlands (includes 16,150 ha for Lake Cowal when full and 4,355 ha for adjoining Lake Nerang Cowal).
** The river generally has a protected buffer zone of 200 m width on each side - length of reach is 60 km.
*** River corridor width is variable up to 2 km wide - length of reach is 52 km.
# also extend into the Goulburn-Broken region.
also extend into the Loddon-Avoca region.
Source: A Directory of Important Wetlands in Australia (Environment Australia, 2001).

2.3 Surface water resources

2.3.1 Rivers and storages

The Murray River flows in a westerly direction from its headwaters in the Great Dividing Range south of Khancoban. The lower Darling River flows from the Menindee Lakes and joins the Murray River at Wentworth in south-western New South Wales. The major tributaries of the Murray River are the Mitta Mitta, Kiewa, Ovens and Goulburn rivers, that flow in a northerly direction to the Murray River, and the Murrumbidgee River which rises in the Snowy Mountains near Cabramurra and joins the Murray River upstream of Euston in southern New South Wales.

Other tributary streams within the region include the Tooma River that flows into the upper Murray River, Billabong Creek in New South Wales and the Campaspe and Loddon rivers and Broken Creek in Victoria that all flow into the mid-Murray River between Echuca and Euston. The Edward and Wakool rivers are a major effluent system in New South Wales that also flow into the Murray River upstream of Euston. Murray River flows are also augmented by releases from the Snowy Mountains Hydro-electric Scheme.

The major storages include Hume Dam, Dartmouth Dam, Menindee Lakes and Lake Victoria. Hume Dam is located on the upper Murray River near Albury and has a storage capacity of 3038 GL. It was constructed in 1936 and was enlarged in 1961. Dartmouth Dam is located on the Mitta Mitta River upstream of Mitta Mitta and has a storage capacity of 3906 GL. It was constructed in 1979 and has a much smaller catchment than the Hume Dam.

The Menindee Lakes storage was constructed in 1968 around ephemeral lakes (with associated wetlands), has a capacity of 2050 GL and involves linked flows between some large lakes. Lake Victoria, located in far-west New South Wales, was constructed in 1925 around natural wetlands and has a storage capacity of 677 GL.

Flows and river heights within the Murray and lower Darling rivers are highly regulated throughout the late spring, summer and autumn each year. The Murray River is less regulated in the winter and early spring when the largely unregulated tributaries of the Kiewa and Ovens rivers provide more natural flow. Major weirs are located at Yarrawonga, Torrumbarry, Mildura and Wentworth. A series of locks are located within the Murray River downstream of Wentworth. River Murray Water, a business unit within the Murray-Darling Basin Commission, is responsible for managing river operations. Daily data relating to water levels and flow, storage levels, rainfall and evaporation, salinity and forecast demand are provided by agencies in New South Wales, Victoria and South Australia and used to facilitate operation of the river system. After consideration of downstream demands, losses and tributary inflows, releases are determined for each major water storage to provide efficient delivery of water for downstream consumptive, environmental, navigation, recreation and hydropower use.

In broad terms, water inflows are captured and stored in Dartmouth and Hume dams and Menindee Lakes. Water is preferably stored in Dartmouth Dam due to lower evaporation losses. Releases are made from Hume Dam and Menindee Lakes to meet daily demand. Water is transferred from Dartmouth Dam to Hume Dam when required to meet forecasted demand. Downstream river flows are captured in Lake Victoria to facilitate and regulate flows to South Australia. Menindee Lakes are used in preference to the upstream Murray River storages to supply water to the lower Murray in order to minimise river conveyance losses and in order to minimise evaporation losses from the Menindee Lakes. End-of-river flows are captured in Lake Alexandrina and Lake Albert and releases are made to the Southern Ocean via the operation of a series of barrages.

There are a number of regulated flow constraints to managing the Murray River system. Flow constraints within the Mitta Mitta River limit the transfer of water from Dartmouth Dam to Hume Dam to around 10 GL/day, flow constraints in the Murray River limit flows between Hume Dam and Lake Mulwala to 25 GL/day, downstream of Yarrawonga Weir the regulated flow constraint of the Barmah-Millewa Forest equates to a flow capacity of 10 GL/day. Other important constraints include the long travel times between the storage and point of diversion which may be in excess of four weeks for the lower Murray and the relatively low volumes of ‘en-route’ storage in the system. These aspects significantly influence system operations and decisions need to be made well in advance of the range of meteorological forecasts.

The Barmah Choke provides a major constraint to meeting the daily demand for irrigation during the summer and autumn period. A series of regulators have been constructed to restrict water flow into the Barmah-Millewa Forest to avoid unseasonal wetting during this period when the river water height is regulated at just below bank height. Murray Irrigation

Limited's channel system is used to bypass this section of river and augment river flows to meet downstream water demand.

Water releases are made based on demand forecasts provided by New South Wales, Victoria and South Australia for urban and irrigation use and for specific environmental flows. The return flows to the river from wetland areas, tributary inflows and irrigation infrastructure are re-regulated for downstream use wherever possible. This involves varying weir pools and storing water in Lake Victoria. The major points of water diversion for irrigation are at Yarrawonga Weir that diverts water for irrigation to southern New South Wales and northern Victoria and at Torrumbarry Weir that diverts water to northern Victoria. Water is also pumped directly from the Murray River by individual irrigators and smaller water supply schemes for irrigation and town water supply along the Murray and lower Darling Rivers in New South Wales, Victoria and South Australia. Water is drawn from the Murray River near Morgan in South Australia for Metropolitan Adelaide and associated country areas' urban water supplies and for industrial water supply purposes. This water is delivered through the Swan Reach-Stockwell, Mannum-Adelaide and Murray Bridge-Onkaparinga pipeline systems.

Snowy Hydro Limited manages several reservoirs in the upper parts of the MDB as part of its hydropower operations. It is required to release 1062 GL into the Murray River system annually, subject to water storage levels in the Snowy Mountains Hydro-electric Scheme and specific agreements made from time to time. Operation of the Scheme also provides capacity to transfer water between the Murrumbidgee catchment and the Murray catchment to meet downstream water demands and to enable water trade to occur between the two valleys. A number of regulators along the length of the Murray River manage flows into adjacent wetlands. These regulators are used to direct environmental flows to particular wetland areas or to exclude river flows from wetlands to avoid unseasonal wetting.

The capacity of on-farm water storage within the New South Wales and Victorian parts of the region is reported as 94 GL (Geosciences Australia, 2007). The capacity of on-farm storage in South Australia has not been estimated, however is considered to be small relative to the storage capacity within New South Wales and Victoria.

2.3.2 Surface water management institutional arrangements

The Murray-Darling Basin Commission is responsible for managing the water resources of the Murray and lower Darling rivers on behalf of Victoria, New South Wales and South Australia. The MDB Agreement (MDBC, 2006g) details how the waters of the Murray system, including the operation of the Menindee Lakes, are shared between the three states. In broad terms, the water resources that flow into the Murray River upstream of Doctors Point, including Dartmouth Dam, and the Kiewa River, are shared equally between New South Wales and Victoria. Victoria and New South Wales have respective rights to all tributary inflows downstream of Doctors Point except for the Darling River. Once storage levels within the Menindee Lakes reach a level of 640 GL the stored water is shared between New South Wales and Victoria. New South Wales have the right to the Darling inflows and the volume in storage when storage levels are below 480 GL and until they again reach 640 GL. The water sharing arrangements between New South Wales, South Australia and Victoria of water made available in the catchment of River Murray above Hume Dam by the Snowy Mountains Hydro-electric Scheme are detailed within Schedule G of the Agreement.

New South Wales and Victoria are required to provide predetermined monthly flows totalling 1850 GL to South Australia including a monthly dilution flow of 58 GL (MDBC, 2006g). Both upstream states are each required to maintain reserves in storage in excess of 1250 GL to meet future downstream requirements to ensure sufficient water is available to South Australia in the following year. Special accounting arrangements are detailed for the sharing of water between New South Wales, Victoria and South Australia when the reserves held by either New South Wales or Victoria are assessed to be less than 1250 GL at the end of May. Each of the three states is currently responsible for the management and seasonal allocation of their share of the water as assessed by River Murray Water in accordance with the MDB Agreement.

River Murray Water manages the operation of Dartmouth Dam, Hume Dam, the Menindee Lakes and Lake Victoria and all the weirs and locks of the River Murray system as detailed in the MDB Agreement. State constructing authorities own and staff the water supply storages and structures but overall operational control is directed by River Murray Water in accordance with the MDB Agreement and agreed operating procedures. For example: Goulburn-Murray Water operates Dartmouth Dam, Yarrawonga Weir (Lake Mulwala), Torrumbarry Weir and Mildura Weir; State Water in New South Wales operates Hume Dam and the Menindee Lakes; and the South Australian Water Corporation operates Lake

Victoria, the barrages on the Lower Lakes and the weirs and locks within the Murray river downstream of the New South Wales border.

Water in Victoria is managed under the Water Act 1989 (Victorian Government, 1989). In regulated river systems (where flow is controlled by major dams or weirs) the Victorian Government allocates water resources by bulk entitlements issued to rural and urban water corporations for consumptive use. These bulk entitlements include water allocated to individuals under licence, water shares, and supply by agreement. Unregulated systems (where there are no major dams or weirs on the river) provide about 2 percent of the water used for consumption in northern Victoria. Water from unregulated systems is allocated by licences to farmers for irrigation or domestic and stock purposes. In unregulated systems many individuals have a right to take water for domestic and stock use without a licence from a water source such as a catchment dam or groundwater bore. The Victorian Government has created an environmental water reserve, which is the amount of water set aside by law to meet environmental benefits. The environmental water reserve includes water held within statutory environmental entitlements. While it is described as environmental water, the environmental water reserve also provides for other community benefits that are dependent on the environmental condition of rivers.

Goulburn-Murray Water is the delegated resource manager and makes water allocations for all Murray water authorities and private diverters according to the water sharing arrangements set out in the Murray Bulk Entitlements. It is also the water authority that manages the Murray Valley and Torrumbarry Irrigation Areas and the Tresco, Nyah and Woorinen irrigation districts, and is the licensing authority for surface water upstream to Nyah. Lower Murray Water (formerly Sunraysia Rural Water Authority) manages Red Cliffs, Robinvale and Merbein irrigation districts, and is the licensing authority between Nyah and the South Australian border. The First Mildura Irrigation Trust is a private irrigation trust that supplies water for irrigation to an area adjacent to Mildura.

On July 1 2007, the Victorian Government ‘unbundled’ water rights for regulated systems in northern Victoria, giving individuals more flexibility to manage water as a valuable asset separate from land (DSE, 2007b). As a result, water rights have now been separated into three components:

- high-reliability water share: an entitlement to an ongoing share of water available from a particular supply source. This amount is equal to the previous ‘water right’
- share of delivery capacity: an entitlement to have water delivered to a property. This is equal to the previous delivery service
- water-use licence: a licence to use water for irrigation on a particular property (including any site-specific conditions on use).

Sales water for customers in the Northern Region of Victoria was also converted to low-reliability water shares on July 1 2007.

North East Water is responsible for urban water supply in the Kiewa valley and manages water supply to towns from Corryong to Yarrawonga. Goulburn Valley Water manages water supply to towns between Yarrawonga and Echuca, whilst Coliban Water supplies Echuca and towns downstream to Cohuna. Lower Murray Water supplies Kerang and downstream towns to the South Australian border.

Water within New South Wales is managed under the Water Management Act 2000 (NSW Government, 2000). The Act requires the implementation of ten-year plans defining water sharing arrangements between the environment and water users and amongst water user groups. These water sharing plans (WSPs) aim to protect rivers and aquifers and their dependent ecosystems, and to provide water users with clarity and certainty regarding water access rights. The Department of Water and Energy is responsible for implementation of the WSPs. State Water is responsible for water licensing and monitoring of use by irrigation authorities, individual licence holders and towns. A number of private water companies and trusts are responsible for water delivery to individual irrigators. These include West Corurgan Private Irrigation District near Corowa, Murray Irrigation Limited centred on Deniliquin and Western Murray Irrigation Limited located at Dareton in the far south-west.

Water access in New South Wales is based on a long-term average annual extraction limit. The basic rights (native title rights, domestic and stock rights) and access licences for stock and domestic 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 and high security has 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 (NSW Government, 1912) in areas where water sharing plans have not yet been gazetted.

The New South Wales water sharing arrangements for this region are contained in the Murray and Lower Darling Regulated Rivers WSP (DIPNR, 2006) and the Upper Billabong Unregulated Water Source WSP (DIPNR, 2004). The Murray and Lower Darling Regulated Rivers WSP applies to the Murray River water source which includes the water between the banks of all rivers from the upper limit of Hume Dam water storage downstream to the South Australian border and the lower Darling water source which includes all water between the banks of all rivers from the upper limit of Lake Wetherall downstream to the upper limit of the Wentworth weir pool (DIPNR, 2006).

Water resources within South Australia are managed under the Natural Resources Management Act 2004 (South Australian Government, 2004). This Act requires the South Australian MDB Natural Resources Management Board to prepare a water allocation plan under the Water Resources Act 1997 (South Australian Government, 1997) for each of the prescribed water resources in its area. A water allocation plan is a statutory instrument used for various purposes in the administration of the Act; in particular, to guide the granting of licences to take water, the transfer of a licence and/or water allocation and long-term, sustainable management of water resources. It sets the limit on the amount of water that can be taken and used for all purposes and in setting the limits it must consider the needs of both the environment and consumptive water uses. It must also consider the water resource's capacity and limits, the demands upon it and the potential impacts on the water resources. Implementation of the water allocation plan for the Murray River must support the state to fulfil its salinity and water diversion obligations to the Murray-Darling Basin Commission under the MDB Agreement (RMCWMB, 2007). The River Murray Water Allocation Plan covers the Prescribed Watercourse of the Murray River from the Victorian Border to the edge of Lakes Alexandrina and Albert and portions of Currency Creek, the Finniss River and the Angas and Bremer Rivers.

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

Table 2-3. Summary of surface water sharing arrangements

Water source plan		Victorian Murray	South Australian Murray	NSW Murray Water Sharing Plan - Murray	NSW Murray Water Sharing Plan - Lower Darling	Upper Billabong Water Sharing Plan
Water products	Priority of access	Allocated entitlement				
		ML/y				
Basic rights						
Stock and domestic rights		not stated	not stated for riparian landholders	2,100	3,700	0.55 ML/day
Native title		none	not stated	none	none	none
Extraction shares						
Total (long-term) extraction limit		1,640,000	724,100	2,014,000[9]	[9]	not specified
Local water utilities	high	57,795[1]	180,000	33,336	10,160	
Industrial	high		3,400			
Rural		2,059,823[2]	603,400			
Unregulated river licences		21,476[3]				
High security access	high			198,011 unit shares	7,999 unit shares	
General security access	medium			1,953,508 unit shares	30,288 unit shares	2,415
Supplementary access	low			252,361 unit shares	250,000 unit shares	
Conveyance - Murray Irrigation	high			300,000 unit shares	0 unit shares	
Stock and domestic	high		1,700	14,518	601	0.55[7]
Environmental provisions						[8]
Total environmental share		not stated		not stated	not stated	
Environmental entitlement	low and high	110,294[4]	5,600[10]	Up to 107,027[5]	30,000[6]	

Source for Victorian Murray: DSE, 2007c.
(1) Urban bulk entitlements: sum of bulk entitlements to Coliban Water, North East Water, Lower Murray Water and Goulburn Valley Water. In addition Goulburn-Murray Water is required to supply a number of urban centres from its channel system.
(2) Maximum of bulk entitlements to Goulburn-Murray Water, Sunraysia Water and First Mildura Irrigation Trust, including distribution losses.
(3) Unregulated river licences: Sum of individual licences including irrigation farm dams.
(4) Environmental Water Reserve for the Murray basin includes passing flows released as a condition of consumptive bulk entitlements held by North East Water and River Murray Water, the Barmah-Millewa Forest Environmental Water Allocation, the River Murray Flora and Fauna Reserve Bulk Entitlement of 27,600 ML, the Murray River - Snowy Environmental reserve of 7,694 ML and 75,000 ML for Barmah-Millewa, giving a total of 110,294 ML. In addition, there is water not allocated for consumptive use that is not included in this figure.
Source for New South Wales: DIPNR, 2006.
(5) The total environmental provisions include reserving all water above the annual extraction limit for the environment, up to 75,000 ML for the Barmah-Millewa Forest water reserve, and 32, 027 ML adaptive environmental water access licences.
(6) A reserve set aside for management of blue-green algae in the Lower Darling
(7) This includes licensed stock and domestic, local water utility and Aboriginal cultural access.
(8) The environmental flow provision for Billabong 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.
(9) This includes both the NSW Murray and lower Darling.
Source for South Australia: RMCWMB, 2004.
(10) In addition, up to 200 GL may be made available for wetland management in years when the flow to South Australia is at or below the South Australian Entitlement Flow pursuant to the Murray-Darling Basin Agreement 1992. An additional volume exceeding 200 GL may be made available for wetland management in years when the flow to South Australia is above the South Australian Entitlement Flow pursuant to the Murray-Darling Basin Agreement 1992.

The water use by each state is limited by the Murray-Darling Basin Ministerial Council Cap on Surface Water Diversions (MDBC, 2007a). The Cap, introduced in 1994/95 was designed to limit water use to the volume of water that would have been diverted under 1993/94 levels of development in recognition of the increasing demand on available water and the environmental impacts of the increasing levels of demand. It has been agreed that:

- For New South Wales and Victoria, the Cap is the volume of water that would have been diverted under 1993/94 levels of development.
- For South Australia, diversions are capped at the level that enables the development of its existing high security entitlements. This represents a small increase in diversions over 1993/94 levels of development and is equal to

the long term average of 90 percent of the amount of very high security licences that existed in 1993/94 (MDBC, 2004).

Annual Cap targets are calculated with climatically adjusted Cap models and then compared with annual diversions. Cap compliance is audited each year by an independent audit group who compare observed diversions with Cap targets that are determined by approved Cap models. The annual and cumulative difference between diversions and Cap targets are recorded as part of the annual Cap audit process. If the cumulative diversions since 1997/98 exceed the long term Cap (after taking into account any cumulative credits from lower annual diversions) by more than 20 percent, special audits are undertaken and the relevant state is required to advise the Ministerial Council what actions will be taken to bring the diversions back into balance with the Cap in the valley concerned. The long-term modelled Cap on surface water diversions is 1640 GL for the Victorian Murray, not including Kiewa and Ovens, 725 GL for South Australia including 180 GL for urban use and 2014 GL for the New South Wales Murray including the lower Darling (MDBC, 2007a).

2.3.3 Water products and use

There is extensive irrigation in the mid- and lower areas of the Murray region. Major irrigation development dates from the 1890s and early 1900s with the development of schemes at Renmark and Mildura. The construction of the Torrumbarry Weir in 1924, Hume Dam in 1928 (and its subsequent expansion in 1961), Yarrawonga Weir in 1939 and Dartmouth Dam in 1979 led to further irrigation development throughout the 1900s and particularly since the 1970s. The main irrigation areas are:

New South Wales

- Murray Irrigation Limited: area of operation located in the Finley/Deniliquin/Wakool region, covering 748,000 ha producing rice, winter cereals and dairying. Water is extracted at Yarrawonga Weir and Edward River and delivered to 2405 irrigation farms via over 3000 km of channels. Water entitlements in the area are 1614.3 GL of predominantly general security water and including 300 GL of conveyance water (Murray Irrigation Limited, 2007). Murray Irrigation Limited also holds a supplementary water access licence for which water can only be extracted in accordance with announcements made by the Department of Water and Energy.
- Western Murray Irrigation Limited: area of operation located near Dareton producing citrus and vines. The area includes the three pumped irrigation systems (Buronga, Coomealla and Curlwaa) and water is extracted directly from the Murray River. The area has a bulk entitlement of 61 GL of high security water and diverted an average 28.7 GL annually between 2003/04 and 2006/07 over approximately 4300 ha (Western Murray Irrigation, 2007).
- Other small schemes including West Corurgan and Moira as well as a number of private diverters located along the Murray River downstream of Hume Dam and along the Darling River downstream of Menindee Lakes producing horticulture, pastures and winter grain crops.

Victoria

- Murray Valley Irrigation Area: extends from Yarrawonga in the east to Barmah in the west, covering 128,372 ha of which 88,969 ha is irrigated with dairying being the most common enterprise. Water is diverted at Yarrawonga weir and delivered to 1483 irrigation holdings via a 962 km channel system. Water entitlements in the area are 246 GL of high reliability water shares.
- Torrumbarry Irrigation Area: extends along the Murray River from Gunbower in the east to Nyah in the west and includes the Cohuna/Kerang area, covering 167,000 ha of which 150,000 ha is suitable for irrigation producing dairying around Cohuna and mixed grazing and cropping around Kerang. Water is diverted at Torrumbarry weir and delivered to 2650 irrigation farms and 600 stock and domestic users. Water entitlements in the area are 362 GL of high reliability water shares.
- Lower Murray Water Operating Area: located along the Murray River from Nyah to the South Australia border including the three pumped irrigation areas of Merbein, Red Cliffs and Robinvale producing citrus and vines. Water is pumped from the Murray River. Water services are provided to 1350 irrigation customers and 305 stock users. Water entitlements in the area are 307 GL of high reliability water shares for diverters from the river and 99 GL of high reliability water shares for the irrigation districts. Lower Murray Water also supplies water to 14 townships along the Murray River from Kerang to Mildura (LMW, 2007).

- Other small schemes: including Nyah and Tresco and First Mildura Irrigation Trust that primarily produce horticulture.

South Australia

- The South Australian region is separated into three irrigation zones: River Murray Irrigation Zone which spans upstream from Mannum to the SA border, the Lower Murray Reclaimed Areas Irrigation Management Zone between Mannum and Lake Alexandrina and the Angas Bremer Irrigation Management Zone which is located on the western side of Lake Alexandrina and includes the Langhorne Creek wine growing area. This zone draws water from Lake Alexandrina.
- Lower Murray Reclaimed Areas Irrigation Management Zone: 67.3 GL is allocated for irrigation and a further 22.2 GL is allocated for environmental land management purposes to manage salinity. There is an additional 9.3 GL allocated for irrigating highland areas associated with the Lower Murray but within the River Murray Irrigation Management Zone. There is a total of 522 GL allocated for irrigation, industrial, stock and domestic purposes in the irrigation zones other than the Lower Murray Reclaimed Areas Irrigation Management Zone.
- The Riverland Region: area of operation spanning from Renmark to Waikarie, producing vines and citrus. Central Irrigation Trust situated at Barmera manages a bulk entitlement of 151.4 GL of South Australia high security water on behalf of nine Irrigation Trusts and pumps water from the Murray River to supply 1600 growers who irrigate 13,824 ha (CIT, 2007). Golden Heights Irrigation pumps water to 750 ha and Sunlands Irrigation Trust Inc pumps water to 795 ha (DEWHA, 2007). Renmark Irrigation Trust has a bulk entitlement of 47.9 GL which is used to irrigate 5238 ha (Sunraysia Mallee Economic Development Board, 2005). In addition there are also private irrigation diversions direct from the Murray River.
- There is 180 GL allocated for metropolitan Adelaide and associated areas and country towns. Of this, 650 GL is allocated for water supply purposes delivered to metropolitan Adelaide and associated country areas through the Swan Reach-Stockwell, Mannum-Adelaide and Murray Bridge-Onkaparinga pipeline systems over any period of five consecutive water use years.

The South Australian water use is much lower than the use within New South Wales and Victoria, however the South Australian entitlement has a much higher level of security as a result of the inter-state water sharing arrangements. Dilution flows of 696 GL/year are provided from the upstream storages to ensure that the water quality in the lower reaches of the River Murray remains within the limits detailed within the MDBC Basin Salinity Management Strategy (MDBMC, 2001). In addition, approximately 1000 GL/year is released from the upstream storages to meet river operation needs and river losses to ensure delivery of the water released for diversion by South Australia, and the downstream regions of New South Wales and Victoria.

The water use for 2000/01 was estimated to be 4684 GL or 39 percent of the total surface water use within the MDB. Surface water diversions within the region have ranged from a high of 4819 GL in 1994/95 to 2651 GL in 2006/07 (Figure 2-3). This decline is a reflection of the reduced water availability that has resulted from lower rainfall and runoff conditions within the storage catchments.

The level of security of the water entitlements within the Murray region varies across each state. In South Australia all rural entitlements are classified as high security, in Victoria around 70 percent of the rural entitlements are high reliability and in New South Wales less than 15 percent of the entitlements are classified as high security. As such, annual water use is more stable in South Australia and to a lesser degree Victoria. New South Wales water allocation policy has involved providing sufficient reserves to protect future high security users needs and then allocating all the water available for consumptive use in any one year. While this has resulted in a higher long-term average annual use, use has varied widely from year to year. The agricultural systems that predominate in each state reflect the annual water security. Irrigation in New South Wales is predominantly used for annual farming systems, South Australian irrigation is almost entirely used for permanent horticulture and Victoria has historically used its irrigation water for horticulture, summer pasture-based dairying supplemented with annual pastures and winter grain cropping.

The security of the respective water licence classes is determined by the allocation processes which apply within each jurisdiction. Until recently New South Wales has been the only state to allow individual licence holders to carry water over from one year to the next. This is considered to be an important Cap management tool and provides individual licence holders with the ability to manage their own level of risk of seasonal water availability.

Water is actively traded both within the Murray region between licence holders within specific geographic zones and between Murray, Goulburn and Murrumbidgee licence holders, particularly in years when the Murray River allocations are relatively low. Historically annual water trade has been dominated by the trade of high security water from South Australia and New South Wales to above the Barmah Choke. Water trading that will result in a transfer of water use from above the Barmah Choke to downstream of the Barmah Choke has not been permitted. As a result of the recent exceptional circumstances trading has been allowed below the Barmah Choke.

The volume of annual or temporary trade has far exceeded the volume of permanent water trade annually with temporary trade being around 90 to 95 percent of the total annual trade. Interstate and intrastate permanent trade has increased in recent years, particularly in the downstream districts of the Victorian Goulburn and Murray areas to the upstream Victorian Goulburn and Murray districts, South Australia and New South Wales.

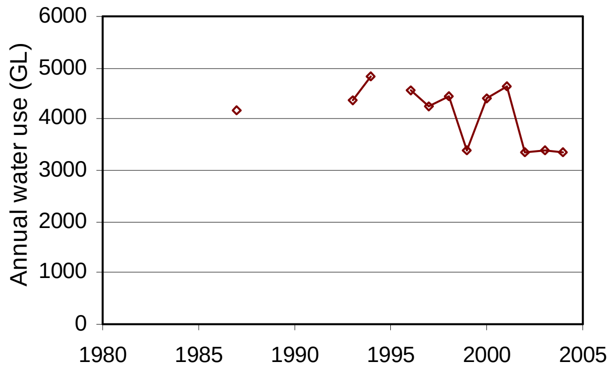

Figure 2-3. Historical surface water diversions

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. Source: MDBC, 2007b.

2.4 Groundwater

2.4.1 Groundwater management units – the hydrogeology and connectivity

The Murray region incorporates equivalent geological units in the Murray Geological Basin and the Darling River Drainage Basin and may be subdivided into three sections: the Murray Uplands; the Riverine Plain; and the Mallee and Lower Lakes.

Murray Uplands

The Murray Uplands extends from the headwaters of the Murray River to Yarrawonga. Groundwater occurs in fractured rock landscapes of the upland regions in a range of different geologies with local and intermediate groundwater flow systems. These aquifers form important water sources in the eastern portion of the Murray Valley. Fractured rock basement constitutes the ‘floor’ of the Murray Basin. It underlies the basin and also outcrops in the surrounding highland areas. Significant runoff from these areas contributes an important component of recharge to the basin sediments. Groundwater quality of the Upper Murray Highlands is generally very good, however these consolidated sediments have low permeability and groundwater use is typically restricted to stock and domestic purposes.

A series of valleys eroded into the fractured rock basement are infilled with significant deposits of alluvial sediments. These are referred to as the Lachlan Formation and the Cowra Formation. The Upper Murray Alluvium (N15) and Mullindolingong (V35) groundwater management units (GMUs) cover the Cowra and Lachlan formation sediments. The Cowra Formation is comprised of alluvial channel sands and floodplain clays. It occurs in close association with the Lachlan Formation and overlies its entire extent. Groundwater extraction from the Cowra Formation is limited due to low yields and is largely utilised for stock and domestic purposes. The Cowra Formation is estimated to receive a large amount of recharge from stream leakage and flood-induced recharge.

The Lachlan Formation is comprised of coarse alluvial sands and gravels. It occurs in the base of valleys of the Upper Murray River and Billabong Creek. In these areas water quality is fair to good and the Lachlan Formation provides useful supplies of groundwater for irrigation and town water. Recharge of the Lachlan Formation is via leakage from the Cowra Formation and increased withdrawal from the Lachlan Formation is likely to induce recharge from the overlying sediments and cause increased induced stream leakage. Rainfall recharge occurs in outcrop areas.

Riverine Plain

The Riverine Plain extends from Yarrawonga to Swan Hill. The Renmark Group is the basal aquifer within the Riverine Plain. It is composed of alluvial sands and gravels with inter-bedded carbonaceous clay-rich units. The Renmark Group is hydraulically connected with the overlying Calivil Formation and contains fresh water within most of this part of the MDB. It is used for irrigation across the Riverine Plain except in the western parts of the region where groundwater salinity is too high.

The Calivil Formation was deposited as an alluvial sequence of river channel sands and clays above the Renmark Group. The Calivil Formation grades into the marine sands of the Loxton-Parilla Sands to the west. The Calivil Formation is up to 80 m thick and consists of quartz sand and gravel. It yields large volumes of high-quality groundwater, although the salinity of groundwater in the Calivil Formation increases in the west where it meets the Loxton-Parilla Sands. In the Katunga Water Supply Protection Area (WSPA) (V39) and the Lower Murray Alluvium (N16) GMUs the Calivil Formation is the primary aquifer used to provide irrigation water supply.

The Shepparton Formation overlies the Calivil Formation and usually forms the watertable aquifer in the Riverine Plains. It is composed of river and lake deposited sediments. The clay-rich nature of the formation means it is characterised by low transmissivities. Water quality in the Shepparton Formation is variable and it is sometimes used for irrigation of crops, particularly from shallow prior stream deposits in the Shepparton region.

Groundwater in the Shepparton Formation is generally saline and there is a risk from rising saline water tables due to irrigation accessions. Within Victoria controls for groundwater contained within the shallower parts of the Shepparton Formation are set out in the Shepparton Irrigation Region Catchment Strategy (GBCMA, 2007). The strategy is designed to protect the region’s agricultural and natural resources from salinity by regular pumping of groundwater to provide salinity control, encouraging groundwater use within salinity limits which are designed to promote sustainable land and water management practices. Similarly the Murray Land and Water Management Plans (Murray Irrigation Limited, 2006) in the New South Wales mid-Murray area detail a series of works and measures to improve water use efficiency, minimise groundwater recharge and manage groundwater levels.

There are two significant water planning areas within the riverine plains:

- the Katunga WSPA in Victoria
- the Lower Murray Alluvium downstream of Corowa in New South Wales.

The Katunga WSPA GMU (V39) is located in Victoria approximately between Cobram and north of Shepparton. The Katunga WSPA management plan governs groundwater extraction from the Calivil Formation and Renmark Group that are related to the Goulburn Deep Lead. This is overlain by the Shepparton Formation, which is governed by the Shepparton WSPA GMU (V43).

The Lower Murray Groundwater Sharing Plan (DIPNR, 2006) applies to the Lower Murray Alluvium GMU (N16) (downstream of Corowa) in the region surrounding Deniliquin. It applies to groundwater contained in the Calivil, Renmark and Lower Shepparton alluvial aquifers within the region.

Mallee and Lower Lakes

The Mallee and Lower Lakes section encompasses the area downstream of Swan Hill. Around the margins and extending beneath it are a range of geologies including metamorphic and consolidated sediments that form fractured rock aquifers including: the Barrier Ranges, the Olary Ranges and the northern Mount Lofty Ranges. GMUs that represent fractured rock aquifers include the New South Wales GMUs of the Kanmantoo Fold Belt (N817) and the Adelaide Fold Belt (N818).

Drainage has eroded the fractured rock aquifers in the upland areas of the Barrier, Olary and northern Mount Lofty Ranges and deposited alluvial clays and gravels that comprise the Quaternary Formations. These sediments are clay-rich and are generally low-yielding but may contain useful quantities of good quality groundwater retained in small pockets of alluvial channel sands. Groundwater is generally used for stock and domestic supplies.

The Renmark Group contains the basal aquifer within the sedimentary basins of the Mallee and Lower Lakes. It is composed of alluvial sands and gravels with interbedded carbonaceous clayey units. Although generally not used as a source of groundwater due to availability of better quality groundwater in the overlying Murray Group Limestone, the Renmark Group is used around the margins of the basin such as on the coastal plains region of the Lower Lakes and within the Peake, Roby and Sherlock Prescribed Wells Area (PWA) GMU (S53). The Renmark Group is also the main supply aquifer in the Kaniva GMU (V51).

In the west of the region the Murray Group Limestone overlies the Renmark Group and extends across the western portion of the Murray Basin. It becomes thinner to the east with the margin forming an approximate arc from Dimboola in the south through Hopetoun and Ouyen towards the Murray River in the north. The Murray Group Limestone is the primary aquifer in the western part of the region supporting town water supplies and potato, olive and pistachio crops. It is the major aquifer in the Murrayville WSPA (V49), Telopea Downs (V50), Mallee Prescribed Water Resources Area (PWA) (S20) and the SA-Vic Border PWA. This aquifer becomes too saline for use in regions closer to the Murray River.

The Loxton-Parilla Sands overlie the Murray Group and consist of fine to coarse sands. The Loxton-Parilla Sands form the watertable aquifer in the central part of the Mallee region. The groundwater salinity increases to the north from 1500 mg/L near Pinnaroo where usage is limited to several stock bores to an average of 35,000 mg/L near Renmark.

The Murray Trench commences near Swan Hill and represents the course taken by successive Murray River systems across the Mallee region to the coast in South Australia. The alluvial sequences within the trench consist of a mixture of coarse sand point-bar sediments grading upwards to finer grained floodplain sequences. The basal unit is referred to as the Channel Sands Aquifer and it is intermittently hydraulically connected to the underlying and adjacent saline aquifers. Saline groundwater from the deeper Loxton-Parilla Sands aquifer can discharge over large areas into the Channel Sands and from there to the river. Some of these saline inflows to the river are intercepted by salt interception schemes such as the Waikerie, Woolpunda and Mildura-Merbein schemes.

In New South Wales the Western Murray Porous Rock GMU (N612) relates to all major sedimentary aquifers in the region including the Renmark Group, the Calivil Formation/Loxton-Parilla Sands and the Shepparton Formation.

Summary of groundwater management units

The location of GMUs within the Murray region is shown in Figure 2-4. The degree of development of the groundwater source in each GMU and the unincorporated areas varies considerably between areas of intensive extraction for irrigation to areas of broad scale stock and domestic use. The GMUs in the region are assessed as very high to very low priority in the context of the overall project on the basis of the size of the aquifers, the level of development and the assumed degree of connectivity with the surface water system. The priority ranking provides a basis for focussing efforts to those aquifers affecting most the total resource across the MDB. There are large areas of South Australia and Victoria that are not part of a GMU and these areas are referred to as unincorporated areas.

The Murray region also contains portions of a number of other GMUs (shown on Figure 2-4) that are assessed in other region reports:

- the Lower Lachlan Alluvium GMU (N12), assessed as part of the Lachlan region
- the Lower Murrumbidgee Alluvium GMU (N02), assessed as part of the Murrumbidgee region
- the Barnawartha GMU (V36), assessed as part of the Ovens region
- the Kialla (V40) and Shepparton WSPA (V43) GMUs, assessed as part of the Goulburn-Broken region
- the Eastern Mount Lofty Ranges (S14) and Marne-Saunders (S23) GMUs, assessed as part of the Eastern Mount Lofty Ranges region.

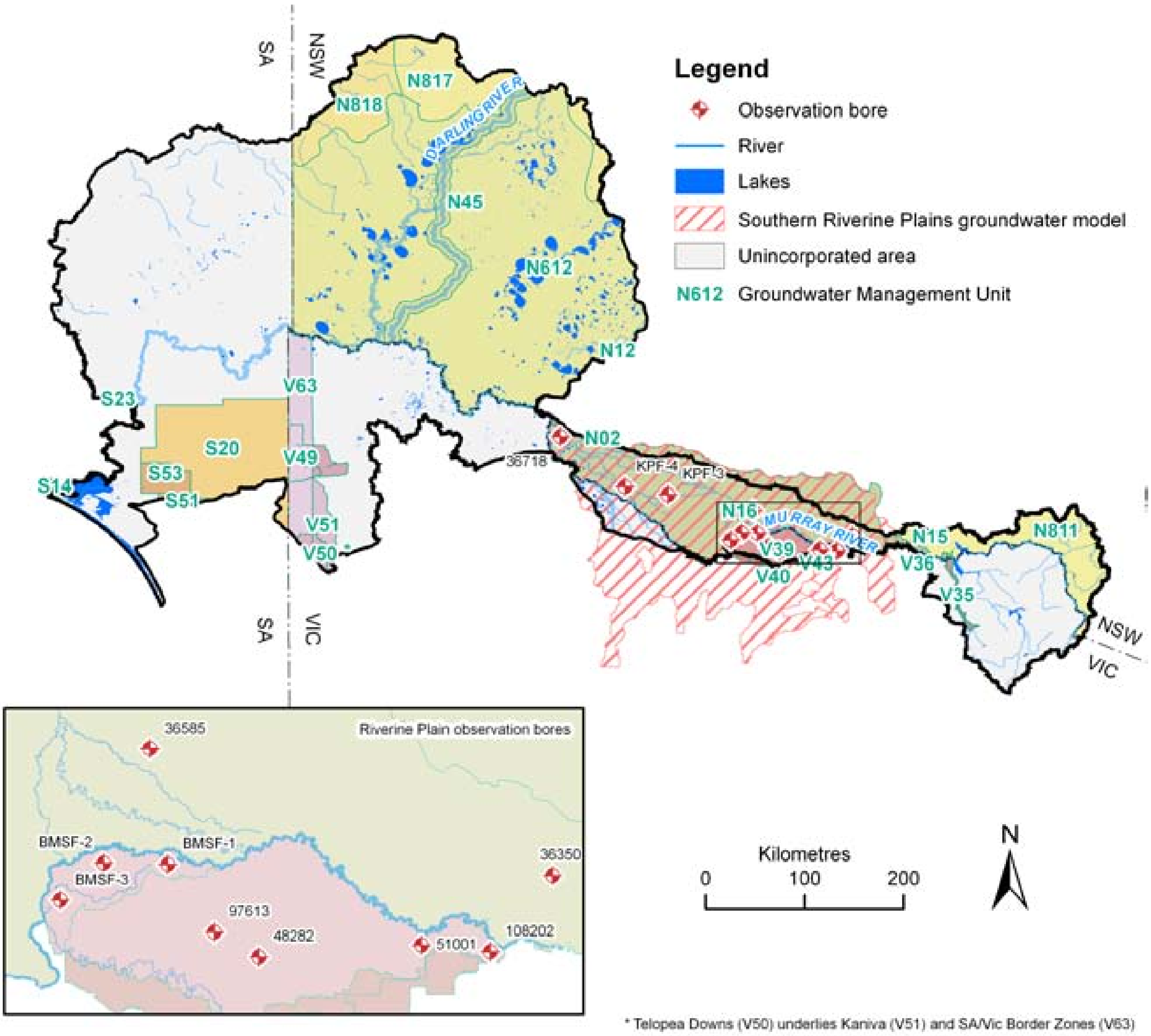

Figure 2-4. Map of groundwater management units in the Murray region showing the extent of the Southern Riverine Plains groundwater model and locations of key indicator bores, with inset showing locations of key indicator bores on the Riverine Plain

Current groundwater extraction, entitlement and recharge data are itemised for each GMU in the Murray region in Table 2-4. Current extraction includes stock and domestic estimates for New South Wales and Victorian GMUs. South Australia stock and domestic estimates for GMUs have been reported separately.

Table 2-4. Categorisation of groundwater management units considered in the Murray region, including annual extraction, entitlement and recharge details

Code	Name	Priority	Assessment	Current extraction (2004/05)	Extraction Limit[1]	Recharge
					GL/y	
N15	Upper Murray Alluvium	very high	simple	[2]30.5	[2]38.6	3.9
N16	Lower Murray Alluvium (Calivil and Renmark)	high	thorough	[2]73.9	[3]83.7	83.7 (plus basic landholder rights)
na	Lower Murray Alluvium (Shepparton)	na	na	18.0	59.9	na
N45	Lower Darling Alluvium	low	simple	[2]2.0	[2]9.3	18.6
N612	Western Murray Porous Rock	low	simple	[2]4.5	[2]663.8	948.3
N811	Lachlan Fold Belt	low	simple	[2]5.2	[2]69.4	138.9
N817	Kanmantoo Fold Belt	very low	simple	[2]0.3	[2]36.0	60.1
N818	Adelaide Fold Belt	very low	simple	[2]0.9	[2]30.4	43.5
V35	Mullindolingong GMA	very low	simple	[4]1.2	7.0	[5]na
V39	Katunga WSPA	medium	thorough	[4]27.4	46.5	[6]27.7
V49	Murrayville WSPA	very low	simple	[4]0.6	10.9	[7]1.8
V50	Telopea Downs	na	simple	[4]0.7	7.5	[7]2.8
V51	Kaniva	very low	simple	[4]0.0	3.7	na
S20	Mallee PWA	low	simple	14.9	[5]52.8	[8,9]6.7
S50	Noora PWA	very low	simple	na	[6]5.1	na
S53	Peake, Roby & Sherlock PWA	na	simple	1.1	na	na
V63	South Australia–Victoria Border Zone PWA	na	simple	24.8	[7]55.0	na
na	Upper Murray unincorporated areas	na	simple	2.3	None set	78.0
na	Kiewa unincorporated areas	na	simple	0.9	None set	17.8
na	Salt interception schemes	na	na	23.3	na	na
na	Vic stock and domestic	na	na	0.2	na	na
na	SA stock and domestic (Mallee. Noora, Peake-Roby-Sherlock)	na	na	0.7	na	na

na – not applicable
[1] Extraction limit refers to:

- New South Wales long-term annual extraction limit
- Victorian licensed entitlement
- South Australian allocation.

[2] Sourced from data supplied by New South Wales Department of Water and Energy.
[3] Source: DIPNR, 2006.
[4] Source: DSE, 2006.
[5] Mullindolingong GMA recharge has been calculated as part of the Kiewa Unincorporated Area.
[6] Recharge to the Katunga WSPA is taken from the Southern Riverine Plains model and includes all forms of recharge in addition to rainfall infiltration.
[7] The aquifers utilised in the Murrayville WSPA and Telopea Downs are confined and recharge estimates do not include rainfall infiltration but represent lateral groundwater flow recharge.
[8] Source: MWRPC, 2000.
[9] Recharge value from Figure 7 Mallee PWA water allocation plan incorporating upward leakage, lateral inflow and infiltration recharge.
[10] Source: RMCWMB, 2001.
[11] Source: BGARC, 2006.

2.4.2 Surface–groundwater connectivity

The Murray River contains losing and gaining river reaches (Figure 2-5). Variation from reach to reach is likely to be due to a combination of river regulation, floodplain groundwater flow processes and the influence of irrigation development near the river. The connectivity mapping undertaken as part of this assessment found that:

- upland tributaries to the Murray River are typically gaining at low rates as groundwater moves down gradient from bedrock highlands
- the river becomes losing on the alluvial plain leading up to Lake Mulwala
- the river is approximately hydraulically neutral in the vicinity of the convergence of the Murray and Ovens rivers
- downstream of Lake Mulwala there is a significant stretch of river under gaining conditions

- between Tocumwal and upstream of the Goulburn River junction the river is 'medium losing'
- where the Goulburn and Campaspe rivers converge with the Murray River the river is 'low gaining'
- the river becomes 'medium losing' downstream of Torrumbarry Weir
- the section between Barham and Swan Hill is highly variable reflecting groundwater highs and lows related to irrigation development and river regulation
- from Swan Hill to Wakool Junction the river alternates between 'low gaining' and 'low losing'
- downstream of the analysed area, in the lower Murray, the river is likely to be gaining.

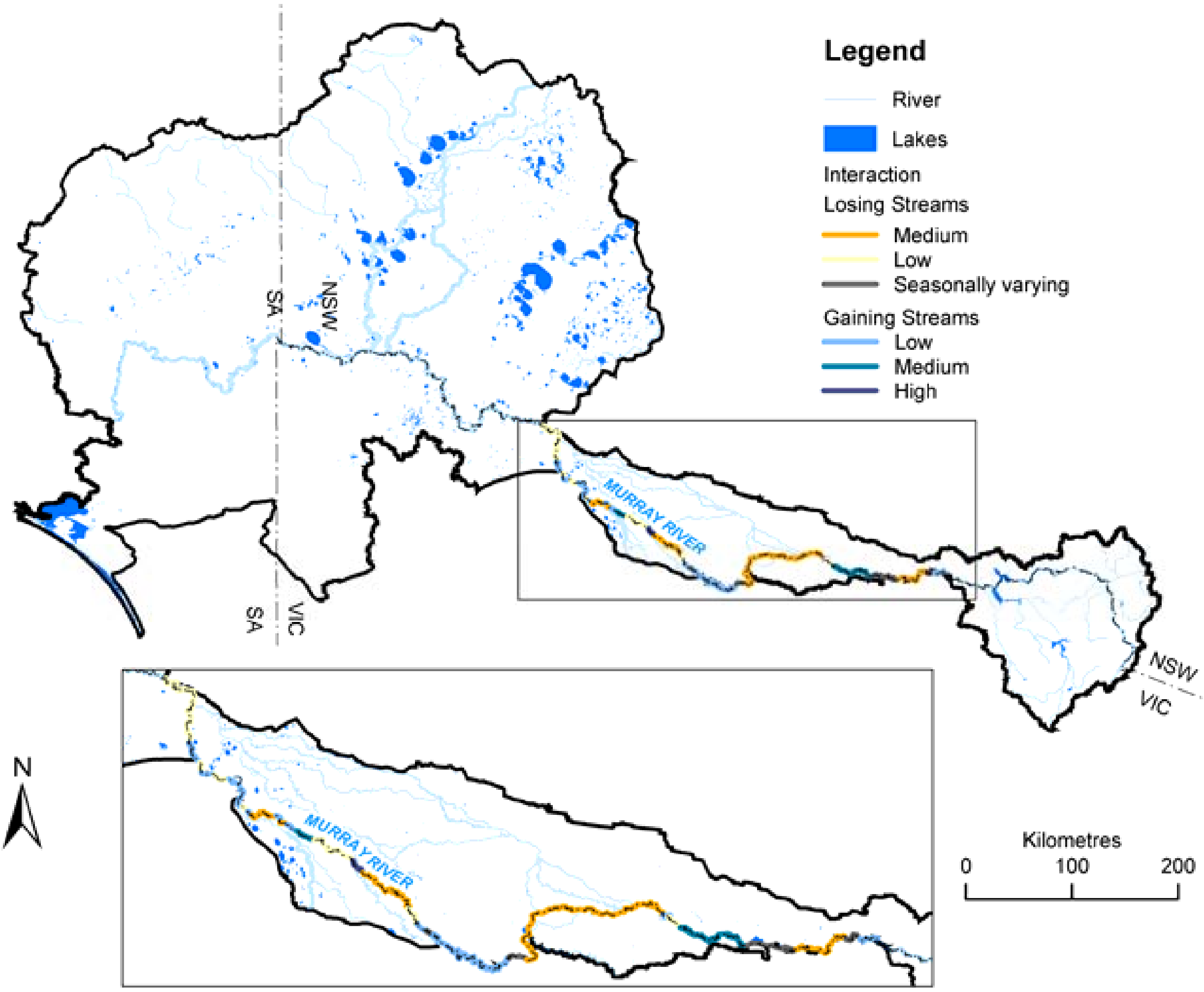

Figure 2-5. Map of surface water–groundwater connectivity

2.4.3 Salt interception schemes

Salt interception schemes operate and/or are being built along the southern parts of the Murray River to intercept saline groundwater that would otherwise discharge to the river. The majority of schemes are in the Sunraysia area near Mildura in Victoria and New South Wales, and between Waikerie and Renmark in the South Australian Riverland. The interception schemes generally use deep bores constructed alongside the river to pump saline groundwater away from the river to disposal basins.

Groundwater extraction rates from all current and future interception schemes along the Murray River upstream from Morgan (Figure 2-6) are summarised in Table 2-5 and Figure 2-7. For the period 2004/05 an estimated 23 GL of saline groundwater was extracted by these schemes. Likely extraction of saline groundwater in the year 2030 from existing schemes and schemes under construction will be about 32 GL/year. Figure 2-7 displays the history of the total volume of water pumped by interception schemes in the MDB. The largest contributor to the cumulative volume is the drainage interception scheme at Barr Creek. Generally Barr Creek and similar schemes (such as Noora Disposal Scheme, Curlwaa Scheme, Lake Hawthorn Drainage Diversion Scheme and Psyche Bend Drainage Diversion Scheme) intercept irrigation drainage and storm water runoff rather than groundwater directly. In the case of Barr Creek some of the drainage water is sourced from regional groundwater. The largest interception schemes are those at Woolpunda and Waikerie.

Table 2-5. Summary of salt interception scheme current and future groundwater extraction volumes for the Murray River upstream of Morgan.

Scheme Ref Number[1]	Groundwater interception scheme	2004/05 volume pumped groundwater	2030 estimated volume pumped groundwater	Status
		GL/y		
1	Waikerie	4.3	3.3	existing scheme
2	Woolpunda	5.3	4.8	existing scheme
4	Bookpurnong	na – commissioned 2006	1.7	existing scheme
5	Rufus River	0.8	1.1	existing scheme
6[2]	Curlwaa	0.4	0.4	existing scheme
8	Buronga	1.6	3.0	existing scheme
10	Mildura-Merbein	1.9	3.0	existing scheme
11	Mallee Cliffs	2.7	3.0	existing scheme
12	Barr Creek Drainage Diversion Scheme	6.8	6.0	existing scheme
13	Pyramid Creek	na – commissioned 2006	1.9	existing scheme
na	Murtho	na	1.9	scheme under construction – SA
na	Loxton	na	1.8	scheme under construction – SA
na	Waikerie 2L	na	0.7	scheme under construction – SA
na	Dareton	na	1.5	possible new scheme – NSW
na	Redcliffs	na	5.0	possible new scheme – Vic
na	Pike River	na	2.0	possible new scheme – SA
	Total	**23.3**	**40.7**	

na – not applicable
[1] Salt interception schemes; 3 (Noora Disposal Scheme), 7 (Lake Hawthorn Drainage Diversion Scheme) and 9 (Psyche Bend Drainage Diversion Scheme) do not pump groundwater. Generally these schemes intercept irrigation drainage and storm water run-off (pers comm. Phil Pfeiffer MDBC).
[2] The Curlwaa scheme (6), a state scheme, is a tubewell system that was installed to provide both agricultural drainage and reduction of salt accessions to the River Murray from the irrigation induced groundwater mound under the Curlwaa irrigation development.

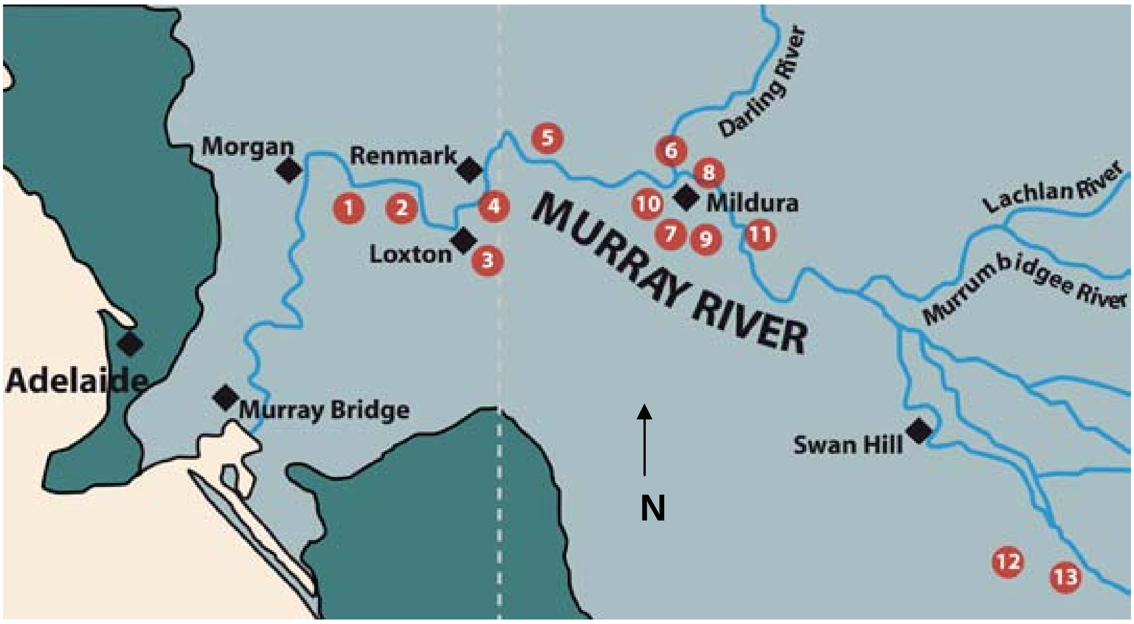

Figure 2-6. Location of salt interception schemes in the Murray Region (from MDBC, 2007c)

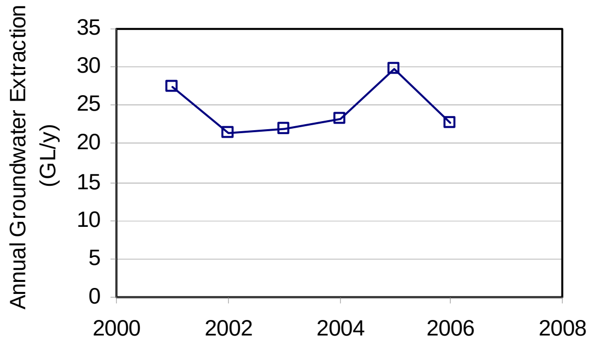

Figure 2-7. Total annual groundwater extraction from salt interception schemes in the Murray region

2.4.4 Water management institutional arrangements

There is a range of groundwater management arrangements in place in all three jurisdictions across the region. The Water Management Act 2000 (NSW Government, 2000) in New South Wales requires the implementation of ten-year plans defining water sharing arrangements between the environment and groundwater users and amongst water user groups in a similar way to that required for surface water diversions. Water sharing plans have been prepared for the more highly developed GMUs to protect rivers and aquifers and their dependent ecosystems, and to provide water users with clarity and certainty regarding water access rights. Where current extraction levels exceed the long-term extraction limit a supplementary access volume has been determined. This access volume will decrease to zero within ten tears of commencement of the water sharing plan. Groundwater extraction in the New South Wales portion of the region not under a WSP will be controlled by New South Wales Groundwater Macro Sharing Plans when enacted. These will provide an extraction limit and environmental requirements. The annual extraction limit is set as a proportion of recharge to the system. The macro planning process does not discount the extraction limit for salinity. As such, the limits reflect groundwater availability in volumetric terms only. The environmental provisions are 30 to 50 percent of the rainfall recharge. The macro groundwater sharing plans are intended to commence in 2009.

The water sharing plan for the New South Wales Lower Murray Groundwater Source (DIPNR, 2006) was enacted in 2006. It applies to all water contained in the Calivil, Renmark and the Lower Shepparton unconsolidated alluvial aquifers deeper than 12 m within the declared area. The estimated volume of recharge within this aquifer is 83.7 GL/year (plus basic landholder rights). The plan allows for Access Licences up to 83.58 GL/year with a supplementary provision initially of 48.5 GL/year reducing to zero GL/year by 2015. An environmental provision of water above the long-term average annual recharge to this groundwater source minus basic landholder rights is provided. A stock and domestic right of 1.5 GL/year is provided. Permanent and temporary trade in groundwater has been introduced in this plan.

In Victoria state legislation broadly controls groundwater extraction within the Victorian portion of the region outside WSPAs. There are provisions that allow for declaration of WSPAs (and implementation of groundwater management plans) where there is a threat from increasing rates of groundwater extraction.

In addition, the South Australia/Victoria Groundwater Border Agreement (MDBC, 2006h) seeks the cooperative control of groundwater extraction along the border between the two states. The border agreement applies to the groundwater resources in a 20 km wide strip covering both sides of the South Australia/Victoria border.

The Katunga Water WSPA in Victoria has a declared permissible consumptive volume of 59.8 GL/year (equivalent to current entitlements for this GMU). There are 184 licensed groundwater users within the Katunga WSPA and the 2004/05 extraction rate was 27.4 GL/year of which 20 ML is an estimate from unmetered bores. The groundwater management plan (GMW, 2006) for the Katunga WSPA limits the amount of groundwater extracted under all groundwater licences to ensure that the groundwater resources are managed sustainably. Seasonal allocation percentages are determined annually. Rights to stock and domestic supplies are not currently restricted. Seasonal allocations are based on average usage over five years (not exceeding 30 GL/year). The proposed allocations are subject to review if levels fall below levels in 2002/03. There are 593 stock and domestic bores in the Katunga WSPA using an estimated 1.2 GL/year of groundwater.

The Murrayville WSPA in the Victorian Mallee has a declared permissible consumptive volume of 10.9 GL/year (equivalent to the extraction limit for this GMU). There are 33 licensed groundwater users within the Murrayville WSPA and the 2004/05 extraction rate was 0.6 GL/year. A limit has been placed on the amount of groundwater extracted from the Murrayville WSPA under all groundwater licences based on taking water from groundwater storage, as there is limited or negligible recharge.

Water resources in South Australia are managed under the Natural Resources Management Act 2004 (South Australian Government, 2004). This Act requires the South Australian MDB Natural Resources Management Board to prepare a water allocation plan for each of the prescribed water resources in its area. This plan is a statutory instrument that is used for various purposes in the administration of the Act; in particular, to guide the granting of licences to take water, the transfer of a licence and/or water allocation and long-term, sustainable management of water resources.

The water allocation plan for South Australia's Mallee PWA has a permissible annual volume of 52.8 GL/year which exceeds the rate of recharge to the PWA. Limited mining of the groundwater resource is permitted on the basis that the future salinity of the groundwater will deteriorate as salt within the unsaturated zone leaches to the aquifer irrespective of groundwater extraction and so benefits from use of groundwater should be realised before the resource becomes too saline for use. The future likely demand in good quality water regions has been considered within this plan. No groundwater dependent ecosystems were identified and specific provisions for the environment are not made explicitly. A groundwater supply of 0.7 GL/year has been allowed for stock and domestic purposes.

Water sharing planning arrangements are summarised in Table 2-6.

Table 2-6. Summary of groundwater management plans

Description	Katunga WSPA	Lower Murray Alluvium (N16)	NSW Macro Groundwater Sharing Plans	Murrayville WSPA	Kaniva WSPA	Telopea Downs WSPA	SA/Vic Border PWA	Noora PWA	Mallee PWA
Year of plan	2006	2004	2007	2001	1997	2001	1986	2001	2000
Environmental provisions									
Planned share	Environmental provisions met from aquifer storage	none	30-50% of rainfall recharge	Investigated in the development of the management plan	Investigated in the development of the management plan	Investigated in the development of the management plan	none	none	none
Supplementary provisions	Investigated in the development of the management plan	48.48 GL/y falling to zero in 2015	One conditional minimum requirement	Investigated in the development of the management plan	Investigated in the development of the management plan	Investigated in the development of the management plan	none	none	none
Adaptive provisions	Investigated in the development of the management plan	Taken as required	none	Investigated in the development of the management plan	Investigated in the development of the management plan	Investigated in the development of the management plan	none	none	none
Basic rights									
	GL/y								
Stock and domestic	1.2	1.5	6.9	0.5	0.0	0.2	none	<0.1	0.7
Native title	none	0	none	none	none	none	none	none	none
Access licenses									
	GL/y								
Urban	none	0.1	0.1	0.2	none	none	none	none	0.5
Planned share	59.8 (adjusted seasonally)	83.6	53.5	10.9	3.7	7.5	55 (2)	5.1	52.8(1)
Announced Allocation	Seasonal allocation percentages determined annually based on trends in groundwater levels	Allocations based on annual water availability determination	none	none	none	none	none	none	none

(1) The licensed volume is currently lower than the (permissible annual volume) extraction limit.
(2) For Border Agreement Zones within the Murray region.

2.4.5 Water products and use

Groundwater extraction within the Murray region accounts for 13.5 percent (233 GL/year) of the total groundwater extraction throughout the MDB. Groundwater use in the major groundwater areas is detailed below.

Murray Uplands

Groundwater extraction from the aquifers is largely confined to alluvial deposits and to fractured granites and sedimentary rocks. A high proportion of the use occurs in the Upper Murray Alluvium. The current extraction level for the Upper Murray Alluvium is 30.5 GL and the extraction limit is 38.6 GL.

Riverine Plain

Groundwater development in the Lower Murray Alluvium began in the 1970s. Records indicate that groundwater extraction experienced strong growth at the end of the 1990s, peaking in 2002/03 at 130 GL/year. Current (2004/05) extraction is 78 GL/year (MDBC, 2007c). Other GMUs in the Riverine Plains region include the Upper Murray Alluvium (upstream of Corowa) (N15, Lachlan and Cowra formations).

Mallee and Lower Lakes

The Kanmantoo Fold Belt (N818, fractured rock aquifer) and the Adelaide Fold Belt (N817, fractured rock aquifer) GMUs occur in the northwest New South Wales portion of the reporting region. These aquifers generally have low permeability and groundwater is generally restricted to stock and domestic purposes. Water quality is variable ranging from fresh in the relatively high rainfall regions in the south to saline in the low rainfall regions of the north.

The Western Murray Porous Rock (N612) GMU lies south of this area in New South Wales. This GMU incorporates the Renmark Group and Calivil Formation in the east which grade into the Murray Group Limestone and Loxton-Parilla Sands to the southwest. Groundwater resources in these areas are generally saline although small isolated pockets of good quality groundwater do occur. The Lower Darling Alluvium GMU (N45) applies to the more recently deposited alluvial sediments of the Murray Trench that generally contain fresh to moderately fresh groundwater. Groundwater extraction in these areas is largely limited to stock and domestic supplies; however, development of groundwater-fed irrigation flanking the Darling River is predicted to increase.

In the Victorian portion of the Mallee there is a large unincorporated area adjacent to the Murray River. This area also includes the GMUs:

- Murrayville (V49) which has a permissible consumptive volume of 10.88 GL/year and an entitlement of 9.63 GL/year
- Telopea Downs (V50) which has a licensed entitlement of 7.48 GL/year. An embargo has been placed on new allocations until a water management plan is approved
- Kaniva (V51) which has a licensed entitlement of 3.67 GL/year and similarly has an embargo on new allocations until a water management plan is approved (DSE, 2006).

The Mallee PWA (S20) within South Australia is associated with the groundwater resources of the Murray Group Limestone. Groundwater extraction in the Mallee PWA has increased rapidly and consistently throughout the 1990s to a current allocation of 32.23 GL/year (MDBC, 2007d).

Further west in South Australia there has been rapid growth in the volume of groundwater extracted for irrigation in the Peake, Roby and Sherlock (S53) district over the past 3 to 4 years, although limited to a small number of users. The development of a water allocation plan for this region will cap the rate of extraction of groundwater from the Buccleuch Formation (part of the Renmark Group). Apart from limited stock and domestic use, little groundwater use occurs in the large area north of the Murray River in South Australia as the groundwater is largely saline. The remaining areas south of the Murray River that are not part of a water sharing plan area are unincorporated areas and groundwater extraction is also largely limited to stock and domestic supply.

Figure 2-8 summarises the extraction history of several of the established water sharing plan areas with historical records. In both the Lower Murray Alluvium and Mallee PWA there is persistent growth in groundwater extraction from the late 1980s to late 1990s. In 2002/03 there is a sharp decline in groundwater extraction related to the re-evaluation of extraction limits based on sustainable yields at this time.

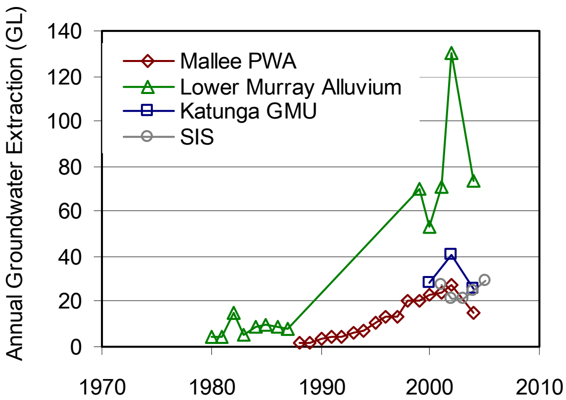

Figure 2-8. Historical groundwater extractions for groundwater management units (and salt interception schemes – SIS) in the Murray region

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3 Rainfall-runoff modelling

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

3.1.2 Key messages

- The annual rainfall and modelled runoff averaged over the Murray region are 340 mm and 24 mm respectively. Rainfall is fairly uniform throughout the year and runoff is highest in winter and spring. The Murray region covers 19.5 percent of the MDB and contributes about 16.5 percent of total MDB runoff.
- The average annual rainfall and runoff over the ten-year period 1997 to 2006 are 8 percent and 21 percent lower respectively than the long-term (1895 to 2006) average values. The 1997 to 2006 rainfall is not statistically different to the 1895 to 1996 average values at a significance level of $\alpha = 0.2$. The 1997 to 2006 runoff is statistically different to the 1895 to 1996 average values at a significance level of $\alpha = 0.2$.
- Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Murray region is more likely to decrease than increase. About three-quarters of the modelling results show a decrease in runoff and about one-quarter of the results show an increase in runoff. Under the best estimate (median) 2030 climate, average annual runoff would be reduced by 10 percent. The extreme estimates (from the high global warming scenario) range from a 37 percent reduction to a 7 percent increase in average annual runoff. The results from the low global warming scenario range from a 12 percent reduction to a 2 percent increase in average annual runoff.
- The area of commercial forestry plantations is projected to increase by 33,000 ha (62 percent) by ~2030. It is assumed that the projected increase would be concentrated in a small number of subcatchments and the impacts may be significant at this scale. However, the impact of projected commercial forestry plantation development on regional average annual runoff would be negligible. Farm dam storage capacity is projected to increase by 10.9 GL by 2030. New farm dams would decrease average annual runoff by less than 1 percent. This is very small compared to the best estimate 2030 climate impact on runoff. The best estimate of the combined impact of climate change and development is an 11 percent reduction in average annual runoff. Extreme estimates (due to climate change uncertainty) range from a 38 percent reduction to a 6 percent increase in average annual runoff.

3.1.3 Uncertainty

- Scenario A – historical climate and current development
  The runoff estimates for the eastern corner of the Murray 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 average 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). There is less confidence in the runoff estimates in the dry central and western parts of the Murray region because there are very few or no calibration catchments from which to estimate the model parameter values.

- Scenario B – recent climate and current development
  Scenario B was modelled because the 1997 to 2006 runoff is significantly different to the (1895 to 2006) long-term means. There is significant 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 of plantations growth are used here (BRS, 2007). 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 the states. 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. (2008a). 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.

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

3.2.2 Rainfall-runoff modelling for the Murray region

The rainfall-runoff modelling estimates runoff in 0.05^{o} grid cells in 22 subcatchments as defined for the river modelling in Chapter 4 for the Murray region (Figure 3-1). The majority of the subcatchments are in the higher elevation areas in the eastern corner of the Murray region where most of the runoff is generated. Optimised parameter values from 11 calibration catchments (seven in the Murray region and four in the Snowy, Goulburn-Broken and Loddon-Avoca regions) are used to model runoff in the eastern half of the Murray region.

Optimised parameter values from two calibration catchments (both in the Eastern Mount Lofty Ranges region) are used to model runoff in the southwest of the Murray region.

The Bureau of Rural Sciences (Parsons, pers. comm.) 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 33,000 ha in the region by ~2030 relative to ~2005. The projected or virtual plantation hectares (33,000 ha) were assigned to particular 0.05^{o} 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'.

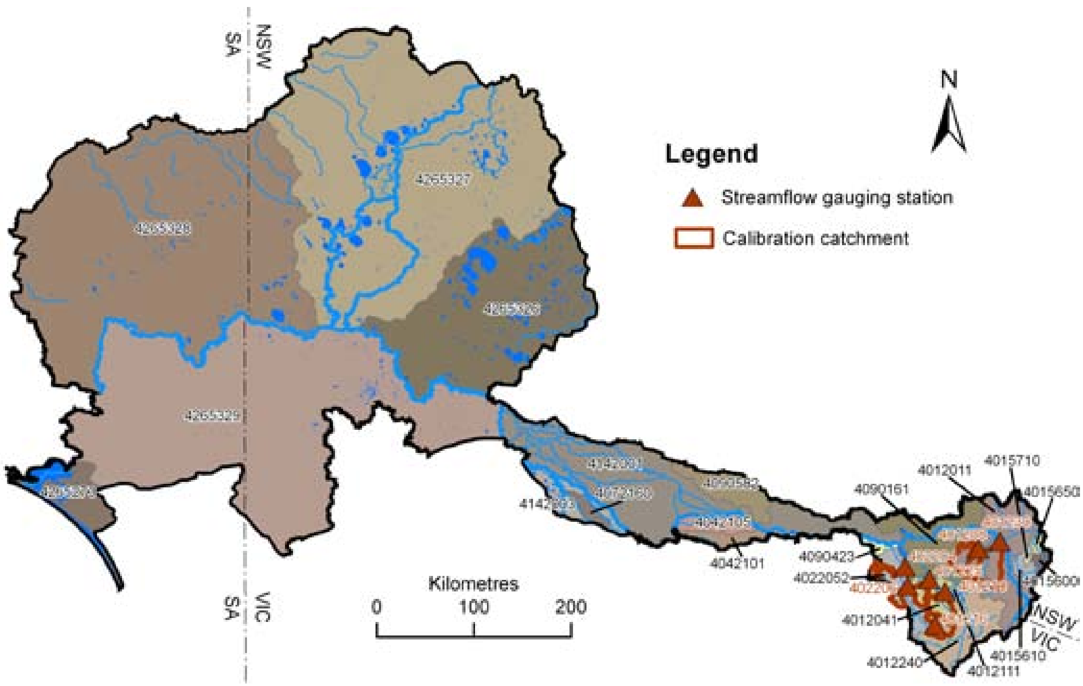

Figure 3-1. Map of the modelling subcatchments and calibration catchments

Across the Murray region, different methods are used to estimate the increase in farm dams in Victoria, South Australia and New South Wales.

The farm dam projection in NSW 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 80 GL. The estimate of current farm dam storage volume is about 70 GL utilising about 24 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 56 GL.

Future farm dam development in Victoria is limited to stock and domestic purposes (Victorian Government, 1989). The increase in farm dams in each subcatchment in the Victorian part of the Murray region is estimated by multiplying the projected increase in rural population of 7 percent by 2030 (DSE, 2004) by the current average storage volume of stock and domestic farm dams (estimated from VicMap 1:25,000 scale topographic mapping) per person for the corresponding subcatchment.

The South Australian part of the Murray region has very low surface runoff, and there is unlikely to be farm dam development there.

The total farm dam storage volume is projected to increase by 10.9 GL (10.2 GL in New South Wales and 0.7 GL in Victoria) by ~2030 relative to ~2005 over the entire Murray region. The projected increases in farm dam storage volume by ~2030 for each subcatchment are given in Appendix A.

3.2.3 Model calibration

Figure 3-2 compares the modelled and observed monthly runoff and daily flow duration curves for the 13 calibration catchments. The results indicate that the SIMHYD calibration reproduced the observed monthly runoff series (Nash-Sutcliffe E values generally greater than 0.7) and the daily flow duration characteristic (Nash-Sutcliffe E values generally greater than 0.8) reasonably. The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

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

The runoff estimates for the eastern corner of the Murray 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 runoff for ungauged catchments is 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. There is less confidence in the runoff estimates in the dry central and western parts of the Murray region because there are very few or no calibration catchments from which to estimate the model parameter values.

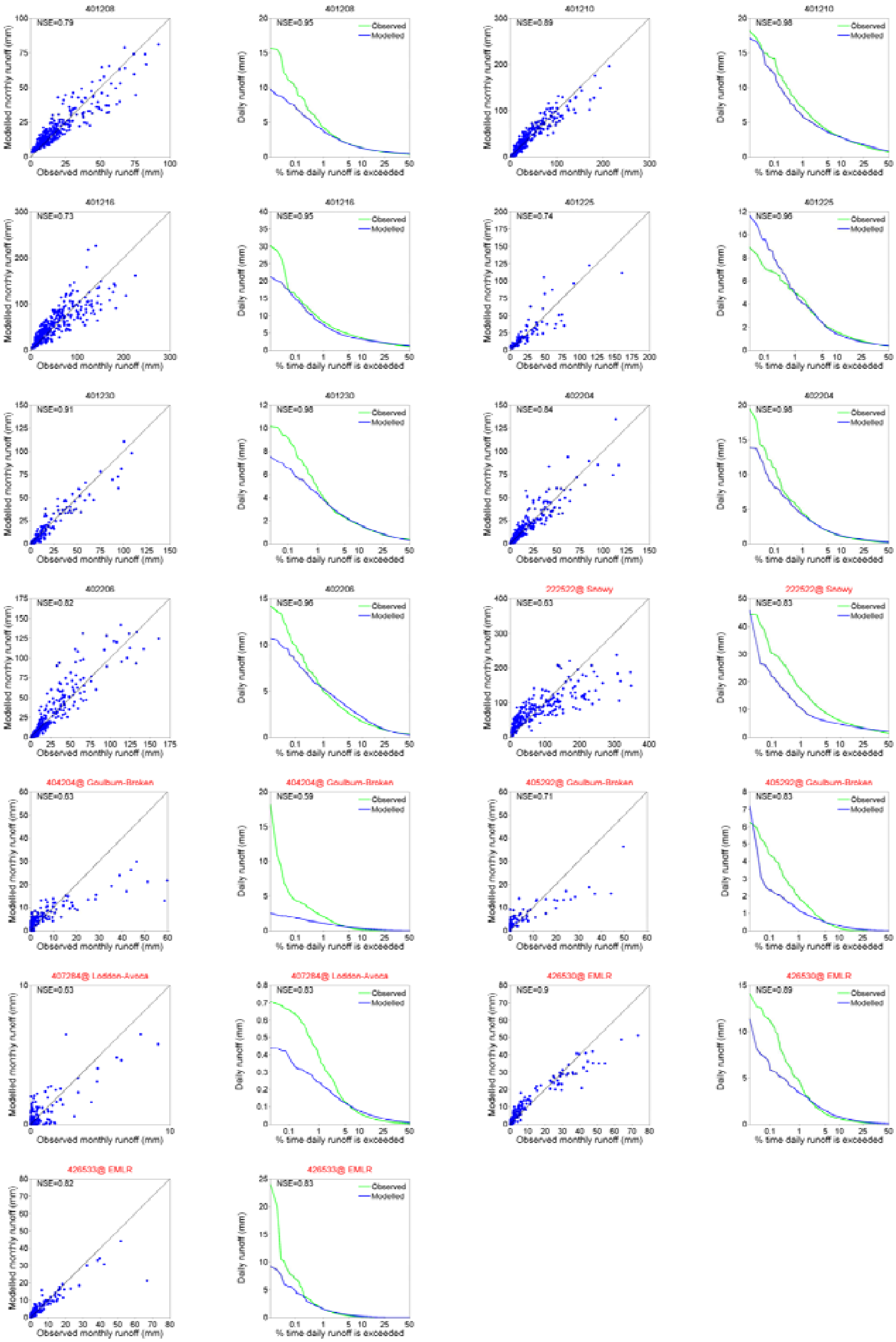

Figure 3-2. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

3.3 Modelling results

3.3.1 Scenario A – historical climate and current development

Figure 3-3 shows the spatial distribution of mean annual rainfall and modelled runoff for 1895 to 2006 across the Murray 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 Murray region are 340 mm and 24 mm respectively. Most of the rainfall and runoff occur in the eastern part of the region. The mean annual rainfall varies from more than 1500 mm in the high elevations areas in the east to less than 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 5 mm in the west (Figure 3-3). Rainfall is fairly uniform throughout the year and runoff is highest in the winter and spring (Figure 3-5). The Murray region covers 19.5 percent of the MDB and contributes about 16.5 percent of total MDB runoff.

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 coefficient of variation of annual rainfall averaged over the Murray region is 0.27, close to the median value of the 18 MDB regions. The coefficient of variation of annual runoff averaged over the Murray region is 0.50, amongst the lowest in the MDB. The 10th percentile, median and 90th percentile values across the 18 regions are 0.22, 0.26 and 0.36 respectively for rainfall and 0.54, 0.75 and 1.19 for runoff.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 8 percent and 21 percent lower respectively than the long-term (1895 to 2006) mean values. The 1997 to 2006 rainfall is not 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 $\alpha = 0.2$ (with the Student-t and Rank-Sum tests). Because the 1997 to 2006 runoff is 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.

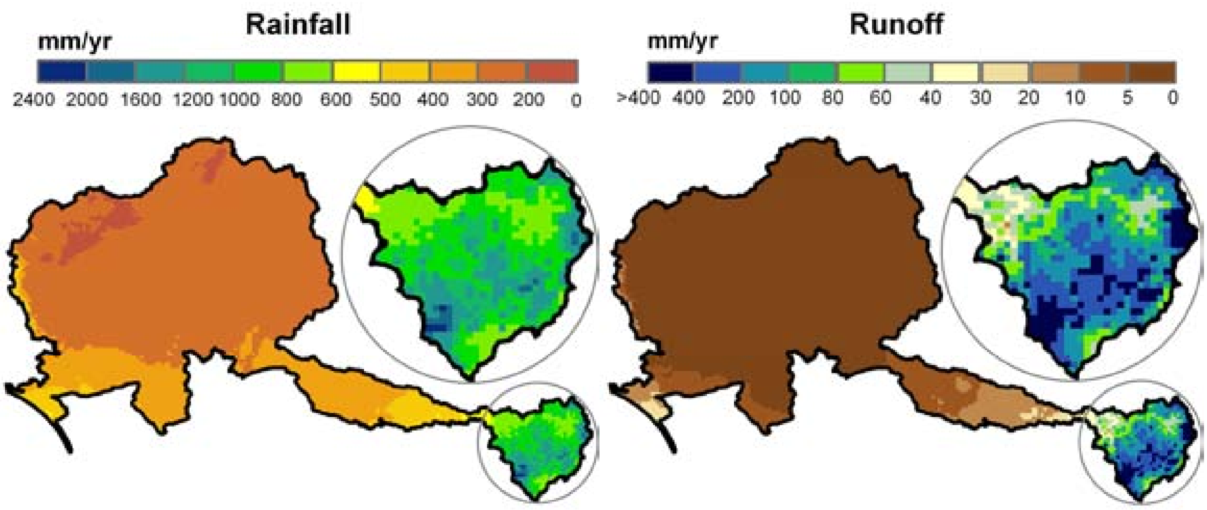

Figure 3-3. Spatial distribution of mean annual rainfall and modelled runoff averaged over 1895 to 2006

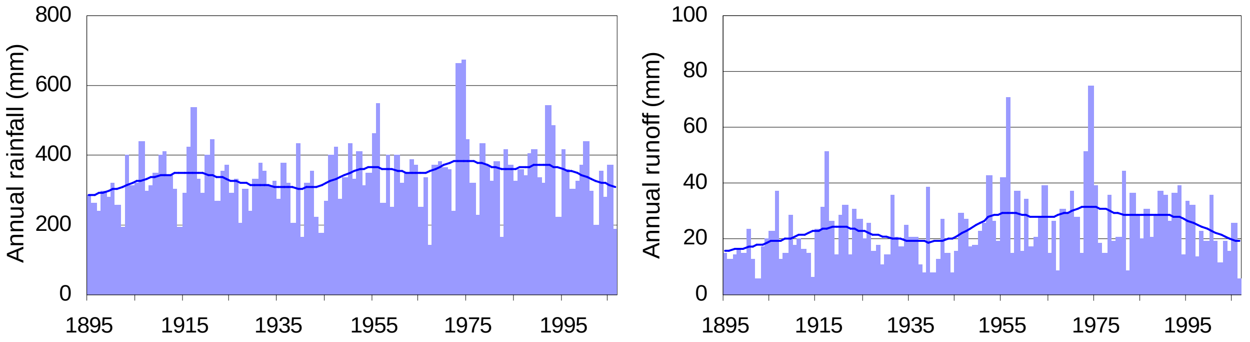

Figure 3-4. 1895 to 2006 annual rainfall and modelled runoff averaged over the region (the curve shows the low frequency variability)

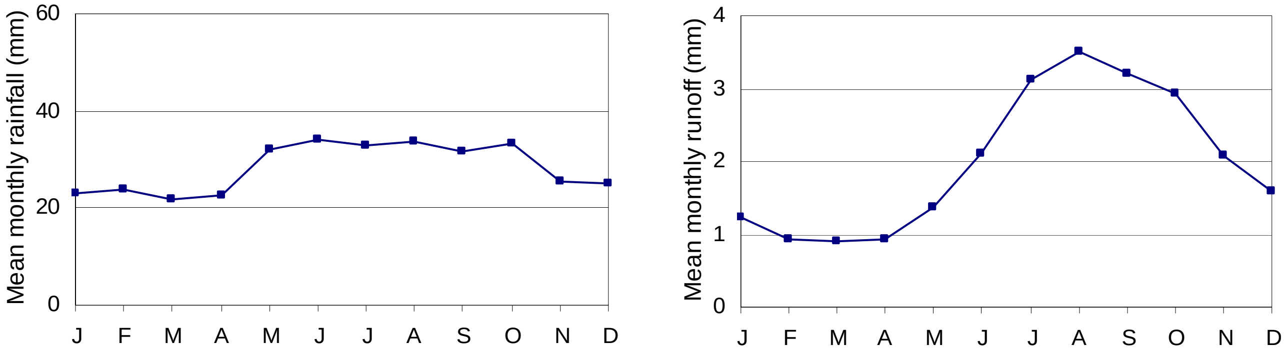

Figure 3-5. Mean monthly rainfall and modelled runoff (averaged over 1895 to 2006 for the region)

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 Murray 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 Murray region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from about three-quarters of the GCMs shows a reduction in mean annual runoff, and rainfall-runoff modelling with climate change projections from about one-quarter 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 and Chiew et al., 2008b), 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 more than half of the GCMs indicates a decrease in mean annual runoff greater than 10 percent, and rainfall-runoff modelling with climate change projections from only one of the 15 GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting, only results from an extreme ‘dry’, ‘mid’ and extreme ‘wet’ variant are shown (referred to as scenarios Cdry, Cmid and Cwet). Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used.

Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table 3-1. Although the choice of scenarios is based on regionally-averaged runoff, they are likely to be heavily influenced by and especially appropriate for the high-yielding eastern part of the catchment since that is where most of the runoff is generated. Scenarios Cdry, Cmid and Cwet indicate a -37, -10 and +7 percent change in mean annual runoff. By comparison, the range based on the low global warming scenario is -12 to +2 percent change in mean annual runoff. Figure 3-7 shows the mean annual runoff across the Murray region under Scenario A and scenarios Cdry, Cmid and Cwet.

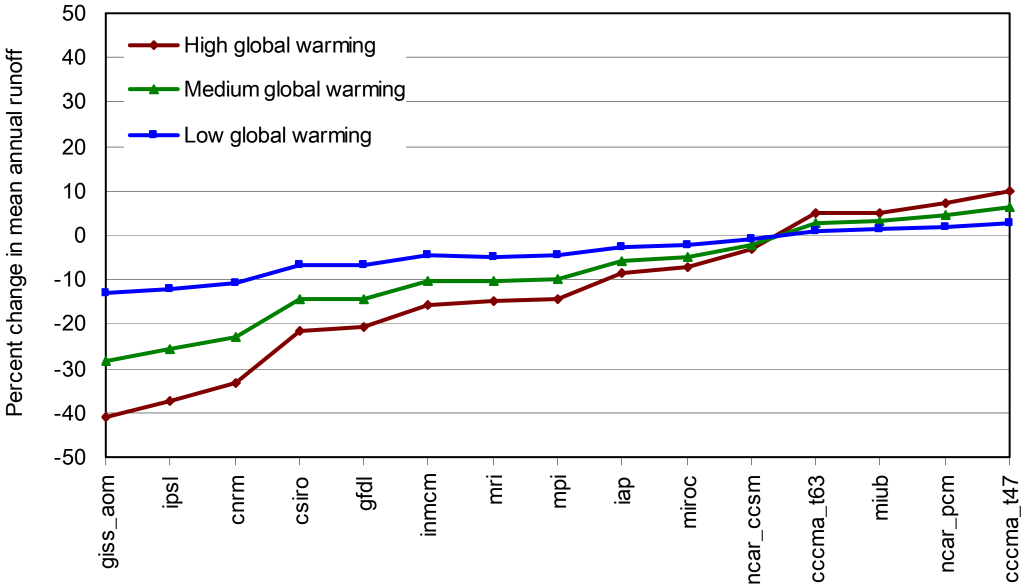

Figure 3-6. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A runoff

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
giss_aom	-20	-41	giss_aom	-13	-28	giss_aom	-6	-13
ipsl	**-19**	**-37**	ipsl	-12	-26	ipsl	-5	-12
cnrm	-13	-33	cnrm	-9	-23	cnrm	-4	-11
csiro	-8	-22	csiro	-5	-14	gfdl	-3	-7
gfdl	-11	-21	gfdl	-7	-14	csiro	-2	-7
inmcm	-6	-16	inmcm	-4	-10	mri	-2	-5
mri	-7	-15	mri	-4	-10	mpi	-1	-5
mpi	-5	-14	**mpi**	**-3**	**-10**	inmcm	-2	-5
iap	-4	-9	iap	-3	-6	iap	-1	-3
miroc	4	-7	miroc	2	-5	miroc	1	-2
ncar_ccsm	2	-3	ncar_ccsm	1	-2	ncar_ccsm	0	-1
cccma_t63	5	5	miub	2	3	miub	1	1
miub	3	5	cccma_t63	3	3	cccma_t63	1	1
ncar_pcm	**6**	**7**	ncar_pcm	4	4	ncar_pcm	2	2
cccma_t47	3	10	cccma_t47	2	6	cccma_t47	1	3

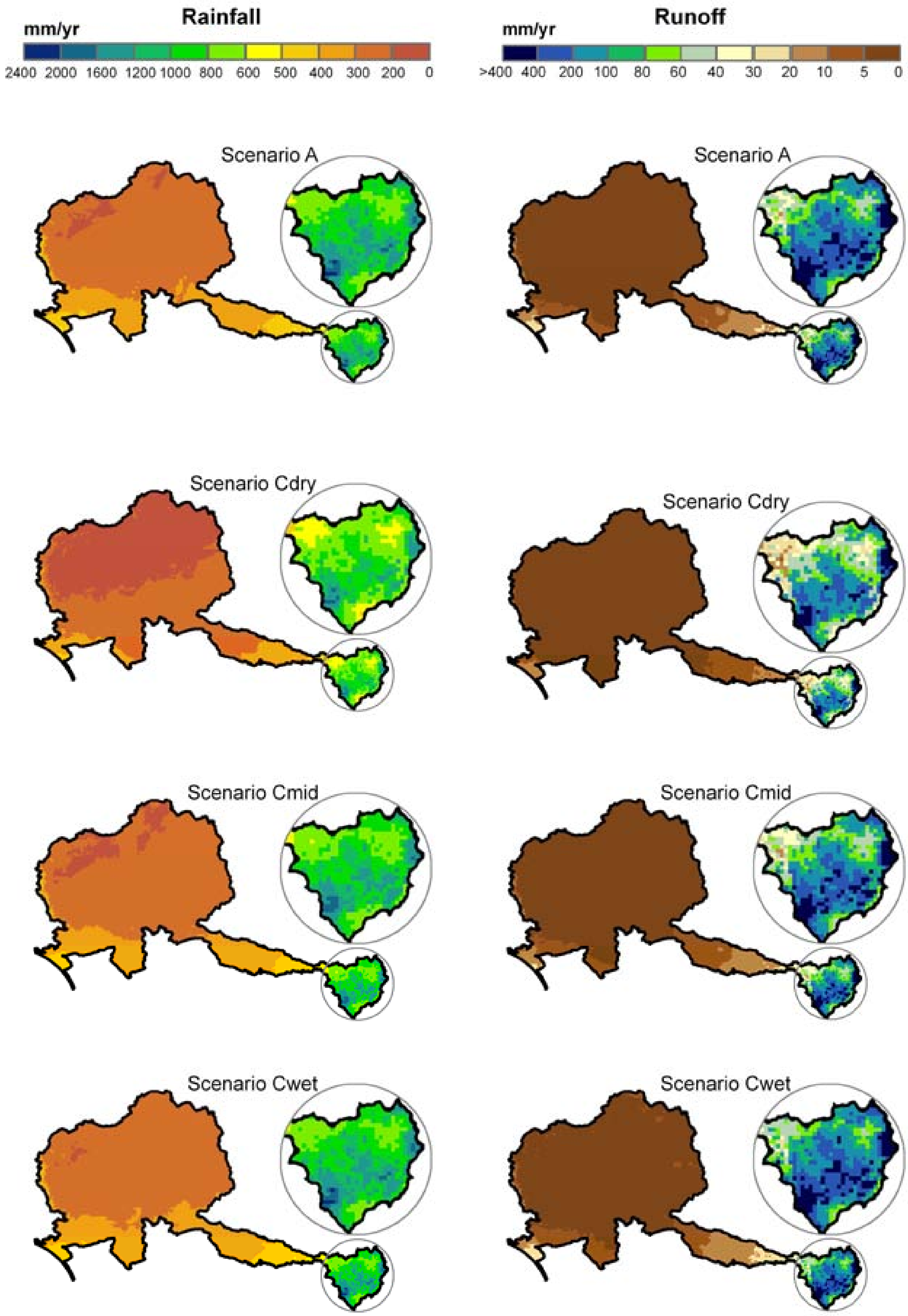

Figure 3-7. Mean annual rainfall and modelled runoff under scenarios A, Cdry, Cmid and Cwet

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 Murray 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 Murray 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 Scenario Cmid is chosen based on mean annual runoff (Section 3.3.2), the comparison of monthly and daily results under Scenario Cmid relative to Scenario A in Figure 3-8 and Figure 3-9 should be interpreted cautiously. However, the Scenario 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 Scenario 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 Scenario C range are therefore not the same as scenarios Cdry and Cwet reported elsewhere and used in the river system and groundwater models. Although three-quarters 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 21 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 a best estimate of a 10 percent reduction in mean annual runoff by ~2030 (Scenario C). However, there is considerable uncertainty in the climate change impact estimate with extreme estimates ranging from -37 to +7 percent.

The commercial forestry plantations in the Murray region are projected to increase by 33,000 ha by ~2030. The total farm dam storage volume over the entire Murray region is projected to increase by 10.9 GL by ~2030. The best estimate of the combined impact of climate change and development is an 11 percent reduction in mean annual runoff, with extreme estimates from -38 to +6 percent (Scenario D).

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

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	340	24	316
		percent change from Scenario A	
B	–	-21%	–
Cdry	-19%	-37%	-18%
Cmid	-3%	-10%	-3%
Cwet	6%	7%	6%
Ddry	-19%	-38%	-18%
Dmid	-3%	-11%	-3%
Dwet	6%	6%	6%

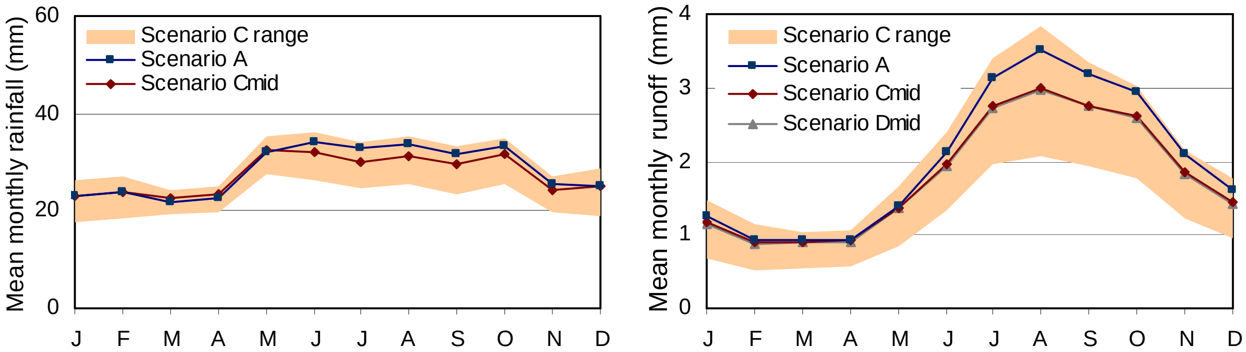

Figure 3-8. Mean monthly rainfall and modelled runoff under scenarios A, C and D averaged over 1895–2006 across the region (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

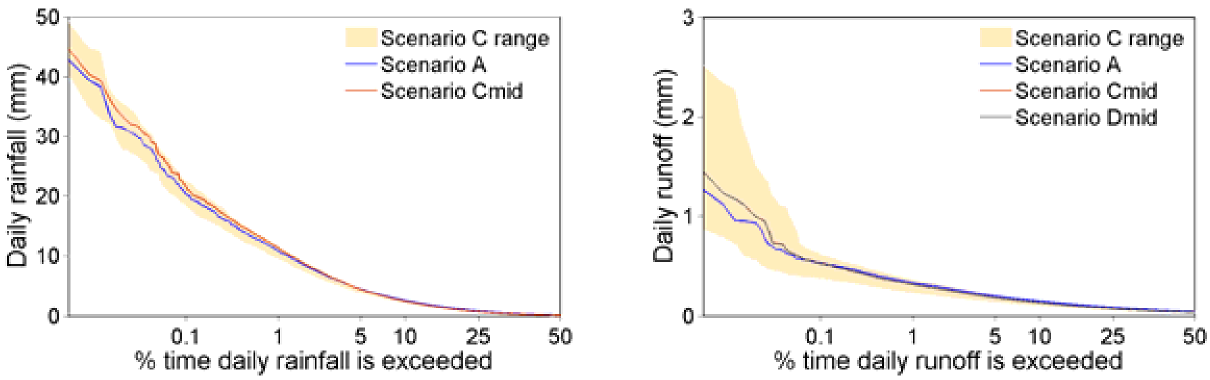

Figure 3-9. Daily flow duration curves under scenarios A, C and D averaged over the region (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

3.4 Discussion of key findings

The mean annual rainfall and modelled runoff averaged over the Murray region are 340 mm and 24 mm respectively. The mean annual rainfall varies from more than 1500 mm in the high elevation areas in the east to less than 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 5 mm in the west. Rainfall is fairly uniform throughout the year and runoff is highest in winter and spring. The Murray region covers 19.5 percent of the MDB and contributes about 16.5 percent of total MDB runoff.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 8 percent and 21 percent lower respectively than the long-term (1895 to 2006) mean values. The 1997 to 2006 rainfall is not 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 $\alpha = 0.2$ (with the Student-t and Rank-Sum tests).

The runoff estimates for the eastern corner of the Murray 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. There is less confidence in the runoff estimates in the dry central and western parts of the Murray region because there are very few or no calibration catchments there from which to estimate the model parameter values.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Murray region is more likely to decrease than increase.

About three-quarters of the modelling results show a decrease in average annual runoff and about one-quarter shows an increase in average annual runoff. However, although three-quarters 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.

The best estimate is a 10 percent reduction in average annual runoff by ~2030 relative to ~1990. However, there is considerable uncertainty in the modelling results with the extreme estimates ranging from -37 to +7 percent. These extreme estimates come from the high global warming scenario, and for comparison the range from the low global warming scenario is -12 to +2 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.

An increase in commercial forestry plantations of 33,000 ha is projected by ~2030 and the impact averaged over subcatchments is relatively small. The total farm dam storage volume is projected to increase by 10.9 GL by ~2030. The best estimate of the combined impact of climate change and commercial forestry plantations and farm dam developments is an 11 percent reduction in average annual runoff, with extreme estimates ranging from -38 to +6 percent. The modelled reduction in future mean annual runoff from the projected developments in farm dams alone is less than 1 percent.

There is considerable uncertainty in the projection 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 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. There is uncertainty both as to how landholders will respond to these policies and how governments may set policies in the future.

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4 River system modelling

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

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

The information in this chapter comes from the calibrated Monthly Simulation Model (MSM) and BigMod models for the Murray River system of the Murray-Darling Basin Commission (Close, 1996a and b).

4.1 Summary

4.1.1 Issues and observations

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

- Scenario O
  This scenario represents the latest version of the Murray and Lower Darling river systems model supplied by the Murray-Darling Basin Commission (MDBMC, 2000). It models 2000/01 development and 2006/07 management rules and covers the original planning period 1 May 1891 to 30 April 2006. It is used by the Murray-Darling Basin Commission to (i) audit compliance with the Cap on surface water diversions; (ii) develop Water Sharing Plans in New South Wales (DIPNR, 2004a and b); and (iii) model Victorian entitlements to the Murray (DSE, 2006).
- Scenario A0
  This scenario incorporates the Scenario O model but covers the shorter common historical climate period (1 June 1895 to 30 June 2006). This scenario 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. This scenario is the baseline for comparison with scenarios B, C and D.
- Scenario P – without-development
  This scenario incorporates the model for Scenario A0 and covers the common historical climate period. Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Natural water bodies, fixed diversion structures and existing catchment runoff characteristics are not adjusted. It includes the net effect of Snowy Mountains Hydro-electric Scheme transfers to the Murrumbidgee and Murray regions.
- Scenario B – recent climate and current development
  This scenario represents a future climate condition based on the climate of 1997 to 2006. The level of development is the same as Scenario A. A without-development model run is undertaken that uses Scenario B climate and Scenario P development conditions.
- Scenarios C – future climate and current development
  Scenarios Cwet, Cmid and Cdry represent a range of future (2030) climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A (Chapter 3). The level of development is the same as Scenario A (2000/01 level of development). Without-development model runs are undertaken that use Scenario Cwet, Cmid and Cdry climates and Scenario P development conditions.

- Scenarios D – future climate and future development
  Scenarios Dwet, Dmid and Ddry incorporate Scenario C with flow inputs adjusted for 2030 projected development in farm dams, commercial forestry plantations and groundwater. Future groundwater effects on river reaches are also considered. The farm dam and commercial forestry plantation projections are discussed in Chapter 3 while groundwater development is discussed in Chapter 6.

The change in inflows between scenarios reported in this chapter differs from the change in runoff reported in Chapter 3 as the majority of inflows to the Murray region are generated in the contributing upstream regions. While this chapter primarily reports on the surface water modelling results for the Murray region, because the models for the entire Murray-Darling Basin (MDB) have been linked to propagate the effects through the entire surface water system, some of the results presented herein pertain to the entire MDB. Where this is the case, they are clearly identified as such. The groundwater assessment (Chapter 6) estimated impacts of groundwater extraction on streamflow and projected future groundwater extraction impacts. Groundwater use and growth in the upstream regions is described in the relevant reports.

The Murray system is described by two models, the monthly time step MSM that controls the management of water resources in the system and the daily time step BigMod that routes flow and salinity through the system.

The river model:

- generates Broken Creek inflows based on a regression model that is a function of climate variables and the natural Goulburn flow at McCoy's Bridge (Foreman, 2002)
- represents different levels of irrigation development (for example, current condition, Cap condition etc.) using regression relationships that are a function of rainfall, temperature and allocation
- represents town water use using regression relationships that are a function of rainfall and temperature.

The South Australian Department of Water, Land and Biodiversity Conservation advise that the function used in the current version of the river model (MSM) to represent the South Australian irrigation allocations does not adequately capture South Australian practices during very low flow periods. This has not affected the usefulness of modelling results in the past and does not affect the accuracy of results for Scenario A. However, the function in MSM does not adequately represent irrigation allocations in years of very low cross-border flows to South Australia. Hence, where possible, results for South Australian irrigation allocations were post-processed using existing annual cross-border flows in combination with an improved irrigation allocation function to cap the existing annual diversions during dry periods.

These adjustments could not be applied to the entire mass balance. Hence, results from the model downstream of South Australian diversion points (the Coorong, Lower Lakes and Murray mouth) are more uncertain than other model predictions and improved modelling is required for this part of the system. Because South Australian irrigation diversions are too high in original modelling, the current modelling will underestimate end-of-system flows. The difference is of the order of less than 1 percent of the total and so does not materially affect average results or their implications. The differences will be larger in dry periods. Levels in the Lower Lakes have been adjusted for reporting, but due to the current limitations of MSM these may still be slight underestimates. As the adjusted results do not indicate major problems with low levels in the Lower Lakes during dry periods, any additional adjustment would only strengthen this finding. Additionally however, the current model does not include aspects of recent management applied as a part of 'contingency planning' to cope with the extreme drought. For this reason, modelled levels for the Lower Lakes would not reproduce recent low levels in the Lower Lakes.

This project considers the impacts of each of the scenarios on the flow regime at key locations in the system, including the end-of-system. Changes in water quality that may result from changes in the flow regime are not considered. The change in water quality may be particularly significant in the lakes at the end of the Murray system. Finally, the scenarios modelled may not eventuate but they describe 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.

4.1.2 Key messages

- Current average surface water availability integrated down the entire MDB to Wentworth on the Lower Murray River is 14,493 GL/year. For the Murray region itself, current average surface water availability is reduced by water use in upstream regions to 11,162 GL/year. Of this, the Murray region contributes 5211 GL/year (or 47 percent) on average, with the remainder of the water is contributed by upstream regions. About one-tenth of the Murray region contribution is an inter-basin transfer from the Snowy Mountains Hydro-electric Scheme into the upper Murray.
- Current total average surface water use across the entire MDB reduces streamflow at Wentworth by 7422 GL/year. On average, an additional 673 GL/year is diverted downstream of Wentworth. Combined, these give a total 'effective use' across the MDB of 8095 GL/year which is 56 percent of the average available 14,493 GL/year. This is an extremely high level of use. Average surface water use just within the Murray region reduces streamflow at Wentworth by 4045 GL/year equivalent to half of the total 'effective use' for the Basin. The relative level of surface water use for the Murray region is therefore 36 percent. This is a high level of use.
- Flows in the Murray River are highly regulated. Dartmouth and Hume dams both regulate 87 percent of their total inflow.
- In the Murray system, New South Wales general security water, Victorian water and South Australian water are all highly used: 79 percent of the allocated New South Wales general security water is used; 87 percent of the Victorian combined high and low reliability water shares (including delivery losses) is used; and 81 percent of the South Australian allocated water is used.
- The end-of-system flow of the Murray River has been significantly reduced by water resource development. The average annual end-of-system flow under without-development conditions is 12,233 GL/year and this has been reduced by 61 percent to 4733 GL/year on average as a result of water resource development. The additional reduction (over the 56 percent relative level of surface water use quoted above) is due to additional evaporative losses from the lower river and the Lower Lakes which means that there is significantly less flow at the mouth than at Wentworth. Cease-to-flow conditions occur at the Murray River mouth 1 percent of the time under without-development conditions; under current development conditions flow ceases 40 percent of the time. In spite of these changes in end-of-system flow conditions, the average (and minimum) areal extent of the Lower Lakes has increased 6 percent due to construction of the barrages across the river mouth. Under the 1895 to 2006 climate and current development, Lower Lakes levels never fall below mean sea level.
- The eventual streamflow impact of current groundwater extraction just on the main stem of the Murray River will be a reduction of about 45 GL/year, changing the river from a river that gains water from groundwater to one that loses water to groundwater.
- Under a long-term continuation of the recent (1997 to 2006) climate and current water sharing arrangements, average surface water availability for the entire MDB would decrease by 27 percent and for the Murray region would decrease by 30 percent. End-of-system flows at the barrages would decrease by 50 percent, and the volume of water diverted for use within the region would decrease by 13 percent. Within the region, diversions would reduce on average by 21 percent in New South Wales and by 7 percent in Victoria. In South Australia, irrigation diversions would reduce by 12 percent; Adelaide and rural town water supply would be unaffected under this or any 2030 climate scenario. Impacts on region diversion volumes would be far greater in dry years: the lowest 1-year diversion volume would be reduced by 60 percent. The relative level of use for the entire MDB would increase from 56 to 66 percent and for the Murray region would increase from 36 to 45 percent. The minimum area of the Lower Lakes (occurring at a level of 0.2 m above mean sea level) would be about 1000 ha less than the minimum under the historical climate.
- Under the best estimate (median) 2030 climate average surface water availability for the entire MDB would fall by 12 percent and for the Murray region would fall by 14 percent. Total diversion volumes in the region would fall by 4 percent and end-of-system flows would fall by 24 percent. Diversion impacts would differ between water products. New South Wales and Victorian diversions in the region would, on average, decrease by 8 and 1 percent respectively. New South Wales general security water use in the region would be decreased by 9 percent, supplementary access would be decreased by 14 percent and high security town water supplies would not be impacted. Irrigation diversions in South Australia would fall by 3 percent. Impacts on region diversion volumes would be far greater in dry years: the lowest 1-year diversion volume would be reduced by

14 percent. The relative level of use for the entire MDB would increase from 56 to 60 percent and for the Murray region would increase from 36 to 40 percent.

- Under the wet extreme 2030 climate average surface water availability for the entire MDB and for the Murray region would increase by 7 percent. End-of-system flows would increase by 20 percent. Diversions in New South Wales would, on average, increase by 2 percent while total Victorian and South Australian diversions would be essentially unaffected.
- Under the dry extreme 2030 climate average surface water availability for the entire MDB would fall by 37 percent and in the Murray region would fall by 41 percent. Total diversion volumes in the region would fall by 23 percent and end-of-system flows would fall by 69 percent. Average New South Wales and Victorian diversions in the region would decrease by 32 and 18 percent respectively. Irrigation diversions in South Australia would fall by 30 percent. Impacts on total diversion volumes for the region would be far greater in dry years: the lowest 1-year diversion volume would be reduced by 64 percent. The minimum area of the Lower Lakes (occurring at a level 0.05 m above mean sea level) would be around 2000 ha lower than the minimum under the historical climate.
- The annual flow in the Murray system at the South Australian border for 2007/08 has been lower than would have ever occurred under the 1895 to 2006 climate at the current level of development. Annual flows this low would not occur under the best estimate or wet extreme 2030 climate, but would occur in 1 percent of the years under a continuation of the 1997 to 2006 climate or in 4 percent of the years under the dry extreme 2030 climate. During the extreme low flow period of 2007/08, South Australian irrigation allocations were lower than modelled because of simplifying assumptions in the modelling. The modelling results reported here have been adjusted to account for this. However, the adjusted results assume accurate implementation of the current South Australian irrigation allocation practices during low flow periods. During the recent drought, South Australian irrigation allocations have sometimes been higher than current practices would recommend due to optimistic expectations of cross-border flows, and have thus been closer to the unadjusted modelled allocations. This could also happen in future dry periods, in which case South Australian diversions would be considerably higher than reported and minimum levels in the Lower Lakes would be considerably lower than reported.
- Projected future regional development (additional groundwater extraction, farm dams and commercial forestry plantations) would reduce inflows by 146 GL/year; of this 90 GL/year would be due to future development in upstream regions, 29 GL/year would be due to future farm dams in the region, 19 GL/year would be due to commercial forestry plantations in the region and about 8 GL/year would be due to future groundwater extraction in the region. Future development alone would cause a 2 percent decrease in average annual streamflow at Wentworth, a 1 percent increase in cease-to-flow periods and a 0.5 percent decrease in average surface water diversions.
- The combined impact of future climate change and development on end-of-system flows is large, because in terms of average diversion volumes, current water sharing arrangements protect consumptive water users from much of the impact of reductions in surface water availability.

4.1.3 Robustness and limitations

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

Problems were encountered during this test scenario and changes to the models were required to ensure that the models behaved robustly in extremely dry conditions. When corrected the model behaved robustly even when allocations were at zero percent for 16.3 years (New South Wales) and 9.6 years (Victoria) out of 111-years and Hume Dam was drawn down below dead storage (30,000 ML) at 29,284 ML.

The model response to increases and decreases in inflow was reasonable and the change in diversions and end-of-system flows (that is, flow over the barrages in the Lower Lakes) is consistent with the change in inflow. Mass balance over the modelling period from Dartmouth Dam to the Murray mouth was maintained within 0.4 percent for all scenarios (Appendix B).

There are four aspects that have limited the Murray model:

- minor errors in estimates of upstream models will be propagated through to the Murray models. Errors have been identified in the models for Murrumbidgee, Goulburn-Broken, Campaspe and Loddon regions. These errors were assessed based on impacts to their respective regions and were determined to be minor. These errors will have even less impact in the Murray region when all the other inflows are considered. Further details on these can be found in (CSIRO, 2008a, b, c and d)
- the groundwater use impacts on the streams and drains that exist in the Southern Riverine Plains groundwater model are not completely considered in the Murray region or upstream regions as not all streams and drains are modelled. The unaccounted groundwater loss is approximately 10 GL/year for Scenario A and will have a minor impact on Murray model results
- the drainage flows that are used for Scenario A are not modified for scenarios B, C and D
- the model does not take into account current low flow water sharing arrangements recently agreed by the jurisdictions.

4.2 Modelling approach

This section provides a summary of the generic river modelling approach, a description of the river model and how it was developed. Chapter 1 contains more details on the overall project methodology.

4.2.1 General

River system models that encapsulate descriptions of 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. It was necessary to use the river system models currently used by state agencies and the Murray-Darling Basin Commission given the time constraints of the project and the need to link the assessments to state water planning processes. The main models in use are IQQM, REALM, MSM-BigMod, WaterCress and a SIMV9 model of the Snowy Mountains Hydro-electric Scheme (SMHS).

4.2.2 Model description

The Murray region (Figure 4-1) is modelled by three connected models: MSM, BigMod and Snowy Hydro model (SIMV9). MSM and BigMod are combined into one system by an interface (the version supplied is V3.1.3; Murray20-10.exe and BIGMODver10-5.exe). The Snowy Hydro model (SIMV9) provides inflows and release projections to MSM. MSM does the management and sharing of water resources in the Murray and Lower Darling river system and BigMod routes flow and salinity through these systems. The extents and time steps of MSM and BigMod vary.

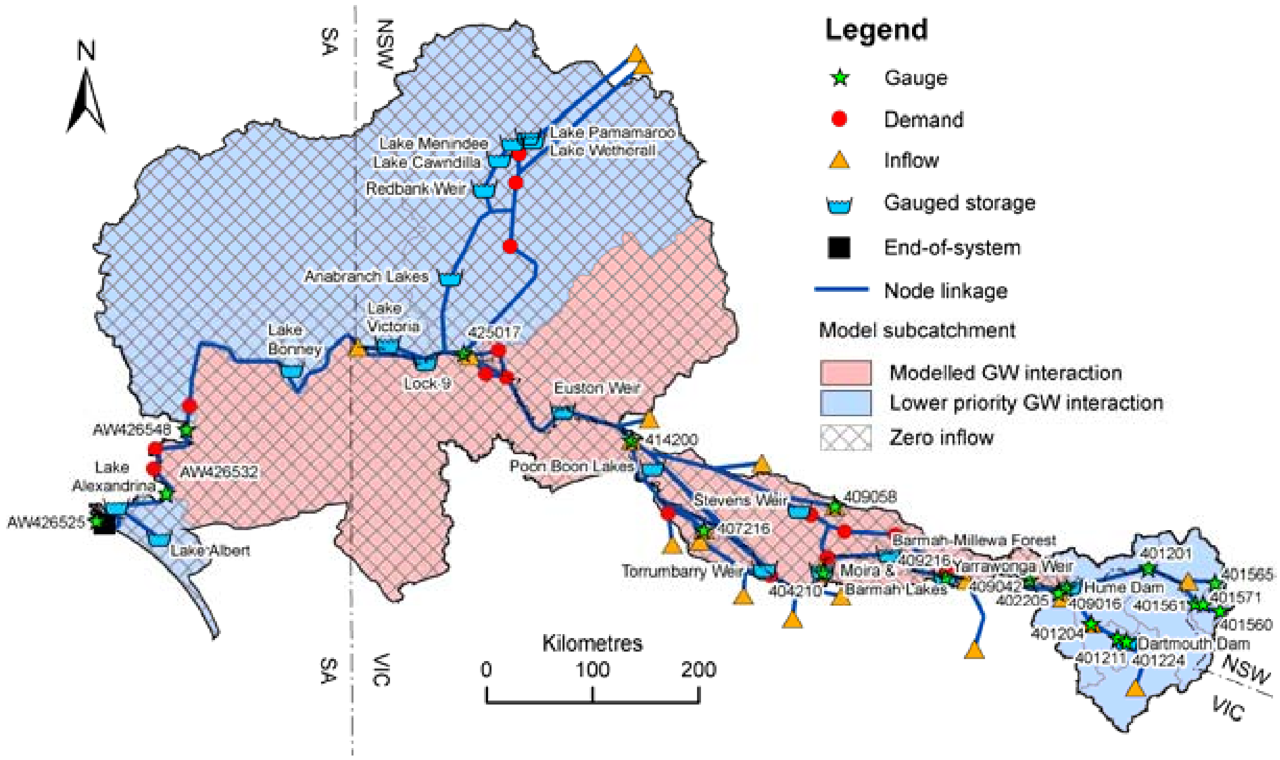


Figure 4-1. River system map showing subcatchments, inflow and demand nodes, links and gauges locations

Snowy Hydro model (SIMV9)

The SMHS is modelled by a custom-built monthly model (SIMV9) developed by the Water Section of Snowy Hydro Limited. This model was used for Snowy corporatisation model studies undertaken with the Murray-Darling Basin Commission and New South Wales Department of Water and Energy; it has undergone some minor modifications for this project. The pre-corporatisation version does not consider reductions in required annual releases and provision of environmental releases according to Snowy Water Licence 2002 rules (WAMC, 2002).

The model simulates the hydraulic operation of the Snowy-Murray and Snowy-Tumut developments of the SMHS according to the ‘target rule’ principle. Scheduled releases are set under this principle 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 afterwards. ‘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.

Water operation is modelled using water balances of reservoir storage, inflows, evaporation at the major storages, diversions and spills to meet scheduled and target releases subject to various constraints and operating guidelines. The model consists of seven SMHS reservoirs and Blowering Dam, six tunnels, five power stations, and one pumping station. There are also a number of additional water accounts that are maintained related to development shares of water, effective and target storages, notional spills and accountable releases. The model ends at four locations: Murrumbidgee River at Tantangara Dam, Tumut River at Blowering Dam, Murray 1 Power Station releases to the Murray and releases to the Snowy River. Blowering Dam operation is modelled using input irrigation release requirements supplied by the Murrumbidgee model. Jounama Dam releases into Blowering Dam are constrained by Tumut River channel capacity and pre-SMHS natural flows. The Tantangara Dam connection with the Upper Murrumbidgee model is not considered as the dam only spills once in 100 years.

Monthly Simulation Model

The Monthly Simulation Model (MSM) was developed initially in 1965 and used for simulating the Murray and Lower Darling River System from Dartmouth Dam to the South Australian border. The model was revised in 1979 to allow water accounting between states. The model has since been updated and its capabilities enhanced to inform water management and various policy options. The current version of MSM is a monthly time step model (with the exception of the Menindee Lakes system which is modelled at a daily time step) that simulates the Murray and Lower Darling River System using the water sharing arrangements under the Murray-Darling Basin Agreement (MDBC, 2006). The model commences with headwater inflows from the Murray River about 40 km south of Mt Kosciusko and Darling River inflows into Menindee Lakes. The model finishes at the South Australian border. The model receives inflows from the SMHS via releases through the Murray 1 Power Station. The Snowy water licence guarantees a minimum amount of water that can be called upon during periods of drought (WAMC, 2002). This amount is called the ‘required annual release’ and involves a release of 1062 GL/year to the Murray River. This is calculated using the ‘dry inflow sequence volume’.

MSM represents the Murray system with ten nodes arranged into nine river sections (MDBC, 2007). The model simulates:

- water accounts using the arrangements in the Murray-Darling Basin Agreement (MDBC, 2006)
- resources available to the states under the Agreement
- allocation by states to groups of water users
- demand for water in the key regions throughout the system
- transfers required between storages to ensure that the demands can be met
- operation of various dams and structures including orders to meet forecast demands and pre-releases from each storage for flood mitigation.

The Murray system is regulated by four major storages: Dartmouth Dam on the Mitta Mitta River, Hume Dam on the Murray River, Menindee Lakes on the Lower Darling system and Lake Victoria (an off-river storage connected to the Murray River). The Menindee Lakes system is modelled as four major lakes: Wetherell, Pamamaroo, Menindee and Cawndilla (Table 4-1). There are a number of weir pools and natural wetlands and floodplains included in the model. A number of smaller weirs are not included as they do not impact on monthly operations.

Table 4-1. Storages in the river system model

Major supply reservoirs	Active storage	Average inflow	Average release	Average net evaporation	Degree of regulation
	GL	GL/y			
Major supply reservoirs					
Dartmouth	3,826.0	895.5	774.3	0.2	0.87
Hume	3,008.0	4,066.4	3,466.3	76.4	0.87
Lake Victoria	591.0	498.5	368.8	128.9	1.00
Menindee Lakes System	2,049.0	1,782.7	533.7	355.4	0.50
Lake Menindee	729.0			125.4	
Lake Pamamaroo	353.0			80.6	
Lake Cawndilla	705.0			92.9	
Lake Wetherell	262.0			56.5	
Sub-total	**11,523.0**	**7,243.1**	**5,143.1**	**916.3**	
Minor supply reservoirs					
Khancoban Pondage	20.1	1,549.7	1,554.3		1.00
Yarrawonga Weir	96.0		5,115.3		
Torrumbarry Weir	30.3		4,213.4		
Euston Weir	17.4		6,790.5		
Stevens Weir	18.6		1,248.2		
Weir 32			1,317.4	2.1	
Little Murray Weir	10.0				
Bulpunga Weir	18.5				
Lock 9 Weir Pool	19.5				
Lock 4 Weir Pool	36.9				
Lock 3 Weir Pool	61.9				
Lock 2 Weir Pool	34.5				
Lock 1 Weir Pool	40.8				
Sub-total	**404.4**	**1,549.7**	**20,239.1**	**2.1**	
Natural water bodies					
Barmah Lake		57.5		3.4	
Moira Lake					
Edward Gulpa wetlands				11.9	
Poon-Boon Lakes				16.8	
Gunbower-Koondrook-Pericoota					
Hattah Lakes					
Chowilla floodplains					
Lake Bonney					
Lake Benanee					
Lower Lakes		5,587.3	4,732.6	799.8	
Sub-total		**5,644.9**	**4,732.6**	**831.9**	**0.99**
Region totals	**9,878.0**	**14,438.0**	**30,115.0**	**1,395.0**	

Note: this table only includes the information that is available from MSM-BigMod outputs

The Menindee Lakes storages are owned by New South Wales and are leased to the Murray-Darling Basin Commission. This arrangement gives New South Wales rights over a minimum volume of water in Menindee Lakes to deliver on high security water entitlements, including Broken Hill water supplies. The control of these storages is transferred to New South Wales if the combined storage volume in the lakes is less than 480 GL. Control does not return to the Murray-Darling Basin Commission until the storage volume exceeds 640 GL. When Menindee Lakes are under New South Wales control the Darling River is treated as a New South Wales tributary and consequently its contribution to the Murray is measured at the Burtundy gauge at the end of the Darling River.

The irrigation demands in MSM are predicted using monthly regression equations relating irrigation diversion demands to water resource availability, rainfall and temperature. The regression equations are calibrated over the period 1 July 1983 to 30 June 2000 and represent the demands at year 2000/01 levels of development (MDBC, 2002). The demands can be set at different levels of development by changing the input parameters. For this project, the model was configured for

2000/01 levels of development. There are eight and eleven irrigation demands in New South Wales and Victoria respectively (Table 4-2). South Australian diversions are estimated based on monthly regressions relating demands to rainfall and temperature that are calibrated based on observed behaviour. These demands are capped based on an allocation function that relates to South Australian entitlements. The South Australian allocation function is derived based on observed allocations up to December 2006 (Figure 4-32).

Table 4-2. Modelled Murray region entitlements

	Licence	Model notes
	GL/y	
New South Wales		
High security		Monthly
Local water utility - private diverters	33.3	demand
Stock and domestic - private diverters	14.5	pattern
Sub-total	**47.9**	
Irrigation - NSW Murray Irrigation Limited	3.3	
Irrigation - NSW Western Murray Irrigation Corporation	61	
Irrigation - NSW private diverters	137	
Sub-total	**201.3**	
NSW adaptive environmental water	2	
Sub-total	**251.2**	
General security		
Irrigation - NSW Murray Irrigation Limited	1190.8	
Irrigation - NSW Western Murray Irrigation Corporation	0	
Irrigation - NSW private diverters	479.7	
Sub-total	**1670.5**	
Supplementary access		
Irrigation - NSW Murray Irrigation Limited	221.7	
Irrigation - NSW private diverters	28.3	
Sub-total	**250**	
Conveyance loss		
Irrigation - NSW Murray Irrigation Limited	300	
NSW adaptive environmental water	30	
Sub-total	**330**	
Lower Darling		
High security		
Local water utility	10.1	
Stock and domestic	1.4	
Sub-total	**11.6**	
Irrigation	8.1	
Sub-total	**19.6**	
General security irrigation	31.4	
Supplementary irrigation	250	

Table 4-2 (Cont.). Modelled Murray region entitlements

	Licence	Model notes
	GL/y	
Victoria		
High Reliability Water Share		
Murray Valley	246.1	
Torrumbarry	357.4	
Pental Island	5.4	
Sunraysia RW	98.8	
First Mildura Irrigation Trust	66.2	
Nyah	11.1	
Dartmouth - Barmah private diverters	36.8	
Barmah - Nyah private diverters	27.3	
Mitta private diverters	14	
Millewa, Carwarp and Yelta	0.8	
Nyah - SA private diverters	321.5	
Wimmera Mallee Water	3.5	
Lower Murray Water - river	29.3	
Lower Murray Water - channel	2	
Coliban Water - river	5.1	
Coliban Water - channel	1.2	
Goulburn Valley Water - river	3.6	
Goulburn Valley Water - channel	0.1	
North East Water	12.8	
Flora and fauna	27.6	
Environmental water - The Living Murray	0	
Environmental water - Snowy	7	
Sub-total	**1277.8**	
Low Reliability Water Share		
Murray Valley	111.6	
Torrumbarry	157.2	
Pental Island	2.6	
Sunraysia RW	0	
First Mildura Irrigation Trust	0	
Nyah	0	
Dartmouth – Barmah private diverters	7.3	
Barmah – Nyah private diverters	6.3	
Mitta private diverters	6.7	
Environmental water - The Living Murray	99.1	
Environmental water - Snowy	0	
Sub-total	**390.7**	
Loss allowance		
Murray Valley	96.8	
Torrumbarry	152.4	
Pental Island	0	
Sunraysia RW	7.7	
First Mildura Irrigation Trust	12	
Nyah	0.5	
Millewa, Carwarp and Yelta	5.4	
Sub-total	**274.8**	

Table 4-2 (Cont.). Modelled Murray region entitlements

	Licence	Model notes
	GL/y	
South Australia		
NSW and Victoria allocation to SA		
Diversion entitlement	1154	
Dilution and loss entitlement	696	
Sub-total	**1850**	
SA allocations*		
Metro-Adelaide allocation	130	
Country towns entitlement	50	
Reclaimed swamps entitlement	99	
Other purpose entitlements	502.5	
Sub-total	**781.5**	

* If New South Wales and Victoria allocation to South Australia is <1850 GL/year, restrictions apply to South Australia allocations

Transmission losses for nine river reaches are computed in the model. The losses in the model are made up of low and high flow components. The low flow losses mostly correspond to in-bank flows and are a function of surface area and net evaporation. The high flow losses in the model are estimated as a function of river flow and are applicable only after an overbank flow threshold is reached.

Minimum flows are maintained below Dartmouth, Hume, Menindee (Weir 32), Yarrawonga, Stevens and Euston storages. Minimum flows are also maintained at Doctors Point, Swan Hill, Wentworth, Edward-Gulpa offtake, Edward escape and to the South Australian border (696 GL/year of dilution flows) (Table 4-3). Flow constraints exist between Dartmouth and Hume, Hume outlet, Doctors Point and Yarrawonga channel (Barmah choke).

Environmental flow allocations exist for the Barmah-Millewa Forest (150 GL) and other wetlands (58 GL). Additional dilution flows were agreed in 1989 to improve river salinity subject to Menindee Lakes storage being above the agreed target level (1650 GL in June and July, 1500 GL in August or 1300 GL in any other month) and Hume plus Dartmouth dams have more than 2000 GL in storage volume.

'Off-allocation' in the Murray is declared when Hume Dam spills or Ovens River inflows are in excess of downstream demands and cannot be re-regulated in Lake Victoria. In New South Wales only irrigators with supplementary access licenses can access off-allocation water (Victoria does not announce off-allocation). Off-allocation is declared in the Lower Darling if inflows would lead to Menindee filling to 1680 GL, Lake Victoria filling completely and if flows are in excess of South Australian requirements. Environmental releases are made down the Darling Anabranch when 'off-allocation' is declared in the Lower Darling. The rules for making these releases are not well defined but MSM uses rules that result in a pattern similar to historical releases. These rules limit off-allocation release to 17.5 GL/month in any one month, 33 GL in any two-month period and 120 GL in any 12-month period.

The model does a monthly resource assessment for allocating water to New South Wales and Victoria using a continuous accounting scheme using a June to May water year (Table 4-3). The model covers the sharing of:

- Inflow: 50:50 between New South Wales and Victoria upstream of Albury. 50:50 from the Darling River while Menindee is under Murray-Darling Basin Commission control. All other inflows belong to the state of origin.
- Ceding: Victoria cedes between 51.6 to 66.5 GL/year of Hume inflows to New South Wales in Hume Dam and 50 GL/year of Darling River inflows in Menindee Lakes.
- Storage capacity: Hume and Dartmouth dams and Lake Victoria are shared 50:50 between New South Wales and Victoria. When Menindee is under Murray-Darling Basin Commission control, capacity above 480 GL is shared 50:50 between New South Wales and Victoria. Water in excess of capacity share will be spilled to the other state (internal spill) until the dam physically spills.
- Losses: In-bank losses upstream of the South Australian border are shared 50:50 between New South Wales and Victoria. Overbank losses are shared in proportion to each state's share of the flows.

- South Australian monthly entitlements (1154 GL/year) under Murray-Darling Basin Agreement shared 50:50 between New South Wales and Victoria except under special accounting. Additionally Victoria provides up to 250 ML/day dilution flows to the South Australian border via the Lindsay River.
- Barmah-Millewa Forest allocation (150 GL) shared 50:50 between New South Wales and Victoria.
- Wetland allocation (58 GL): 30 GL/year supplied by New South Wales and 28 GL/year by Victoria.

Special accounting applies when either New South Wales or Victoria is predicted to hold a reserve of less than 1250 GL at the end of May. South Australia is entitled during the periods of special accounting to one-third of the total Murray-Darling Basin Commission resource (that is, excluding tributary inflows) either as a flow or as a reserve limited to a maximum of its entitlement and a reserve of 835 GL. The special reserve is shared equally between New South Wales and Victoria.

Table 4-3. Model water management

Minimum flow requirements	
Dartmouth release	5.6 to 6.2 GL/month
Hume release	19.5 GL/month
Albury (Doctors Point)	33.6 to 37.2 GL/month
Yarrawonga	50 to 56 GL/month
Swan Hill	62 GL/month
Euston (added to Sunraysia demands)	70 to 77.5 ML/month
Wentworth	33.6 to 37.2 GL/month
Weir 32	6.8 to 15.4 GL/month
Edward Gulpa offtake	10 to 29.5 GL/month
Stevens Weir	3.4 to 7.13 GL/month
Edward escape	0 to 2 GL/month
Victorian dilution flows to Lindsay River	250 ML/day
Dilution entitlement flows to SA	58 GL/month
Additional dilution flow to SA	3000 ML/day when Menindee Lakes storage is above the agreed target level (1650 GL in June and July, 1500 GL in August or 1300 GL in any other month) and Hume plus Dartmouth Dams have more than 2000 GL in storage
Flow constraints	
Mitta Mitta channel	9500 ML/day but up to 10,000 ML/day
Hume outlet capacity	100 GL: 460 GL/month to 1780 GL 1550 GL/month
Albury (Doctors Point)	700-775 GL/month shared 52:48 NSW and Victoria
Yarrawonga channel	316 to 425 GL/month shared 39:61 NSW and Victoria
Environment water allocation	
Barmah-Millewa Forest	150 GL/year
Wetlands	NSW 30 GL/year, Victoria 27.6 GL/year
Darling Anabranch environmental release	Extra water released at times of supplementary access
Water sharing	
Inflows upstream of Albury	50:50 NSW: Victoria
Inflows to Menindee	50:50 NSW: Victoria when Menindee is under Murray-Darling Basin Commission control, 100% NSW otherwise
All other Victorian inflows	100% Victoria
All other NSW inflows	100% NSW
SA entitlement flow	Dilution and loss entitlement = 696 GL
	Diversion entitlement = 1154 GL
	Total entitlement = 1850 GL supplied 50:50 NSW: Victoria
All water entering in SA	100% SA
Losses to SA border	Regulated flow: 50:50 NSW: Victoria, overbank in proportion to flow
Losses in SA	100% SA

Table 4-3 (Cont.). Model water management

Ceding	
	Victoria cedes 51.6-66.8 GL/year to NSW from Hume inflows
	Victoria cedes 50 GL/year to NSW from Menindee inflows
Continuous accounting between states	
	Continuous accounting according to the Murray-Darling Basin Agreement. Monthly accounts kept of NSW and Victorian shares of inflows, flows, diversions and losses. The state order required to meet downstream demand is used to define the sharing of releases from storages
State allocations	
	Assessments are made each month of the water available to each state. These are based on the shares of the water in storage, the forecast inflows and losses to the end of May, and water used to date
Special accounting with SA	
Purpose	To determine SA's restricted allocation in times of scarce resource
Instigation	Once an upper state's forecast reserve at 31 May drops below 1250 GL
Available water	Based on forecast resource under Murray-Darling Basin Commission control
SA entitlement	SA has the lesser of one-third of the available water and the diversion entitlement up to 1154 GL plus the dilution and loss entitlement of 696 GL
Minimum reserve	835 GL share 50:50 by NSW and Victoria
Menindee operation	
NSW control commences	When storage drops below 480 GL
Murray-Darling Basin Commission control resumes	When storage goes above 640 GL
Sharing under Murray-Darling Basin Commission control	Shared 50:50 NSW and Victoria. Shares when it goes under NSW control are restored when it returns to Murray-Darling Basin Commission control
State allocation system (water year July to June)	
1. NSW: Murray annual allocation	Annual allocation based on water allocated to state
	Four basic types of entitlement:
	High security - first priority
	Conveyance allowance - covers losses in irrigation districts
	General security - share remaining state allocation
	Supplementary access - only available at times of surplus flow and announced supplementary flow
	General security entitlements are permitted to carryover their unused allocation up to 50% of their entitlement but may not use more than 100% of their entitlement in any year
2. NSW: Lower Darling	Supplementary access
3. Vic: Murray annual allocation	Annual allocation based on water allocated to state
	Two basic types of entitlement:
	High Reliability Water Share (HRWS) – first priority
	Low Reliability Water Share (LRWS) – available only when reserve is sufficient to guarantee HRWS in next year
Supplementary access	
NSW Murray	If spills from Hume and unregulated flows from tributaries are in excess of downstream demands including SA
Lower Darling	If Menindee Lakes are spilling and Lake Victoria will spill, water will flow to SA
Internal spills	
	Each state's share of the allocation is stored on their respective sides of the storages. If storage of one state is full then it's account internally spills to other state

BigMod

BigMod is a daily time step model that relies on MSM to determine diversions, transfers of water between storages, operation of regulated branches such as the Edward and Gulpa offtakes, calculation of target storage volumes for flood mitigation or environmental needs and target flows required to meet: minimum flow criteria, environmental target flows and the supply to South Australia. BigMod commences at Dartmouth Dam and Weir 32 and finishes at the barrages between Lake Alexandrina and the sea. Using this information BigMod does its own ordering process for meeting daily demand and also manages daily flood operation of storages and the compliance with the maximum daily rates of rise and fall. It also routes flow and salt throughout the system and manages the flushing rules for Lake Victoria that are dependent on flow and salinity levels. It also models the operation of the Barr Creek Salinity Reduction Scheme. The key outputs from BigMod are daily flow, salinity and water levels. More detailed descriptions of BigMod can be found in Murray-Darling Basin Commission (2002) and Close (1996a and b). BigMod represents the Murray system with 189 river reaches. There are14 natural lakes, 23 weir pools, 60 branches, 64 tributary inflows and 11 point diversions.

Upstream models

The Murray models receive inflows from the Menindee IQQM; Murrumbidgee IQQM at Balranald gauge (410130) and Billabong Creek at Darlot gauge (410134); the Snowy Hydro model (as Murray 1 Power Station releases and estimates of assured releases for current SMHS water year) as well as without-development inflows from Geehi and Tooma dam subcatchments; the Ovens REALM at Peechelba; and the Goulburn Simulation Model (GSM) REALM at McCoy's Bridge, Rochester and Appin South. MSM-BigMod also receives diversions from the Ovens REALM at Peechelba; allocations from the GSM for the Goulburn, Campaspe and Loddon systems; and spills from Eildon Dam, Campaspe River and Loddon River. MSM provides Menindee lake storage volumes to the New South Wales Barwon-Darling model; forecasts of South Australian surplus flow to South Australia; and the New South Wales effective allocation (excluding supplementary) to the Murrumbidgee model. These variables are used in the Murrumbidgee model to provide surplus flows to the Lowbidgee Irrigation District. The connection of models and feedbacks required to run MSM-BigMod are shown in Figure 4-2. The weekly and monthly inputs from the REALM and Snowy Hydro models are disaggregated using a daily historical flow pattern.

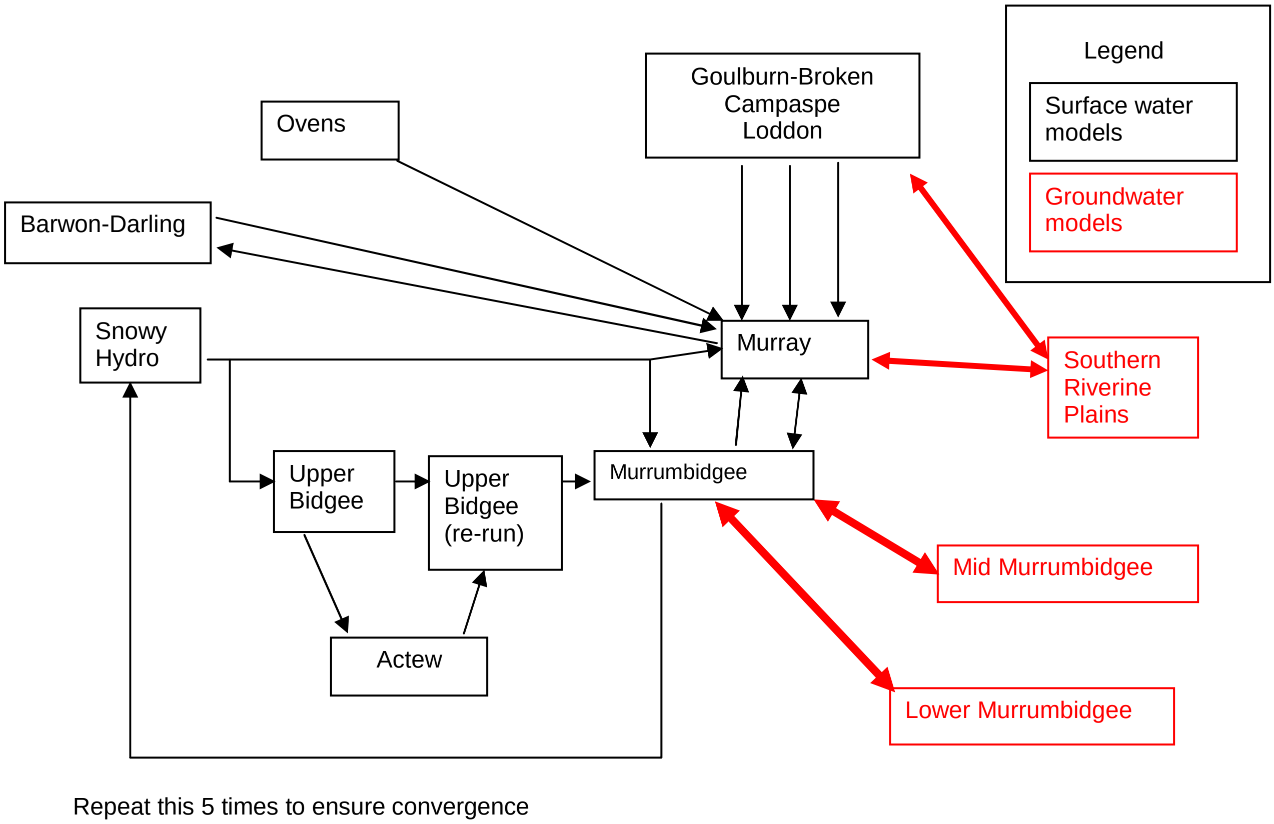


Figure 4-2. Connections of models in the Murray River system

4.2.3 Model setup

The original Murray system model and associated MSM-BigMod executable code were obtained from the Murray-Darling Basin Commission. This model was run for the original period of 1 May 1891 to 30 April 2006 and validated against previous results. This model was modified subsequently to include 99.1 GL of Victorian sales water transferred to the environment for the Living Murray Initiative of the Murray-Darling Basin Commission (MDBC, 2008) and a 7 GL Victorian Murray entitlements transfer to the Snowy River. The 99.1 GL is only part of the 500 GL to be allocated to the Living Murray Initiative that is considered. The model was also modified to accept outputs from the Ovens model at Peechelba rather than historical flows at Greta and Wangaratta, accept inputs from the Southern Riverine Plains groundwater model and be able to run in batch mode in the river modelling framework. Some additional modifications were required so the model would operate robustly in extremely dry conditions.

The time series rainfall, evaporation and flow inputs to this model did not require extension as it had been done by the Murray-Darling Basin Commission. However transfers from the Barwon-Darling model were adjusted to include recent model results for the Barwon-Darling IQQM starting from 1 January 1891 to 30 June 2006. This required an adjustment to the time series of flows that are used to make peaks from the Barwon-Darling model match historical observed peaks at Menindee. Many of the upstream models were recalibrated but they had different settings to the water sharing plan so a new set of inflows were used. The flows for Broken Creek at Rices Weir were recalculated using the existing regression relationship and new climate and flow data.

A without-development version of the Murray models was created by removing all public storages (including locks and barrages), all irrigators, fixed demands and South Australian requirements. The releases from Murray 1 Power Station were replaced by natural flows from the Geehi and Tooma catchments and a 526 GL SMHS release. This value represents the average difference between the natural flows and the SMHS 1062 GL release.

The Murray system contains a large amount of public and private storage. The initial state of these storages can influence the results obtained. As the Murray models start with a warm-up period from 1 May 1895 to 30 June 1895 the initial state of public storages was required. To do this the models were started with all of the storages empty and run up to 30 April 1895. This was repeated with all of the storages initially full. The results of this analysis are presented in Table 4-4 and show that under both cases the storages converged to a similar result. Each storage was configured with this volume.

Table 4-4. Model setup information

Model setup information		Version	Start date	End date
Original model				
Murray River and Lower Darling	MSM-BigMod (Murray20-10.exe, BIGMODver10-5.exe)	3.1.3	01/5/1891	30/4/2006
Connection				
Snowy to Murray	Murray 1 release, Geehi inflows (401560), Tooma inflows (401565), Dry Inflow Sequence Volume			
Murrumbidgee to Murray and feedback	Murrumbidgee River and Billabong Creek outflow to Murray at Balranald (410130) and Darlot (410134) respectively. No explicit feedback from Murray			
Darling to Murray and feedback	Barwon-Darling model provides Lake Wetherell inflows, Talyawalka flows and Bourke flows. Extra floods added to Menindee inflows to match historical records. No explicit feedback from Murray			
Ovens to Murray	Ovens model outflows to Murray at Wangaratta including 15 Mile Creek at Greta South. Ovens diversion calculated by MSM			
Broken Creek to Murray	MSM regression relationship with climate variables and Goulburn McCoy's Bridge flows used to calculate flows at Rices Weir (404210)			
GSM to Murray	Goulburn-Broken, Campaspe and Loddon Rivers outflow to Murray at McCoy's Bridge (405232), Rochester (406202) and Appin South (407205) respectively. Goulburn allocation (%) also provided			
Avoca to Murray	Avoca is represented in MSM as one of three Torrumbarry tributaries, the other two being Mt. Hope and Barr creeks			

Table 4-4 (Cont.). Model setup information

Model setup information		Version	Start date	End date
Baseline models				
Warm-up period			01/5/1895	30/6/1895
Murray River and Lower Darling	MSM-BigMod (Murray-V324.exe, BigMod-V44.exe)	3.1.3	01/7/1895	30/6/2006
Connection				
Snowy to Murray	SMHS provides Murray1 releases and an estimate of release for current SMHS water year (Dry Inflow Sequence Volume) including Geehi (401560) and Tooma (401565) flows for without-development condition. Disaggregation of SMHS outputs from monthly to daily			
Murrumbidgee to Murray and feedback	Murrumbidgee outflows to Murray at Balranald (410130) and Billabong Creek at Darlot (410134). Murray provides following feedback to Murrumbidgee - 75% exceedance forecast SA surplus flow to May and NSW effective allocation excluding supplementary (%)			
Darling to Murray and feedback	Darling model provides inflows to Lake Wetherell, Talywaka flows and Bourke flows. Modified extra floods for Menindee. Murray feedbacks Darling with Menindee storage volume			
Ovens to Murray	Ovens outflows to Murray at Peechelba (403241) and Ovens diversion supplied by Ovens model. Disaggregation of Ovens outputs from weekly to daily			
GSM to Murray	Goulburn outflows to Murray at McCoy's Bridge (405232), Campaspe at Rochester (406202) and Loddon at Appin South (407205). Also included are (1) allocation (%) for Goulburn, Campaspe and Loddon; and (2) spills for Goulburn (at Eildon), Campaspe and Loddon. Disaggregation of GSM outputs from monthly to daily			
Broken Creek to Murray	MSM regression relationship with climate variables and Goulburn McCoy's Bridge flows used to calculate flows at Rices Weir (404210)			
Avoca to Murray	Represented in MSM as one of three Torrumbarry tributaries, the other two being Mt Hope and Barr creeks			
Murray River modifications				
Model	MSM-BigMod substantially modified to link-up with other models. Modification included incorporation of Victorian unbundling of sales package and The Living Murray water recovery measures, groundwater loss nodes, changes to Ovens model, Snowy Hydro model, GSM. Development of batch scripts and changes to MSM-BigMod to run in batch mode within the Murray-Darling Basin Sustainable Yields cluster. During the process a number of bugs were also fixed			
Data	Extend to 30/6/2006			
Inflows	SMHS Dry Inflow Sequence Volume, Ovens outflows, and modification of extra flood added to Menindee inflows, inclusion of groundwater loss nodes, GSM spills, Campaspe and Loddon allocations. Disaggregation of GSM, Ovens and Snowy Hydro model outputs from weekly/monthly to daily			
Diversions	Not estimated by MSM. Weekly Ovens diversions from Ovens model disaggregated to daily			
Groundwater loss nodes	Configured to the 8 MSM reaches. GWloss02 (reach between Yarrawonga Weir to Torrumbarry), GWloss03 (reach between Edward River offtake to Stevens Weir), GWloss04 (reach between Torrumbarry to Wakool Junction), GWloss06 (reach between Stevens Weir to Kyalite)			
Groundwater gain nodes	GWloss01 (reach between Albury and Yarrawonga Weir)			
Initial storage volume Dartmouth Dam (GL)	3577.3			
Initial storage volume Hume Dam (GL)	2075.5			
Initial storage volume Lake Victoria (GL)	396.0			
Initial storage volume Menindee Lakes (GL)	1678.7			
Lake Cawndilla (GL)	662.4			
Lake Menindee (GL)	675.3			
Lake Pamamaroo (GL)	254.8			
Lake Wetherell (GL)	86.2			

Table 4-4 (Cont.). Model setup information

Warm-up test results				
Setting initial storage volumes	Storages commence		Difference	Percent of full volume
	empty	full		
	GL		percent	
Initial storage volume Dartmouth Dam (GL) 30/4/1895	3595.8	3558.8	-1.03%	-0.95%
Initial storage volume Hume Dam (GL) 30/4/1895	2057.1	2094.0	1.8%	1.22%
Initial storage volume Lake Victoria (GL) 30/4/1895	396.0	396.0	0%	0%
Initial storage volume Menindee Lakes (GL) 30/4/1895	1678.7	1678.7	0%	0%
Lake Cawndilla (GL)	662.4	662.4	0%	0%
Lake Menindee (GL)	675.3	675.3	0%	0%
Lake Pamamaroo (GL)	254.8	254.8	0%	0%
Lake Wetherell (GL)	86.2	86.2	0%	0%
Natural water bodies storage volume 30/4/1895				
Storage volume 30 April (1895-2006)	Mean	Median		
	GL			
Dartmouth Dam	2892.5	3286.0		
Hume Dam	1068.6	1146.6		
Lake Victoria	376.3	396.0		
Menindee Lakes	827.7	547.8		
Lake Cawndilla	267.3	243.2		
Lake Menindee	261.0	100.0		
Lake Pamamaroo	200.0	228.0		
Lake Wetherell	99.4	74.4		
Natural water bodies				
Robustness test results				
Minimum allocation (%)				
NSW declared allocation	0%			
Vic declared allocation	0%			
SA announced allocation	34%			
Minimum storage volume (GL)				
Dartmouth Dam (DSV 80 GL)	79.3			
Hume Dam (DSV 30 GL)	29.3			
Lake Victoria (DSV 86 GL)	118.5			
Menindee Lakes (DSV 0 GL)	0.7			
Lake Cawndilla	0			
Lake Menindee	0			
Lake Pamamaroo	0			
Lake Wetherell	0.5			

The model was configured for an extreme dry climate scenario by applying seasonal factors to rainfall, evaporation and inflows (Table 4-5). The model was run and behaved robustly, allocations reached zero percent for 16.3 years in New South Wales and 9.6 years in Victoria (out of 111 years) while Hume Dam was below dead storage.

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

Season	Rainfall	Evaporation	Flow
Upper Murray			
DJF	0.97	1.06	0.95
MAM	0.95	1.05	0.80
JJA	0.83	1.05	0.45
SON	0.83	1.06	0.64
Lower Murray			
DJF	0.98	1.06	
MAM	0.90	1.06	
JJA	0.76	1.05	
SON	0.86	1.06	

4.3 Modelling results

4.3.1 River system water balance

The mass balance table (Table 4-6) shows the net fluxes for the Murray River system. Scenario O fluxes, Scenario A0 (without groundwater at dynamic equilibrium) and Scenario A (with groundwater at dynamic equilibrium) fluxes are displayed as GL/year, while all other scenarios are presented as a percentage change from Scenario A. The averaging period for Scenario O differs from all other scenarios and inflows into the Murray model are for corresponding scenarios in all upstream regional models. The directly gauged inflows represent model inflows based on a river gauge or upstream model. The indirectly gauged inflows represent the inflows that are derived to achieve mass balance between mainstream gauges. Diversions are listed by different water products in the region. End-of-system flows are shown for the Murray River at the Lower Lakes barrages. The change in storage between 30 June 1895 and 30 June 2006 averaged over the 111-year period is also included.

Appendix B contains mass balance tables for the eight reaches in the model. The mass balance of each of these river reaches and the overall mass balance were checked by calculating the difference between total inflows and outflows of the system (including the difference in starting and ending storage for the river reaches and major reservoirs). There was a difference of less than 0.4 percent in all cases.

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

	O	A0	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/5/1891	01/7/1895									
Model end date	30/4/2006	30/6/2006									
	GL/y				percent change from Scenario A						
Storage volume											
Change over period	-41.2	-44.0	-16.0	-44.4	48%	8%	29%	59%	12%	32%	59%
Inflows											
Up-stream model inputs											
Darling (inflow Menindee Lakes)	2,131.9	1,787.4	2,943.8	1,782.7	0%	47%	-10%	-35%	43%	-13%	-38%
Murrumbidgee Balranald	1,124.8	1,152.4	2,865.4	1,151.9	-54%	23%	-19%	-47%	21%	-21%	-49%
Murrumbidgee Darlot	292.1	322.3	84.8	328.6	-35%	13%	-11%	-34%	11%	-12%	-35%
SMHS releases	1,169.6	1,164.5	526.3	1,164.5	-22%	4%	-5%	-18%	4%	-5%	-18%
Ovens at Peechelba	1,754.3	1,751.8	1,775.7	1,751.8	-27%	2%	-13%	-46%	1%	-14%	-46%
Goulburn at McCoy's Bridge	1,631.2	1,585.1	3,233.1	1,585.3	-58%	-5%	-22%	-62%	-6%	-23%	-62%
Campaspe at Rochester	159.1	154.5	274.8	154.5	-76%	-10%	-27%	-69%	-12%	-29%	-71%
Loddon at Appin South	62.9	54.2	122.3	54.0	-60%	-7%	-23%	-55%	-7%	-24%	-55%
Sub-total	**8,326.1**	**7,972.1**	**11,826.1**	**7,973.0**	**-32%**	**14%**	**-14%**	**-43%**	**12%**	**-15%**	**-44%**
Murray subcatchments											
Directly gauged	4,199.3	4,122.2	4,771.5	4,098.1	-25%	4%	-12%	-39%	2%	-14%	-40%
Indirectly gauged	479.1	470.9	257.2	470.9	-19%	4%	-6%	-27%	4%	-6%	-27%
Groundwater inflows	0.0	0.0	0.0	0.6	-100%	99%	-40%	-100%	64%	-52%	-100%
Sub-total	**4,678.4**	**4,593.2**	**5,028.7**	**4,569.6**	**-24%**	**4%**	**-12%**	**-38%**	**3%**	**-13%**	**-39%**
Sub-total	**13,004.5**	**12,565.3**	**16,854.9**	**12,542.6**	**-29%**	**10%**	**-13%**	**-41%**	**9%**	**-14%**	**-42%**
Diversions											
NSW diversions											
NSW Murray diversions											
High security	147.5	147.7	0.0	147.8	2%	-2%	2%	5%	-2%	2%	5%
General security	1,165.4	1,166.4	0.0	1,163.9	-25%	2%	-9%	-38%	1%	-10%	-39%
Supplementary	187.1	186.8	0.0	188.5	-39%	-5%	-14%	-55%	-9%	-16%	-58%
Conveyance	378.3	380.9	0.0	379.7	-14%	1%	-6%	-19%	0%	-6%	-19%
Sub-total	**1,878.4**	**1,881.7**	**0.0**	**1,879.9**	**-22%**	**1%**	**-8%**	**-32%**	**-1%**	**-9%**	**-33%**
Lower-Darling diversions											
Cap diversions	127.4	114.8	0.0	113.0	-2%	23%	-7%	-29%	20%	-8%	-30%
Anabranch supplementary	18.1	13.8	0.0	13.7	-14%	41%	-12%	-55%	38%	-14%	-60%
Sub-total	**145.4**	**128.6**	**0.0**	**126.7**	**-3%**	**25%**	**-7%**	**-32%**	**22%**	**-9%**	**-33%**
NSW sub-total	**2,023.8**	**2,010.3**	**0.0**	**2,006.6**	**-21%**	**2%**	**-8%**	**-32%**	**1%**	**-9%**	**-33%**
Victoria Cap diversions	**1,653.1**	**1,646.1**	**0.0**	**1,646.9**	**-7%**	**0%**	**-1%**	**-18%**	**0%**	**-1%**	**-18%**
South Australia diversions	**634.8**	**634.3**	**0.0**	**634.7**	**-2%**	**-1%**	**0%**	**-6%**	**-1%**	**0%**	**-6%**
Sub-total	**4,311.7**	**4,290.6**	**0.0**	**4,288.2**	**-13%**	**1%**	**-4%**	**-23%**	**0%**	**-5%**	**-23%**
Outflows											
End-of-system flow											
Barrage flow	4800.3	4764.9	12232.8	4732.6	-50%	20%	-24%	-69%	17%	-26%	-70%
Net evaporation											
Public storages	593.5	563.2	399.6	562.9	-4%	15%	-1%	-12%	13%	-3%	-13%
Natural water bodies and floodplains	2164.8	1811.3	3153.1	1802.2	-36%	14%	-18%	-47%	12%	-19%	-48%
Sub-total	**2758.3**	**2374.5**	**3552.7**	**2365.2**	**-29%**	**14%**	**-14%**	**-39%**	**13%**	**-15%**	**-39%**
Other losses											
River groundwater loss	0	0	0	25.8	-55%	-6%	-25%	-71%	-2%	-21%	-68%
South Australia loss	1135.2	1134.5	1080.9	1134.6	-4%	0%	1%	2%	0%	1%	2%
Sub-total	**8693.8**	**8273.9**	**16866.4**	**8258.1**	**-38%**	**15%**	**-18%**	**-50%**	**13%**	**-19%**	**-51%**
Unattributed fluxes											
Total	**40.1**	**44.8**	**4.5**	**40.7**	**23%**	**1%**	**3%**	**42%**	**1%**	**6%**	**45%**

4.3.2 Inflows and water availability

Inflows

The total inflows into the Murray region under without-development conditions are estimated to be 16,855 GL/year on average, of which 11,826 GL/year (70 percent of the total inflow) is contributed by upstream regions. Under current conditions (Scenario A), inflows to the Murray region have been reduced by 26 percent to 12,543 GL/year on average – largely due to development in upstream regions. Table 4-6 also shows a change in inflows within the region from Scenario P to Scenario A. The directly gauged inflows differ between scenarios P and A because Scenario P includes 638 GL/year of inflows from the Geehi and Tooma catchments above these reservoirs. In Scenario A these are included as SMHS releases. The indirectly gauged inflows differ between scenarios P and A because the regression relationship used to derive these flows does not include the drainage returns from Broken Creek and downstream of Albury for Scenario P.

Comparing between regions, different fractions of inflows are estimated as part of model calibration, and the approaches used to calibrate these inflows varies between model implementations. Inflows are either inflated and subsequently compensated for by loss relationships or the losses are inherent in the inflows. For this reason, totalling inflows does not provide a consistent assessment of the total surface water resource between regions.

An alternative to totalling modelled inflows is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated as 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.

A degree of streamflow leakage induced by current groundwater use in the region is implicitly included in the river model calibration. An adjustment to the modelled without-development water availability is required to assess the total without-development surface water availability as this is water that is removed from the river due to groundwater extraction. No adjustments have been made in determining surface water availability under scenarios A, B and C for the impacts of existing farm dams or changes in forest cover. Thus the without-development model is not a representation of pre-European settlement conditions. These impacts are not included as they are difficult to quantify and are not relevant for guiding future policy.

This approach can be repeated for each of the climate scenarios by running the without-development model with each of the corresponding climate scenario flow inputs from the without-development upstream regional models. The Lower Darling inflows are explicitly included as this system is modelled from Menindee Lakes to Burtundy gauge and inflows are considered at the Wentworth gauge just below the Darling River confluence.

A comparison between scenarios for reaches along the Murray is shown in Figure 4-3. The transect starts at Khancoban in the upper Murray and ends at the barrages in the Lower Lakes. Displaying this transect for the Murray system is difficult as there are anabranch networks along the system. The Edward-Gulpa flow escapes from the Murray River main stem through the braided network. This is captured by adding Deniliquin flow (409003) to three reaches (Barmah (409215), Echuca (409200) and Torrumbarry (409207)). Similarly, Billabong Creek flow at Liewah (409035) and Wakool system flow at Stony-Crossing (409013) are included in the Swan Hill (409204) flow to get the correct system flow.

The location (using this description of the system) of maximum average annual mainstream flow occurs at the Wentworth gauge (425010) just below the Darling River confluence. The maximum modelled average annual flow is 14,459 GL/year (this value includes 782 GL/year from the net effect (at Wentworth) of SMHS inter-basin transfers to both the Murray and Murrumbidgee regions) under Scenario A.

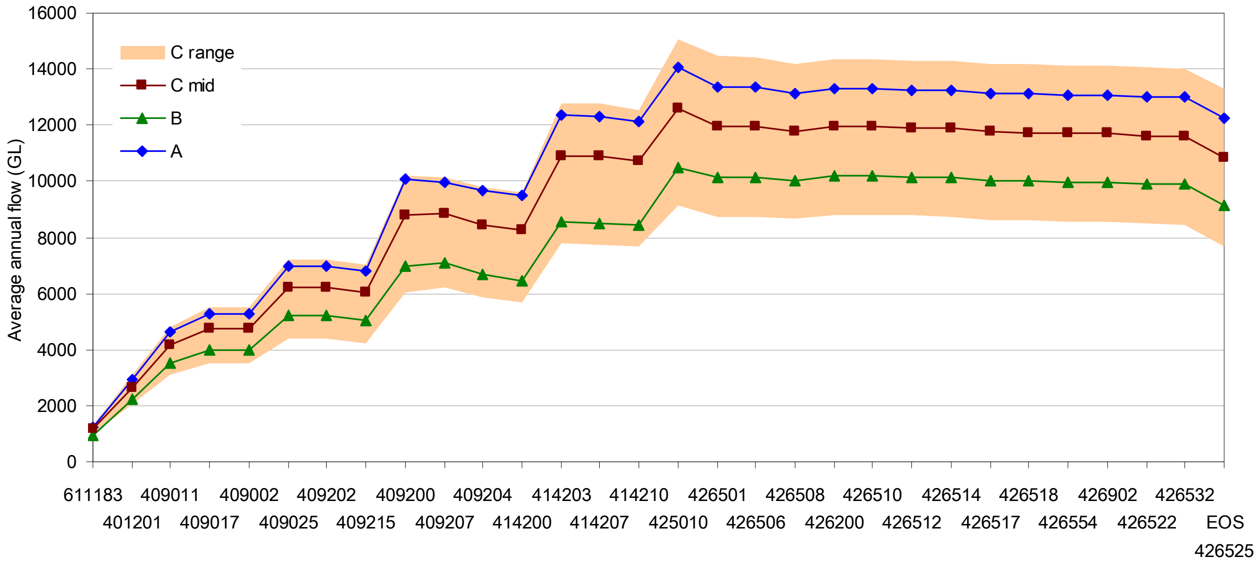


Figure 4-3. Transect of total river flow under scenarios A, B and C

Water availability

For all 'primary' regions – that is, regions with no upstream regions – water availability is simply a function of climate and is assessed for scenarios A, B and C under without-development conditions. An assessment of this type is given here for the entire MDB. However, in determining the water availability for the Murray region both the climate and usage in upstream regions needs to be considered as this reduces the tributary inflows to the Murray region.

The entire MDB water availability assessment presented (in Table 4-7) shows (in GL/year):

- the upstream (without-development) regional contributions to Wentworth flows
- adjustment for groundwater use implicit in upstream model calibrations
- Murray region (without development) contributions to Wentworth flows
- the reductions in mainstream flow (at the point of maximum flow) caused by leakage that is induced by the current groundwater use that is implicitly included in the Murray river model calibration. Groundwater use that is implicit in the Murray calibration is added to the water availability
- adjustment for the contribution to Wentworth flows of the SMHS transfers into the Murrumbidgee and the Murray
- the total surface water availability for the MDB which is the sum of the above components.

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

	A	B	Cwet	Cmid	Cdry
Upstream region contributions to Wentworth flows (without-development)	GL/y				
Ovens	1,521	1,105	1,540	1,314	827
Loddon-Avoca	114	60	108	95	62
Campaspe	255	117	243	212	136
Goulburn-Broken	3,004	1,758	2,916	2,579	1,646
Murrumbidgee	2,554	1,754	2,841	2,308	1,795
Leakage induced by current groundwater use implicit in Murrumbidgee calibration	8	8	8	8	8
Darling basin	1,800	1,875	2,377	1,656	1,297
Leakage induced by current groundwater use implicit in Condamine-Balonne calibration	1	1	1	1	1
Reductions in Namoi inflows caused by current groundwater use	3	3	3	3	3
Leakage induced by current groundwater use implicit in Namoi calibration	22	22	22	22	22
Sub-total	**9,282**	**6,703**	**10,059**	**8,197**	**5,797**
Murray region contributions to Wentworth flows (without-development)					
Snowy-Murray inter-basin transfer	490	321	485	467	386
Geehi and Tooma catchments	595	444	640	528	421
Other	4,126	3,080	4,265	3,620	2,552
Leakage induced by current groundwater use implicit in Murray calibration	0	0	0	0	0
Sub-total	**5,211**	**3,846**	**5,391**	**4,614**	**3,358**
Modelled without-development Wentworth mainstream flow	**14,493**	**10,548**	**15,450**	**12,811**	**9,155**
		percent change from Scenario A			
Change in average surface water availability		-27%	7%	-12%	-37%

A time series of total annual surface water availability for the entire MDB under Scenario A is shown in Figure 4-4. The lowest annual total surface water availability was 3194 GL in 1914 while the greatest was 43,589 GL in 1956. Figure 4-5 shows the difference in annual total surface water availability for the entire MDB under scenarios B and C relative to Scenario A.

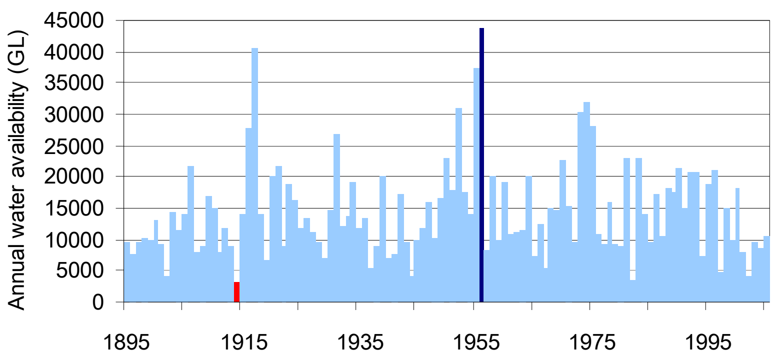


Figure 4-4. Murray-Darling Basin surface water availability under Scenario A

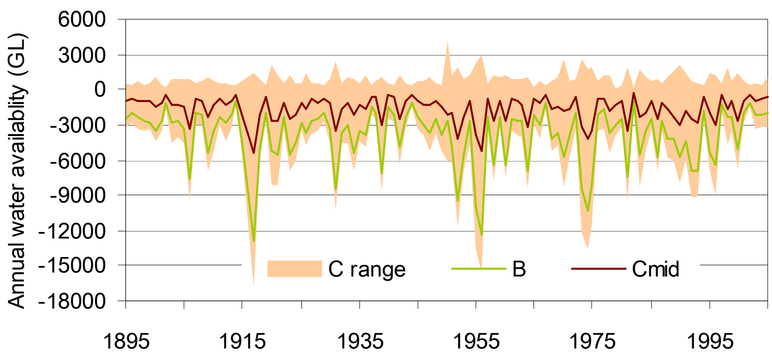


Figure 4-5. Time series of change in Murray-Darling Basin surface water availability relative to Scenario A under scenarios B and C

The Murray region water availability assessment is presented (in Table 4-8) and shows (in GL/year):

- the upstream regional contributions to Wentworth flows under current development conditions
- adjustment for groundwater use implicit in upstream model calibrations
- Murray region (without-development) contributions to Wentworth flows
- the reductions in mainstream flow (at the point of maximum flow) caused by leakage that is induced by the current groundwater use that is implicitly included in the Murray river model calibration. Groundwater use that is implicit in the Murray calibration is added to the water availability
- adjustment for the contribution to Wentworth flows of the SMHS Murray 1 transfers into the Murray
- the total surface water availability for the Murray region which is the sum of the above components.

Table 4-8. Annual water availability for the Murray region under Scenario A and relative change under scenarios B and C (assessed for without-development conditions, which for Scenario A is synonymous with Scenario P)

	A	B	Cwet	Cmid	Cdry
Upstream region contributions to Wentworth flows (current development)			GL/y		
Ovens	1,563	1,219	1,560	1,360	886
Loddon-Avoca	52	22	48	40	25
Campaspe	149	38	133	110	48
Goulburn-Broken	1,534	686	1,430	1,196	613
Murrumbidgee	1,482	796	1,760	1,229	864
Leakage induced by current groundwater use implicit in Murrumbidgee calibration	8	8	8	8	8
Darling basin	1,136	1,213	1,636	1,025	768
Leakage induced by current groundwater use implicit in Condamine-Balonne calibration	1	1	1	1	1
Reductions in Namoi inflows caused by current groundwater use	3	3	3	3	3
Leakage induced by current groundwater use implicit in Namoi calibration	22	22	22	22	22
Sub-total	**5,951**	**4,007**	**6,600**	**4,994**	**3,238**
Murray region contributions to Wentworth flows (without-development)					
Snowy-Murray inter-basin transfer	490	321	485	467	386
Geehi and Tooma catchments	595	444	640	528	421
Other	4,126	3,080	4,265	3,620	2,552
Leakage induced by current groundwater use implicit in Murray calibration	0	0	0	0	0
Sub-total	**5,211**	**3,846**	**5,391**	**4,614**	**3,358**
Modelled without-development Wentworth mainstream flow	**11,162**	**7,853**	**11,991**	**9,608**	**6,597**
		percent change from Scenario A			
Change in average surface water availability		-30%	7%	-14%	-41%

A time series of total annual surface water availability for the Murray region under Scenario A is shown in Figure 4-6. The lowest annual total surface water availability was 6075 GL in 1914 while the greatest was 47,592 GL in 1956. Figure 4-7 shows the difference in annual total surface water availability for the Murray region under scenarios B and C relative to Scenario A.

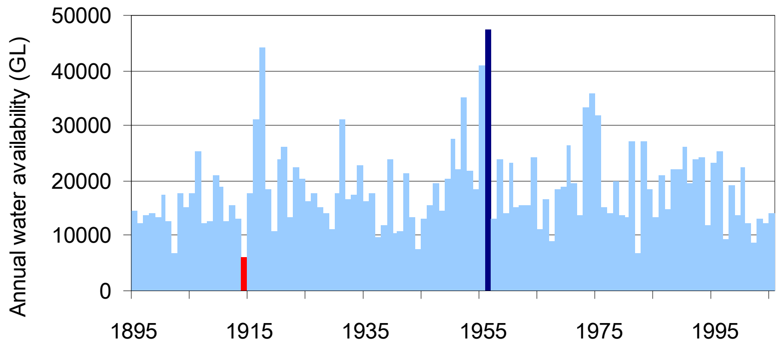


Figure 4-6. Murray region surface water availability under Scenario A

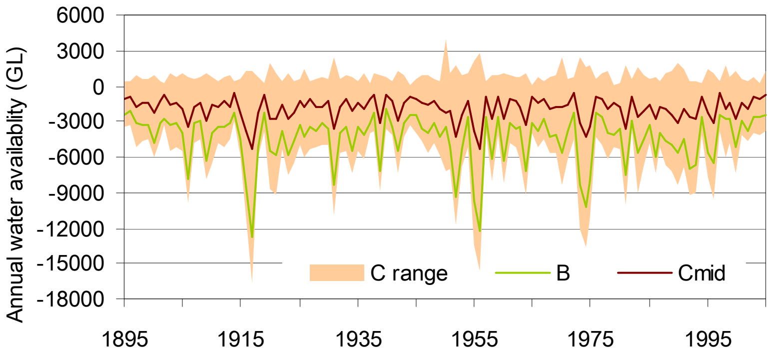


Figure 4-7. Time series of change in Murray region surface water availability relative to Scenario A under scenarios B and C

4.3.3 Storage behaviour

The modelled behaviour of major public storages gives an indication of the level of regulation of a system as well as how reliable the storage is during extended periods of low or no inflows. Table 4-9 provides indicators that show the lowest recorded storage volume and the corresponding date for Dartmouth Dam, Hume Dam, total Menindee storage and Lake Victoria storage for each of the scenarios. The average and maximum years between spills are also provided. The period of time that Menindee Lakes storages are under New South Wales control has also been included. The period between spills for this project 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 distorting the analysis.

Table 4-9. Details of storage behaviour

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Dartmouth Dam								
Minimum storage volume (ML)	103,132	79,285	171,097	79,937	79,298	127,128	79,937	79,102
Minimum storage date	03/1903	01/2003	03/1903	04/1915	02/1968	03/1903	04/1915	01/1939
Average years between spills	3.8	12.2	4.2	6.3	30.2	3.5	7.0	30.3
Maximum years between spills	14.8	34.2	12.8	21.0	60.0	12.8	21.0	60.1
Hume Dam								
Minimum storage volume (ML)	29,995	29,268	29,997	29,932	29,284	70,400	29,999	29,284
Minimum storage date	03/2003	01/2003	03/1983	03/1903	02/1903	03/2003	04/1905	02/1903
Average years between spills	1.4	4.1	1.3	2.1	6.8	1.3	2.2	8.7
Maximum years between spills	10.8	12.8	10.8	11.7	21.8	10.8	11.7	33.8
Menindee Lakes system								
Minimum storage volume (ML)	6,335	8,648	16,547	2,538	682	11,901	1,309	1,009
Minimum storage date	02/1945	01/2004	01/2004	02/1981	02/1981	01/2004	01/1981	02/1981
Average years between spills	3.7	3.9	2.4	4.1	7.7	2.4	4.3	7.7
Maximum years between spills	28.7	28.7	18.5	28.7	28.7	18.5	28.7	28.7
Percentage of time under NSW control	45.3%	52.0%	28.2%	51.9%	65.2%	29.2%	54.0%	67.0%
Lake Victoria								
Minimum storage volume (ML)	129,602	82,762	119,540	142,984	123,674	118,080	148,116	120,730
Minimum storage date	01/2003	05/2003	01/1983	03/1920	02/1906	01/1983	02/1983	03/1898
Average years between spills	0.4	0.5	0.4	0.4	0.6	0.4	0.5	0.6
Maximum years between spills	1.8	2.4	1.8	2.2	2.5	1.8	2.2	2.7

The time series of storage behaviour for Dartmouth Dam, Hume Dam, total Menindee storage and Lake Victoria storage for the maximum period between spills for each of the scenarios are shown in Figure 4-8 to Figure 4-11.

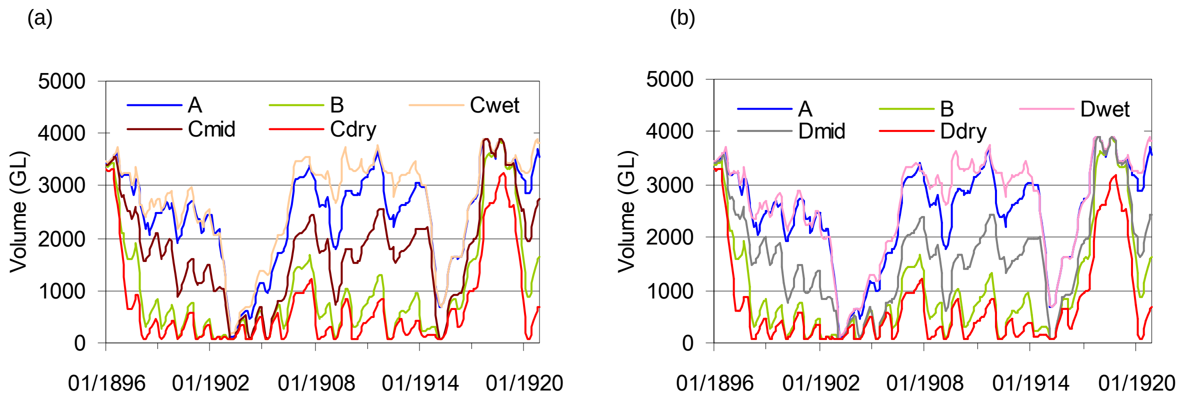


Figure 4-8. Dartmouth Dam behaviour over the maximum days between spills under Scenario A (11/1896 to 09/1911), and change in storage behaviour under (a) scenarios B and C and (b) scenarios B and D

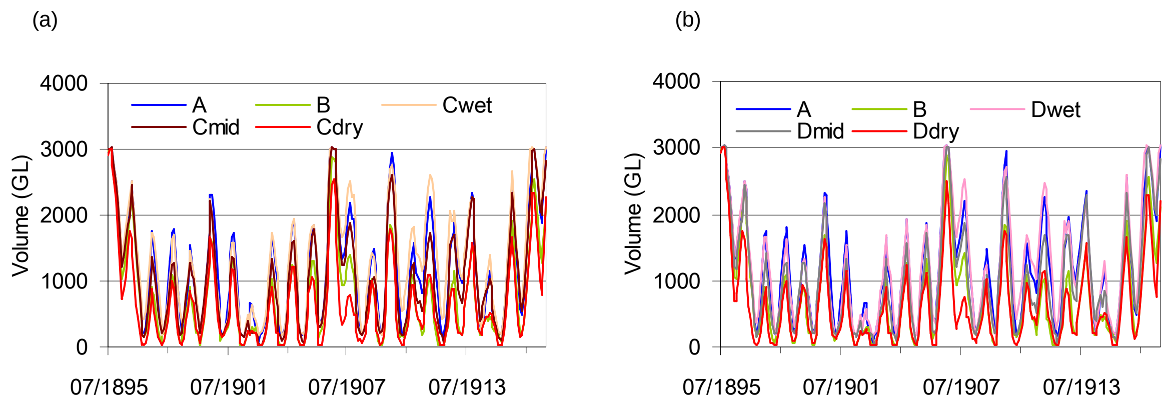


Figure 4-9. Hume Dam behaviour over the maximum days between spills under Scenario A (12/1895 to 09/1906), and change in storage behaviour under (a) scenarios B and C and (b) scenarios B and D

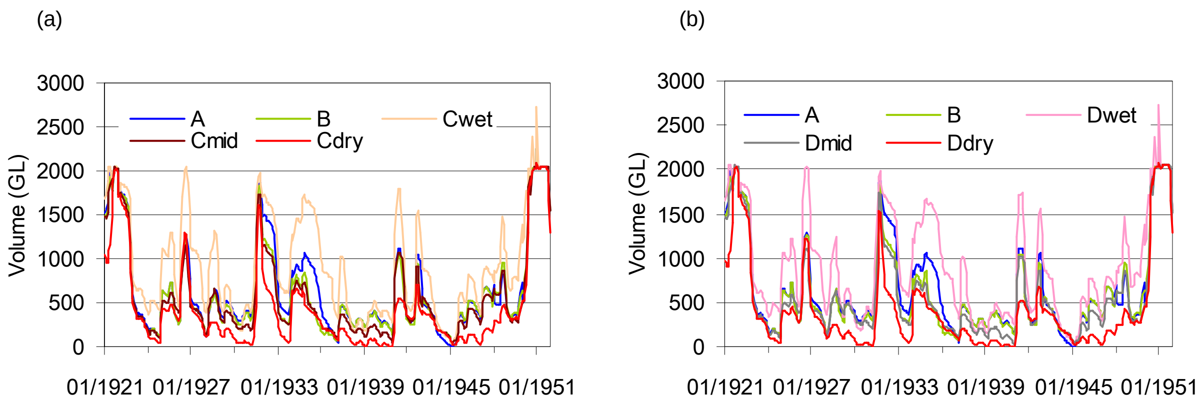


Figure 4-10. Total Menindee storage behaviour over the maximum days between spills under Scenario A (12/1921 to 09/1950), and change in storage behaviour under (a) scenarios B and C and (b) scenarios B and D

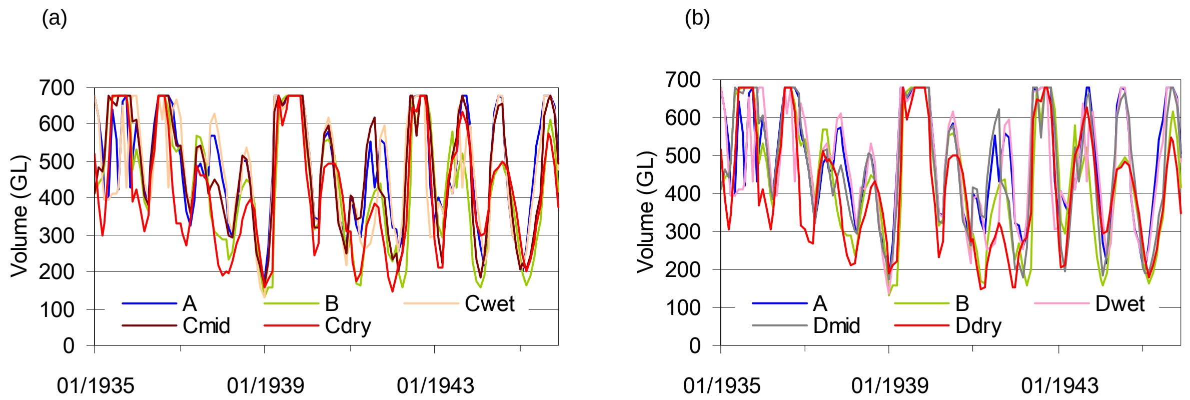


Figure 4-11. Lake Victoria storage behaviour over the maximum days between being full under Scenario A (08/1940 to 06/1942), and change in storage behaviour under (a) scenarios B and C and (b) scenarios B and D

4.3.4 Consumptive water use

Diversions

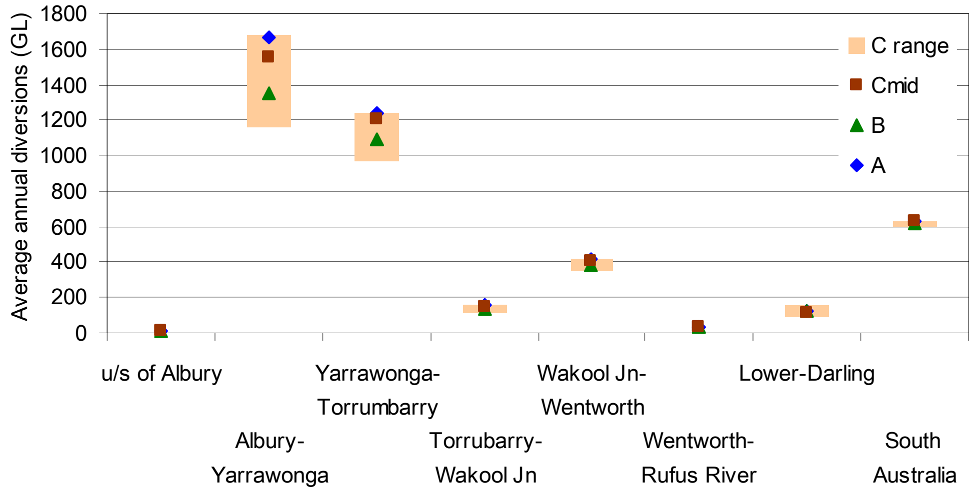
Table 4-10 shows each state's total average annual diversions by reach under Scenario A and the percentage change under all other scenarios compared to Scenario A. The impacts are substantially different between states. The greatest impacts are in New South Wales and the smallest impacts are in South Australia.

Table 4-10. Change in each state's total diversions in each reach under Scenario A and under scenarios B, C and D relative to Scenario A

Reach	State	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
		GL/y	percent change from Scenario A						
Upstream of Albury	NSW	0.1	-20.7%	0.6%	-7.7%	-33.3%	-0.5%	-8.6%	-34.1%
	Vic	14.6	-4.1%	0.4%	-0.6%	-14.9%	0.3%	-0.8%	-15.6%
Albury - Yarrawonga	NSW	1194.5	-23.9%	0.8%	-8.5%	-34.2%	-0.5%	-9.5%	-35.1%
	Vic	468.3	-6.9%	-0.3%	-1.6%	-19.6%	-0.4%	-1.9%	-20.6%
Yarrawonga - Torrumbarry	NSW	488.9	-20.1%	-0.1%	-6.8%	-29.7%	-1.1%	-7.6%	-30.5%
	Vic	751.5	-6.5%	-0.3%	-1.0%	-17.4%	-0.5%	-1.1%	-18.4%
Torrumbarry - Wakool Junction	NSW	96.6	-21.2%	0.4%	-7.5%	-33.9%	-0.7%	-8.4%	-34.8%
	Vic	59.8	-7.1%	0.6%	-1.3%	-16.6%	0.5%	-1.4%	-17.3%
Wakool Junction - Wentworth	NSW	85.1	-15.5%	0.9%	-4.2%	-18.7%	0.2%	-4.7%	-19.2%
	Vic	328.9	-6.2%	-0.1%	-0.5%	-15.2%	-0.1%	-0.7%	-16.0%
Wentworth - Rufus River	NSW	14.7	-23.4%	2.2%	-7.5%	-31.9%	1.2%	-8.4%	-32.7%
	Vic	23.8	-7.0%	0.6%	-1.0%	-16.3%	0.5%	-1.1%	-17.1%
Lower Darling	NSW	126.7	-3.3%	24.8%	-7.3%	-31.5%	22.2%	-9.0%	-33.2%
South Australia	SA	634.7	619.7	631.5	633.1	599.5	631.5	631.7	597.4
Sub-total	**NSW**	**2006.6**	**-21.2%**	**2.1%**	**-7.7%**	**-32.3%**	**0.8%**	**-8.7%**	**-33.2%**
	Vic	**1646.9**	**-6.6%**	**-0.2%**	**-1.1%**	**-17.5%**	**-0.3%**	**-1.2%**	**-18.5%**
	SA	**634.7**	**-2.4%**	**-0.5%**	**-0.3%**	**-5.5%**	**-0.5%**	**-0.5%**	**-5.9%**
Total		**4288.2**	**-12.8%**	**0.8%**	**-4.1%**	**-22.6%**	**0.2%**	**-4.6%**	**-23.5%**

Figure 4-12 shows total average annual diversions under scenarios A, B, C and D from upstream to downstream.

(a)



(b)

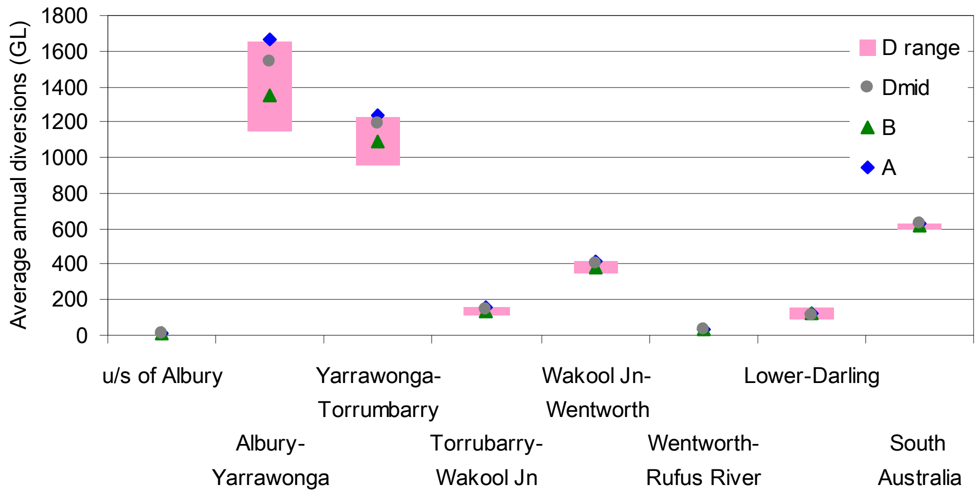


Figure 4-12. Total average annual diversions for reaches under (a) scenarios A, B and C and (b) scenarios A, B and D

Figure 4-13 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 4917 GL in 1950 and 2837 GL in 1902 respectively.

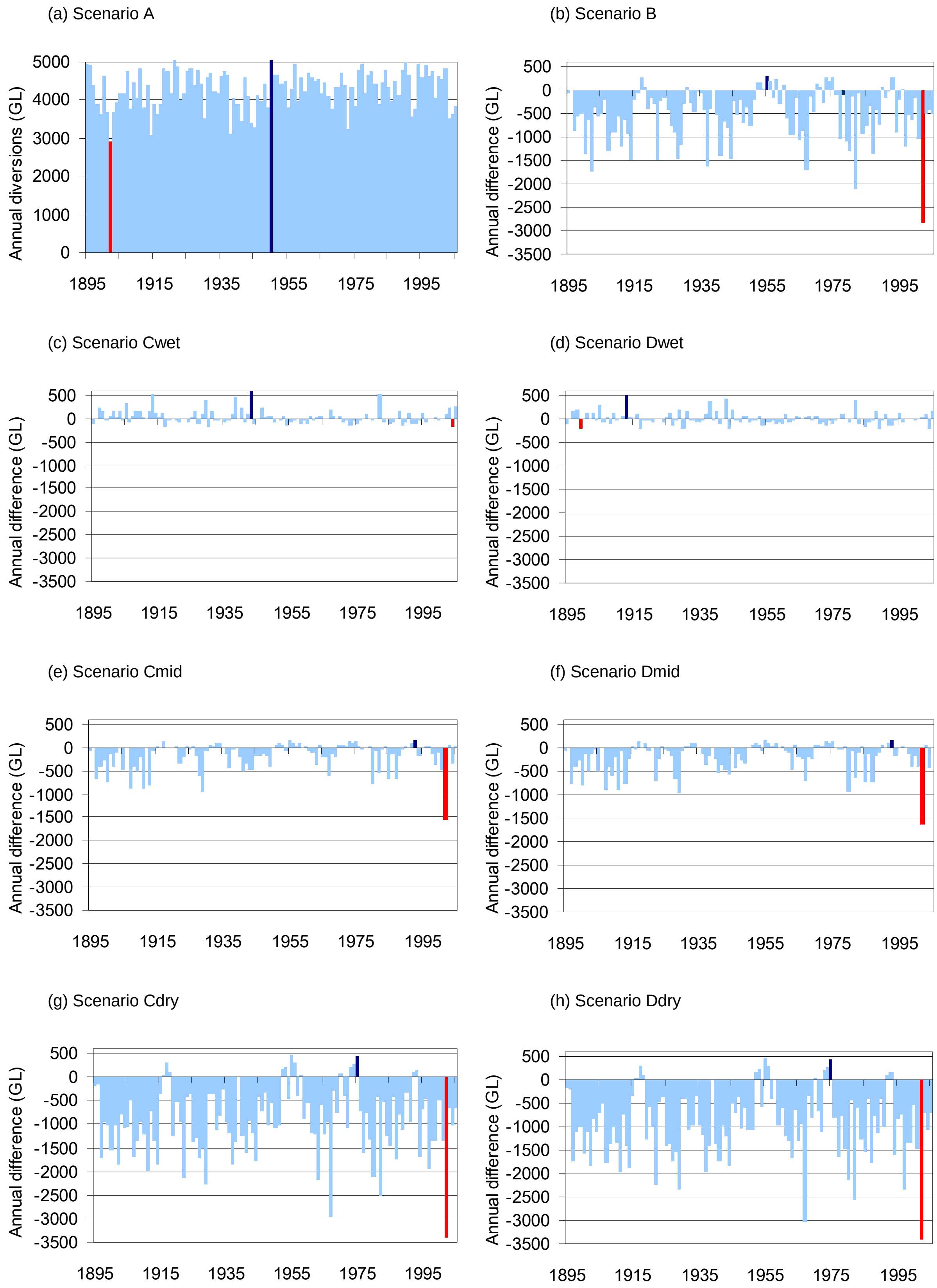


Figure 4-13. Total diversions under (a) Scenario A and difference between total water under (b) Scenario B, (c) Scenario Cwet, (d) Scenario Dwet, (e) Scenario Cmid, (f) Scenario Dmid, (g) Scenario Cdry and (h) Scenario Ddry

Level of use across the entire Murray-Darling Basin

The relative level of water use is the ratio of total use to total surface water availability. An assessment is provided below of the relative level of surface water use for the entire MDB to Wentworth. For the entire MDB, total use comprises upstream region use, subcatchment use and streamflow use (including within-region diversions). Upstream regional use is determined by taking the difference between the inflows of the without-development scenario and the respective scenario. This is adjusted to the point of maximum flow by applying a factor. The factor is determined by removing the without-development regional contributions to the Murray model one at a time and recording the deficit at the point of maximum flow. The factor is then determined as the deficit for the region divided by the sum of deficits for all the other regions (which is approximately equal to the total surface water availability). The upstream regional use values are thus 'discounted' to reflect the losses inherent in the river system, and are less than the total use volumes for these upstream regions.

Subcatchment use includes:

- the inflow impacts due to groundwater use in Murray region subcatchments. This includes groundwater use explicitly included in inflows (23.2 GL/year) and an estimate of groundwater use implicit in the inflows during model calibration (0 GL/year)
- inflow impacts due to future farm dams (28.5 GL/year) and future plantation forestry (19.0 GL/year)
- additional inflow impacts due to future groundwater development (8.3 GL/year)
- 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 (14,459 GL/year) and without-development total inflow (16,855 GL/year).

Streamflow use includes:

- leakage to groundwater induced by groundwater use. This only includes groundwater use explicitly included in the river model as there is no groundwater use implicit in the river model calibration
- total net diversions, which are defined as the net water diverted for the full range of water products transferred to the point of maximum flow by applying a factor (0.92). Net diversions are used to reflect the change in mass balance of the system. The difference in water quality that may exist between diversions and returns is not considered.

The average total net use in upstream regions is 6354 GL/year. This reduces to 4050 GL/year at Wentworth allowing for instream losses (Table 4-11). Diversions in the Murray region currently average 4288 GL/year and 673 GL/year of this is diverted downstream of Wentworth. Allowing for instream losses to Wentworth, the 3615 GL/year of upstream region usage is reduced by 8 percent to 3327 GL/year. The total impact of Murray regional groundwater use at Wentworth is 45 GL/year comprising 20 GL/year in regional catchments and 25 GL/year of instream leakage losses. The combination of upstream regional use, regional use and regional groundwater use estimates a total effective use of 8095 GL/year at Wentworth (the point of maximum flow), which is 56 percent of the total water available at that point is extremely high.

In this project the following qualitative scale is used to describe the relative level of surface water use: low, <0.10; moderate, 0.10 to <0.20; moderately high, 0.20 to <0.30; high, 0.30 to <0.40; very high, 0.40 to <0.50; and extremely high, >0.50. This scale has been used for describing the relative level of use in all 18 regions of the MDB. For the Murray region integrated to Wentworth the current relative level of surface water use is, on this scale, high.

Table 4-11. Relative level of use for the entire Murray-Darling Basin to Wentworth under scenarios A, B, C and D

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y							
Total surface water availability	14,493	10,548	15,450	12,811	9,155	15,450	12,811	9,155
Upstream regional use								
Darling	659	659	720	637	557	746	654	567
Murrumbidgee	1,605	1,359	1,677	1,579	1,403	1,668	1,564	1,383
Ovens at Peechelba	22	22	22	22	23	22	22	23
Goulburn at McCoy's Bridge	1,599	1,206	1,587	1,511	1,122	1,598	1,520	1,129
Campaspe at Rochester	81	69	83	81	76	87	85	78
Loddon at Appin South	85	81	85	84	82	87	86	83
Sub-total	**4,050**	**3,397**	**4,174**	**3,914**	**3,262**	**4,207**	**3,932**	**3,263**
Murray region use								
Subcatchment use								
Groundwater use impacts	20	20	20	20	20	27	27	27
Future farm dam impacts	0	0	0	0	0	29	24	19
Future plantation forestry impacts	0	0	0	0	0	19	16	13
Streamflow use								
Total net diversions (u/s of Wentworth)	3,327	2,860	3,336	3,103	2,377	3,419	3,181	2,439
Leakage induced by groundwater use	25	12	23	19	7	24	20	8
Downstream use								
Wentworth-Rufus diversion	39	33	39	37	30	39	37	30
South Australian diversion	635	620	632	633	600	631	632	597
Sub-total	**4,045**	**3,544**	**4,050**	**3,812**	**3,034**	**4,189**	**3,937**	**3,134**
Total basin use	**8,095**	**6,941**	**8,223**	**7,726**	**6,296**	**8,396**	**7,869**	**6,397**
Relative level of use (%)	56%	66%	53%	60%	69%	54%	61%	70%

Level of use in the Murray region

For the Murray region, average surface water availability is defined as the average annual streamflow at Wentworth if there was no consumptive water use within the region. The water availability for the region is thus a function of climate in the region and in upstream regions, as well as use in upstream regions that reduces the water available for use in the Murray region. Total use comprises subcatchment use and streamflow use in the region (including diversions).

Subcatchment use includes:

- the inflow impacts due to groundwater use in Murray region subcatchments. This includes groundwater use explicitly included in inflows (23.2 GL/year) and an estimate of groundwater use implicit in the inflows during model calibration (0 GL/year)
- inflow impacts due to future farm dams (28.5 GL/year) and future plantation forestry (19.0 GL/year) in the region
- additional inflow impacts due to future groundwater development in the region (8.3 GL/year)
- 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 (14,459 GL/year) and without-development total inflow (16,855 GL/year).

Streamflow use includes:

- leakage to groundwater induced by groundwater use in the region. This only includes groundwater use explicitly included in the river model as there is no groundwater use implicit in the river model calibration
- total net diversions in the region, which are defined as the net water diverted for the full range of water products transferred to the point of maximum flow by applying a factor (0.92). Net diversions are used to reflect the

change in mass balance of the system. The difference in water quality that may exist between diversions and returns is not considered.

Diversions in the Murray region currently average 4288 GL/year and 673 GL/year of this is diverted downstream of Wentworth. Allowing for instream losses to Wentworth, the 3615 GL/year of upstream region usage is reduced by 8 percent to 3327 GL/year (Table 4-12). The total impact of Murray regional groundwater use at Wentworth is 45 GL/year comprising 20 GL/year in regional catchments and 25 GL/year of instream leakage losses. The combination of regional use and regional streamflow loss induced by groundwater use estimates a total effective use of 4045 GL/year at Wentworth (the point of maximum flow), which is 37 percent of the total water available in the Murray region at that point.

Table 4-12. Relative level of use for Murray region to Wentworth under scenarios A, B, C and D

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y							
Total surface water availability	11,162	7,836	11,990	9,606	6,550	11,990	9,606	6,550
Subcatchment use								
Groundwater use impacts	20	20	20	20	20	27	27	27
Future farm dam impacts	0	0	0	0	0	29	24	19
Future plantation forestry impacts	0	0	0	0	0	19	16	13
Streamflow use								
Total net diversions (u/s of Wentworth)	3,327	2,860	3,336	3,103	2,377	3,419	3,181	2,439
Leakage induced by groundwater use	25	12	23	19	7	24	20	8
Downstream use								
Wentworth-Rufus diversion	39	33	39	37	30	39	37	30
South Australian diversion	635	620	632	633	600	631	632	597
Sub-total	**4,045**	**3,544**	**4,050**	**3,812**	**3,034**	**4,189**	**3,937**	**3,134**
Relative level of use (%)	36%	45%	34%	40%	46%	35%	41%	48%

Use during dry periods

Table 4-13 shows by state and region the average use for all water products, 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 4-13. Indicators of use during dry periods under scenarios A, B, C and D

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percentage change from Scenario A						
NSW Murray diversions								
Lowest 1-year period	527.5	-71%	-1%	-5%	-58%	-5%	2%	-65%
Lowest 3-year period	1108.2	-30%	0%	-9%	-37%	-1%	-9%	-38%
Lowest 5-year period	1326.7	-32%	-1%	-14%	-38%	-4%	-14%	-41%
Average	1879.9	-22%	23%	-8%	-25%	32%	-8%	-24%
Lower Darling diversions								
Lowest 1-year period	9.6	6%	20%	1%	5%	20%	1%	3%
Lowest 3-year period	22.0	-51%	151%	-13%	-49%	136%	-13%	-52%
Lowest 5-year period	37.9	-39%	97%	-38%	-65%	85%	-40%	-67%
Average	126.7	-3%	25%	-7%	-32%	22%	-9%	-33%
Victoria diversions								
Lowest 1-year period	982.4	-80%	-5%	5%	-89%	-5%	5%	-94%
Lowest 3-year period	1276.0	-37%	-3%	4%	-46%	-3%	4%	-47%
Lowest 5-year period	1439.8	-30%	-2%	2%	-41%	-2%	1%	-42%
Average	1646.9	-7%	0%	-1%	-18%	0%	-1%	-18%
South Australia diversions								
Lowest 1-year period	511.4	-15%	-1%	-9%	-22%	-1%	-15%	-22%
Lowest 3-year period	552.3	-3%	-1%	0%	-12%	-1%	0%	-12%
Lowest 5-year period	574.9	-2%	-1%	0%	-11%	-1%	0%	-13%
Average	634.7	-2%	-1%	0%	-6%	-1%	0%	-6%
Murray region diversions								
Lowest 1-year period	2884.5	-69%	0%	-22%	-74%	-1%	-26%	-74%
Lowest 3-year period	3413.3	-30%	3%	-9%	-40%	2%	-10%	-42%
Lowest 5-year period	3668.0	-27%	3%	-10%	-37%	1%	-11%	-39%
Average	4288.2	-13%	1%	-4%	-23%	0%	-5%	-23%

Utilisation

The ratio of total net diversions for each water product to the respective entitlement or share of resource can indicate the average utilisation of water products. New South Wales general security use for the Murray region is compared against a licence volume of 1670.5 GL, high security use against a licence volume of 251.2 GL and the supplementary access is compared against the 250 GL of entitlement volume. The New South Wales Lower Darling usage is compared against an entitlement volume of 301 GL that includes high security, general security and supplementary entitlements. Victorian water use for the Murray region is compared against a High Reliability Water Share (HRWS) and Low Reliability Water Share (LRWS) licence volume including delivery losses with a total entitlement of 1942 GL. South Australian water use is compared against an allocation of 782 GL. The average use is shown in Table 4-14.

Table 4-14. Average utilisation of water products under scenarios A, B, C and D

License private usage	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
NSW high security (entitlements 251 GL/year)	59%	60%	58%	60%	62%	58%	60%	62%
NSW general security (entitlements 1671 GL/year)	70%	52%	71%	64%	43%	70%	63%	43%
NSW supplementary (entitlements 250 GL/year)	75%	46%	71%	65%	34%	68%	64%	32%
Lower Darling total diversion (entitlements 301 GL/year)	42%	41%	53%	39%	29%	51%	38%	28%
Victoria CAP diversion (entitlements 1668 GL/year)	99%	92%	99%	98%	81%	98%	97%	80%
South Australia total diversion (entitlement 782 GL/year)	81%	79%	81%	81%	77%	81%	81%	76%

There is a difference in most systems between the water that is available for use and the water that is actually diverted for use. The difference is due to the provision of water from other sources such as rainfall, surplus flows, on-farm storages and groundwater. The difference between the available and diverted water will vary considerably across products and time. Figure 4-14 shows the difference between the maximum yearly allocated New South Wales general security water and the general security use for each of the scenarios in volume utilisation plots. MSM does not directly output New South Wales general security allocation volume or general security use.

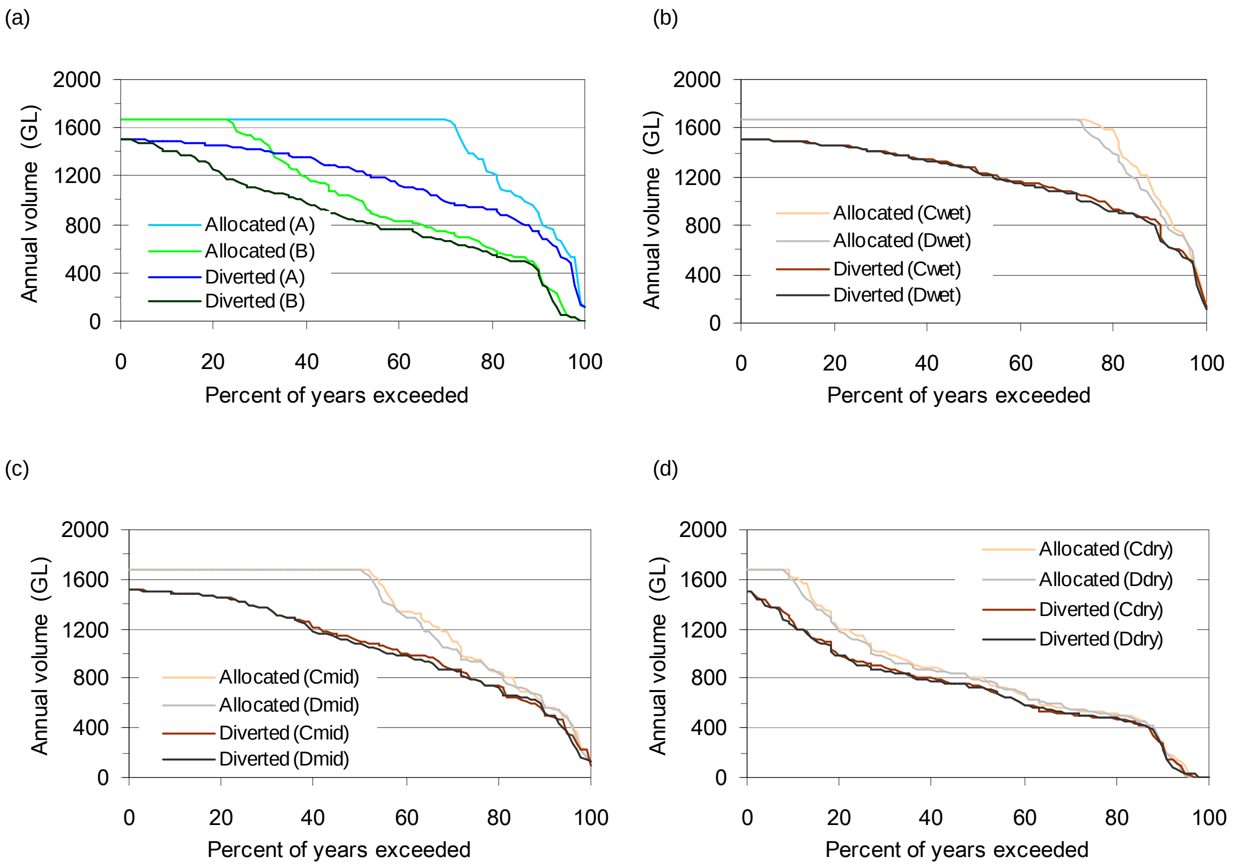


Figure 4-14. New South Wales general security utilisation under scenarios (a) A and B, (b) Cwet and Dwet, (c) Cmid and Dmid and (d) Cdry and Ddry

These were determined by the following equations:

For (TNSW – SNSW) ≤ 1200.305

GSANSW = TNSW – SNSW – 165 – 76.883 * (TNSW – SNSW) / 1200.305 Equation 4-1

GSDNSW = TDNSW – HSNSW – SNSW – 168.3 – 76.883 * (TNSW – SNSW) / 1200.305 Equation 4-2

For (TNSW – SNSW) > 1200.305

GSANSW = TNSW – SNSW – 241.883 + 88.117 * (TNSW – SNSW – 1200.305) / 800.203 Equation 4-3

GSDNSW = TDNSW – HSNSW – SNSW – 244.983 – 88.117 * (TNSW – SNSW – 1200.305) / 800.203 Equation 4-4

where:

GSANSW: New South Wales general security allocation (GL)
GSDNSW: New South Wales general security diversion (GL)
TNSW: Total New South Wales allocation (GL)
SNSW: New South Wales supplementary allocation (GL)
TDNSW: Total New South Wales diversions
HSNSW: High security diversions

Figure 4-15 shows the difference between the maximum yearly allocated Victorian water shares (both the low and high reliability together, including delivery losses) and the use under each of the scenarios in volume utilisation plots. MSM does not directly output the Victorian water share volume – instead it outputs the HRWS and LWRS allocations as a percentage.

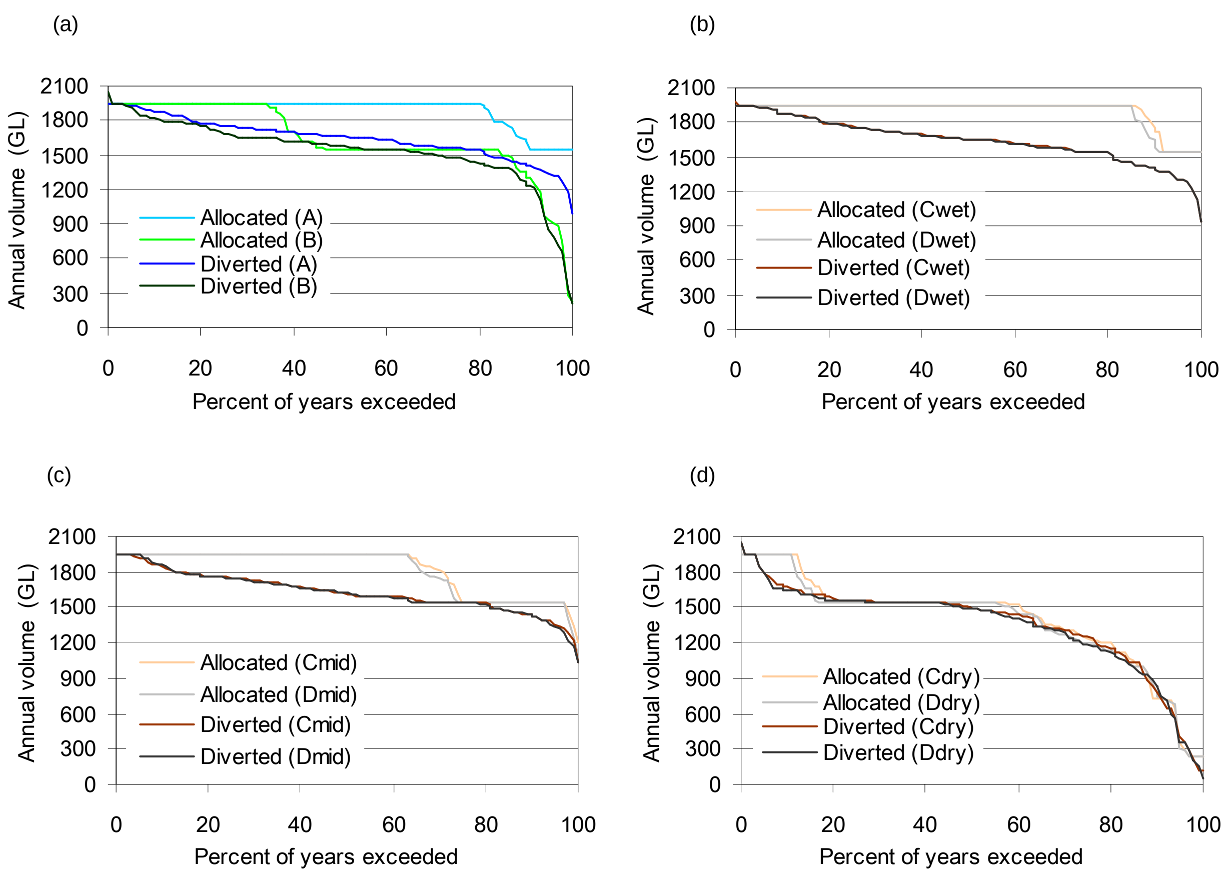


Figure 4-15. Victorian water shares (both the low and high reliability products) utilisation under scenarios (a) A and B, (b) Cwet and Dwet, (c) Cmid and Dmid and (d) Cdry and Ddry

The water share volume was determined by the following equation:

$$WSV = 230.932 + HRWSA * 13.1476 + LRWSA * 3.961813 \quad \text{Equation 4-5}$$

where:

WSV: Water share volume (GL)
HRWSA: High reliability water share allocation (%)
LRWSA: Low reliability water share allocation (%)

The step in the allocation at 1546 GL is the point where the LRWS is allocated. Under scenarios Cdry and Ddry HRWS allocations are almost fully utilised.

Figure 4-16 shows the utilisation of the diverted New South Wales and Lower Darling general security water and the diverted Victorian water shares (both the low and high reliability together) under each of the scenarios including the ranges for scenarios C and D. MSM does not directly output Lower Darling general security but instead combines Lower Darling general security with 20 GL of general security water traded from the Murrumbidgee region and access to Lake Cawndilla supplementary water released down the Darling Anabranch when Lake Cawndilla is isolated from the other lakes in the Menindee system. The separation of these components of water from the MSM output is not possible. Consequently the Lower Darling general security usage exceeds the 31 GL entitlement in Figure 4-16.

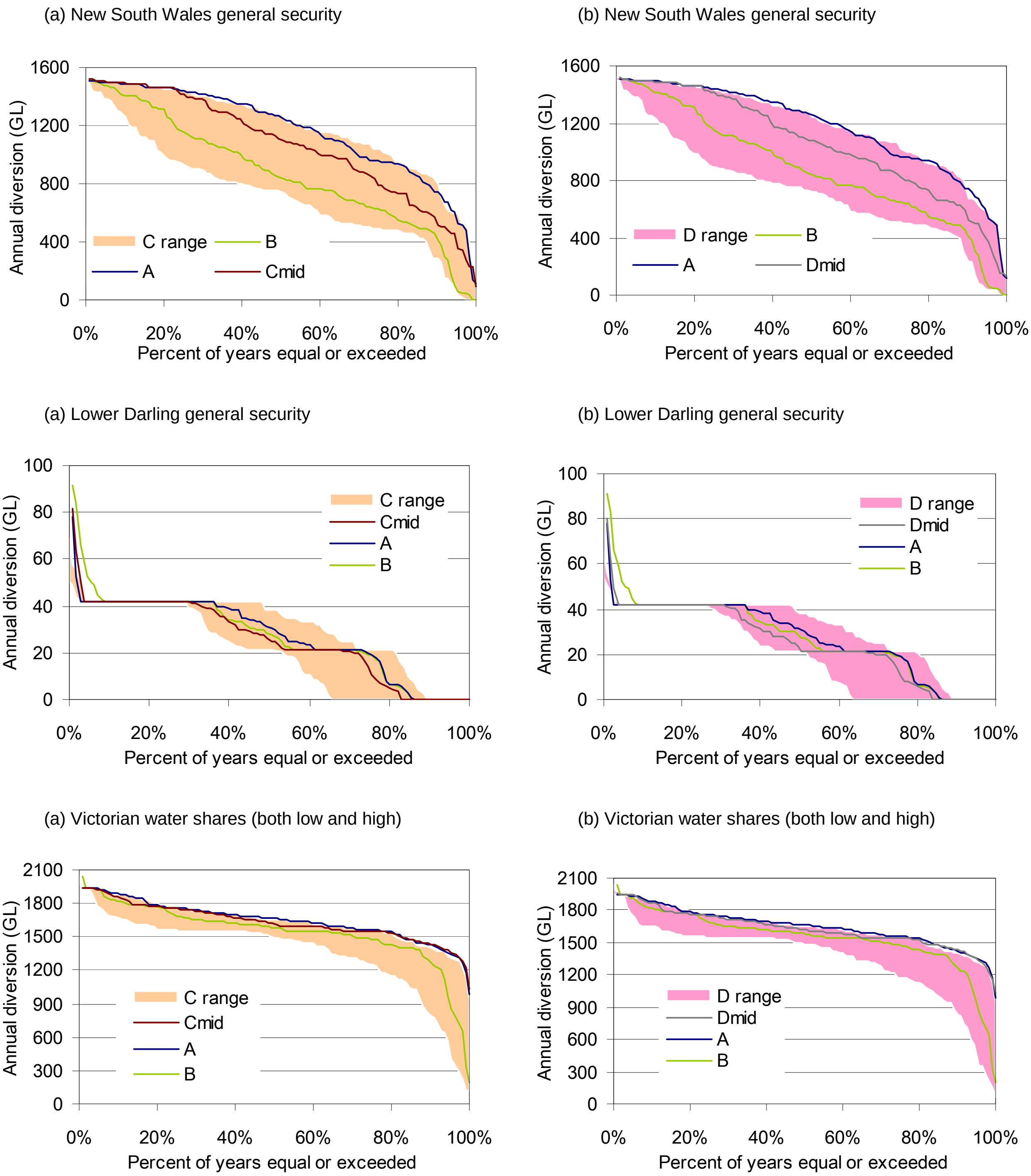


Figure 4-16. New South Wales and Lower Darling general security diversions and Victorian water shares diversion utilisation under scenarios A, B, (a) Scenario C and (b) Scenario D

Figure 4-17 shows the utilisation of New South Wales and Lower Darling supplementary water access for Murray under each of the scenarios including the ranges for scenarios C and D. MSM does not directly output New South Wales supplementary access but instead combines New South Wales supplementary access with without debit access. Without debit access water is available to New South Wales irrigators when general security allocations are below 60 percent. During these periods unregulated flows may be accessed up to full entitlement. This water is accounted as general security usage if subsequent allocation announcements within the water year exceed 60 percent. The separation of these components of water usage from the MSM output is not possible. Consequently the New South Wales supplementary usage exceeds the 250 GL entitlement in Figure 4-17.

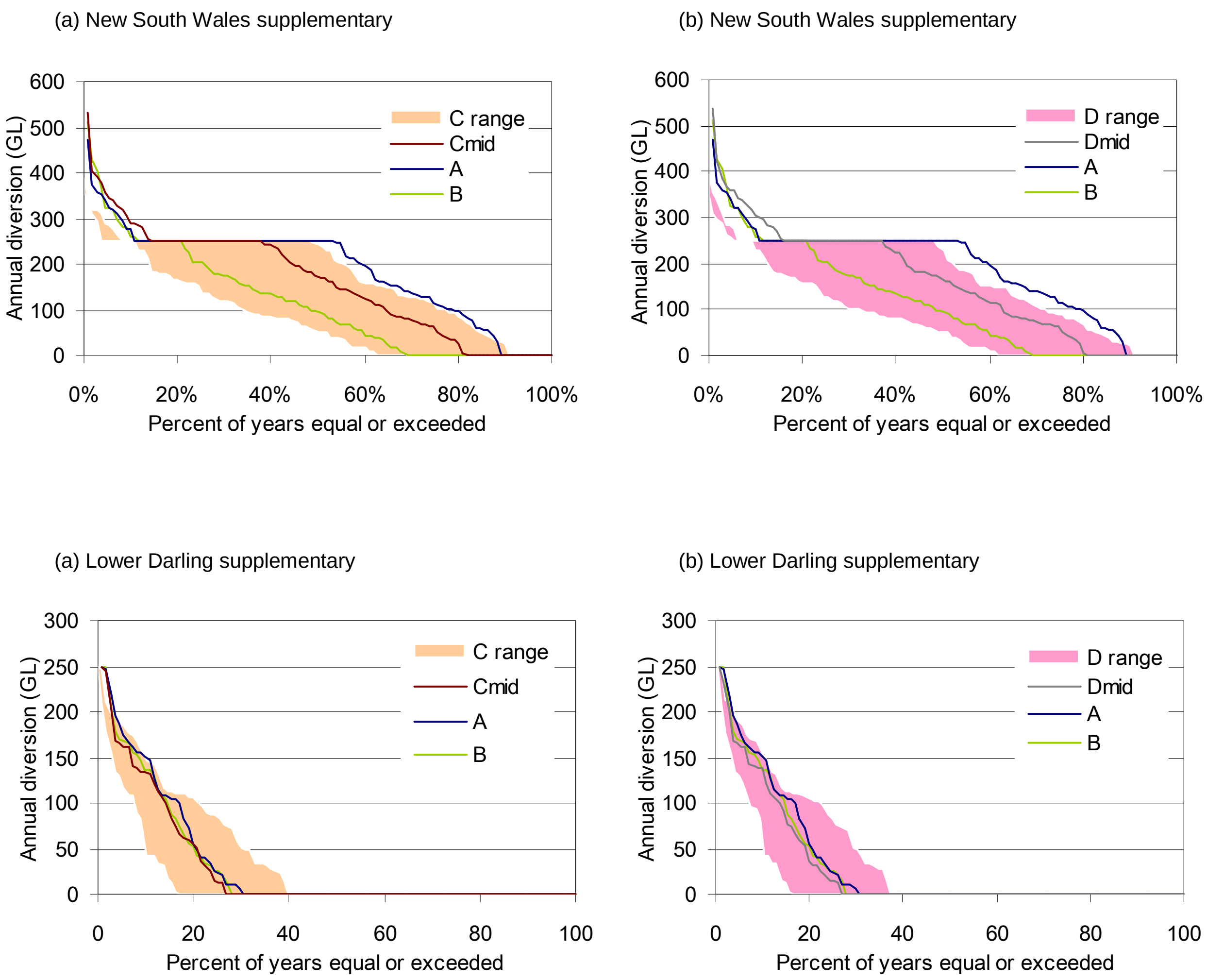


Figure 4-17. Utilisation of New South Wales and Lower Darling supplementary water under scenarios A, B, (a) Scenario C and (b) Scenario D

Table 4-15 shows the average annual difference between water use and allocated water for various water products in New South Wales, Lower Darling and Victoria. This table gives an indication of the level of utilisation of the various water products.

Table 4-15. Average level of utilisation of water products

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y							
New South Wales general security water*								
Allocated water	1975	1418	2015	1772	1164	1984	1751	1144
Diversion	1437	1069	1449	1307	901	1430	1292	887
Difference	538	349	566	466	264	554	460	257
New South Wales supplementary water*								
Allocated water	187.7	114.6	176.4	159.9	84	170.8	156.4	79.2
Diversion	188.5	115.2	178.6	161.6	84.8	170.8	158.8	80
Difference	-0.9	-0.7	-2.1	-1.6	-0.8	0	-2.4	-0.8
Lower Darling general security water**								
Allocated water	28.3	28	29.7	26.8	20.6	29.7	26.8	20.1
Diversion	27.2	27.4	31	25.5	20.1	30.7	25.1	19.8
Difference	1.1	0.6	-1.3	1.4	0.6	-1.1	1.8	0.3
Lower Darling supplementary water**								
Allocated water	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0
Diversion	31.2	29.1	43.3	27.6	16.0	42.2	26.6	15.6
Difference	218.8	220.9	206.7	222.4	234.0	207.8	223.4	234.4
Victorian water shares (includes both low and high reliability water products)								
Allocated water	1887	1633	1902	1821	1397	1894	1812	1381
Diversion	1647	1539	1644	1629	1358	1641	1626	1343
Difference	240	94	258	191	39	253	185	38

*MSM output of New South Wales supplementary usage includes without debit water that should be included in the general security usage. Consequently supplementary diversions are higher than they should be and general security diversions are less than they should be.

**MSM output of Lower Darling general security water includes 20 GL of water traded from the Murrumbidgee that is not included in the allocated water it also includes Cawndilla low level supplementary water that should be accounted in the Lower Darling supplementary water. Consequently supplementary diversions are lower than they should be and general security diversions are higher than they should be.

Reliability of supply

An indication of the reliability of supply is given by the percentage of years in which available water is less than the maximum allocation. Reliability of supply is reported for allocations in April to represent final allocations. Reliability of supply for individual New South Wales, Victoria and South Australia water products are shown in Figure 4-18 to Figure 4-20. The Y-axis is the percentage of the maximum allocation in April. The dry scenarios significantly reduce the percentage of years in which 100 percent allocations occur.

The New South Wales high security diverters receive the maximum allocation in almost all years under all scenarios. The New South Wales general security diverters and irrigators receive the maximum allocation in 52 percent of years under Scenario Cmid compared to 75 percent of years under Scenario A.

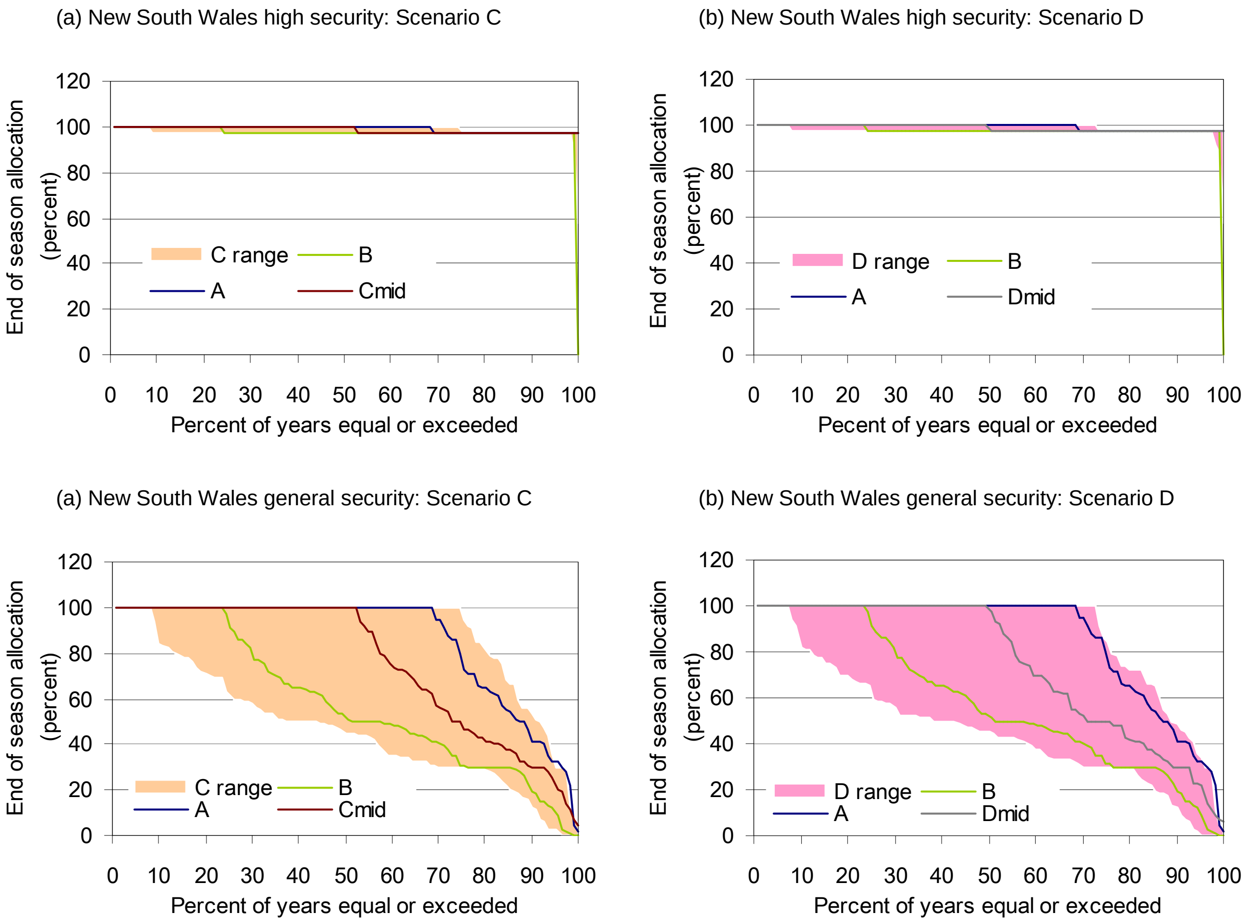


Figure 4-18. Reliability of New South Wales high and general security allocations under scenarios A, B, (a) Scenario C and (b) Scenario D

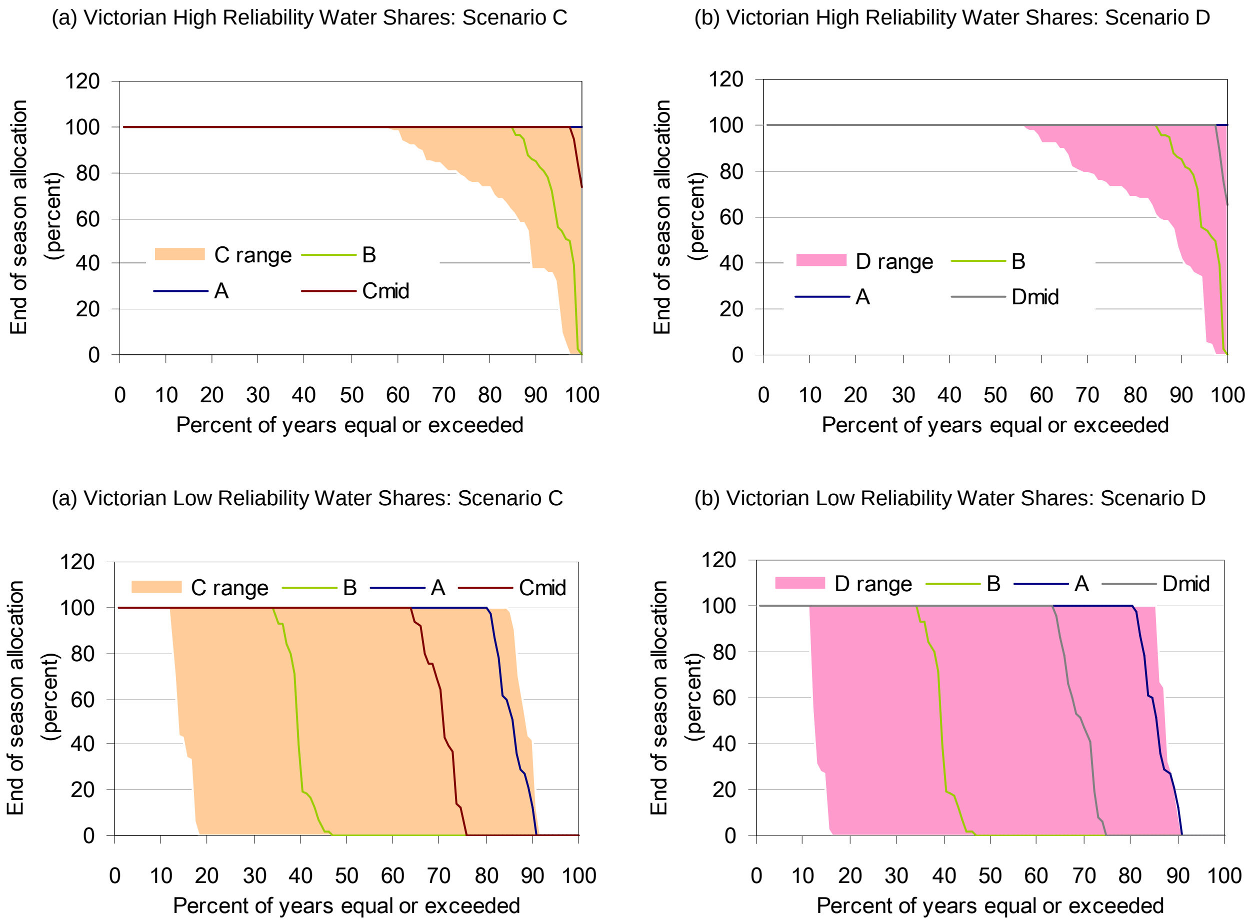


Figure 4-19. Reliability of Victorian high and low reliability water shares under scenarios A, B, (a) Scenario C and (b) Scenario D

Victorian private diverters and irrigators receive the maximum LRWS allocation in 64 percent of years under Scenario Cmid compared to 80 percent under Scenario A. The South Australian diverters received full entitlement each year under all scenarios.

Figure 4-20 shows the South Australian entitlement at the beginning (initial) and end (final) of the water year. The entitlement at the beginning of the water year indicates early restrictions on delivering the entitlement to South Australia. The figure shows that under Scenario A the entitlement is not met at the beginning of the water year 13 percent of the time which increases to 32 percent of the time under Scenario Cmid. However, the final allocation for most years represents the allocation at the start of the summer growing season and consequently modelled usage is better represented by this curve. Table 4-6 shows that under the extreme dry climate scenarios usage increases despite allocations being reduced in 22 percent of years. This increase in average usage can be explained by increased demand in a drier climate during full allocation years which more than offsets the reduction in usage in the constrained allocation years.

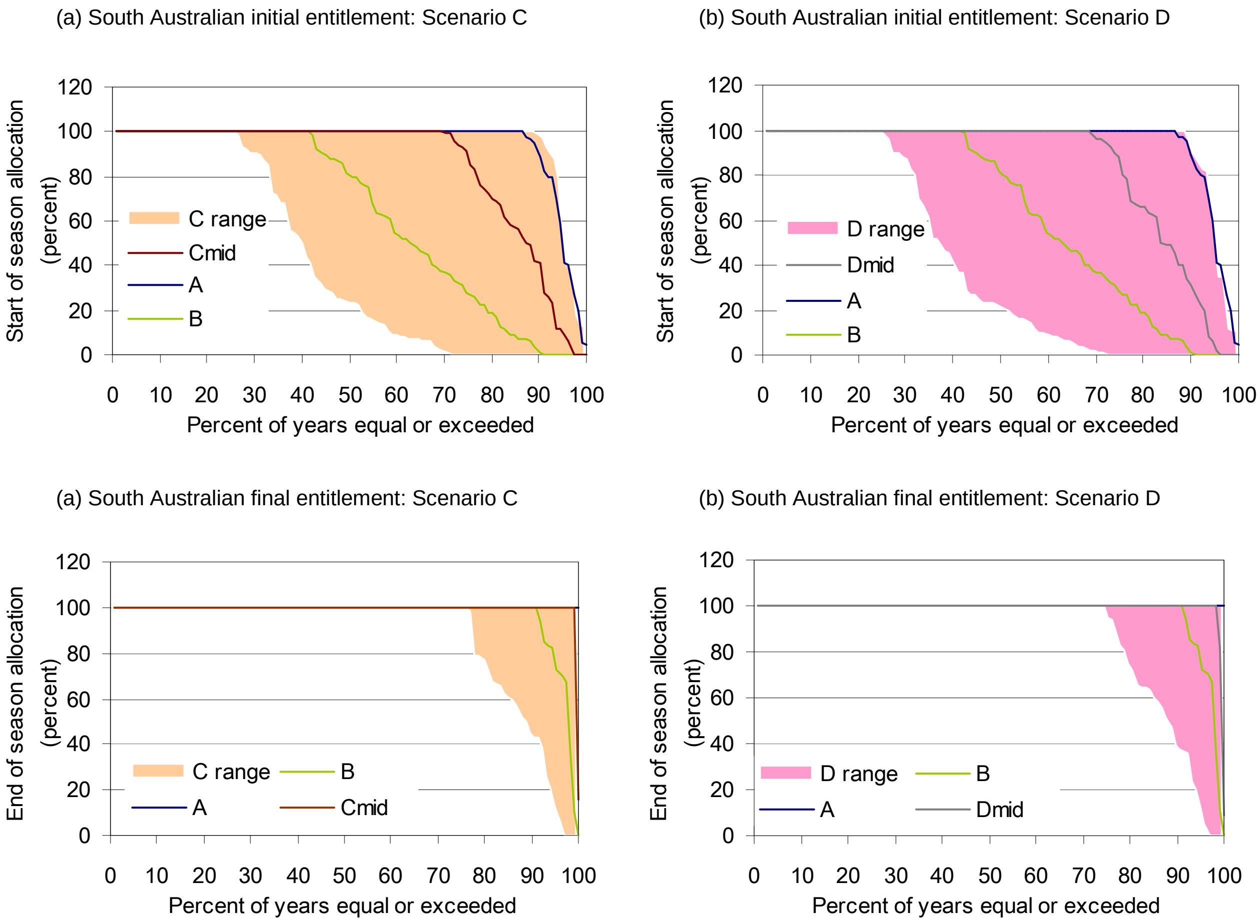


Figure 4-20. Reliability of South Australian entitlement under scenarios A, B, (a) Scenario C and (b) Scenario D

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 plot and daily event frequency. These are considered for four locations: Murray River at Yarrawonga Weir (409025), Darling River at Burtundy gauge (425007), Murray River at Wentworth (425010) and Lower Lakes Barrage 4 (end-of-system).

Yarrawonga Weir, Burtundy and Wentworth flow characteristics

The flow regime will vary depending on the location in the river that is selected. Three locations were selected for presenting flow characteristics: Yarrawonga Weir gauge (409025) representing the upper Murray; Burtundy gauge (425007) representing the Lower Darling; and Wentworth gauge (425010) representing the Lower Murray.

Figure 4-21 to Figure 4-23 show the daily flow duration curves under scenarios P, A and B and the range of variability 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 and the plots use a logarithmic scale that distorts the difference of lower flows and hides the differences at higher flows. Flows below 10 ML/day are not relevant as this is within the accuracy of streamflow measurement.

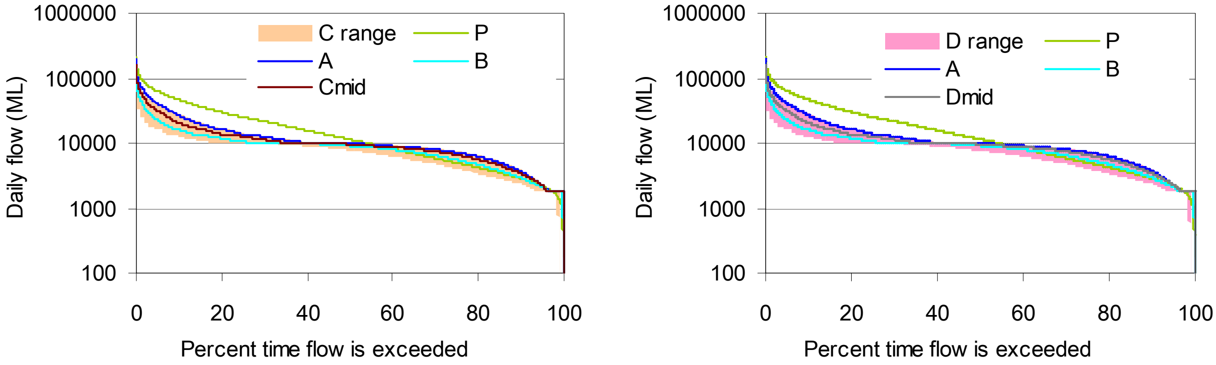


Figure 4-21. Daily flow duration curves at Yarrawonga gauge (409025) under scenarios P, A, B, C and D

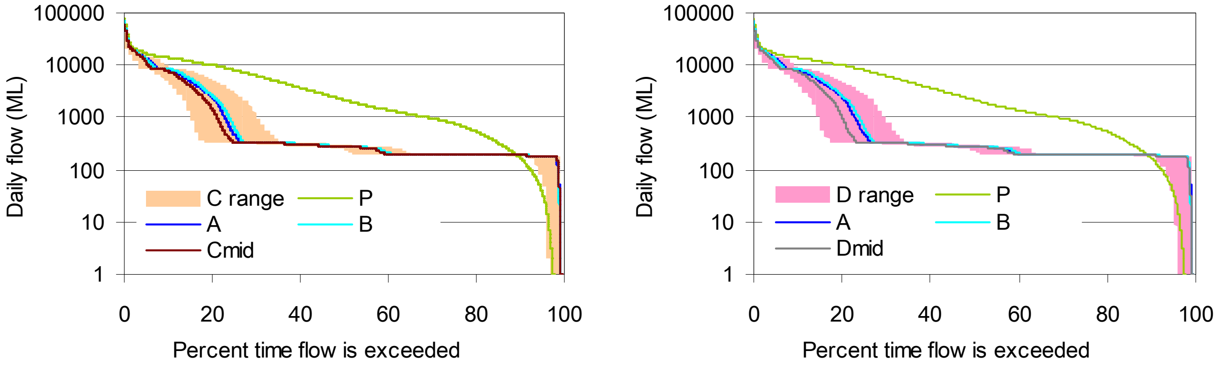


Figure 4-22. Daily flow duration curves at Burtundy gauge (425007) under scenarios P, A, B, C and D

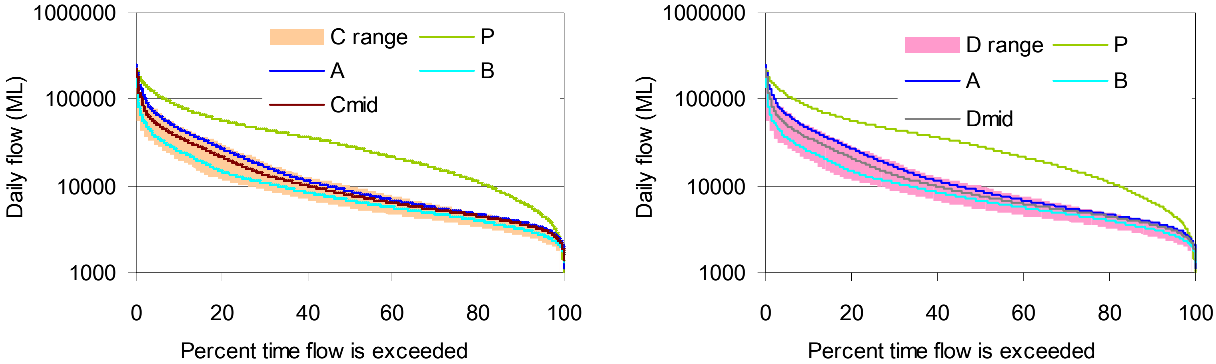


Figure 4-23. Daily flow duration curves at Wentworth gauge (425010) under scenarios P, A, B, C and D

Figure 4-24 to Figure 4-26 show the mean monthly flow under scenarios P, A, B, C and D. The seasonality at Yarrawonga is altered and there are more flows in summer and substantially less flows in winter when dams catch water. The seasonality at Burtundy has also been altered and there is a reduction in inflows from autumn to spring and a flattening of the seasonality. The seasonality at Wentworth is preserved but there is less water in winter and spring.

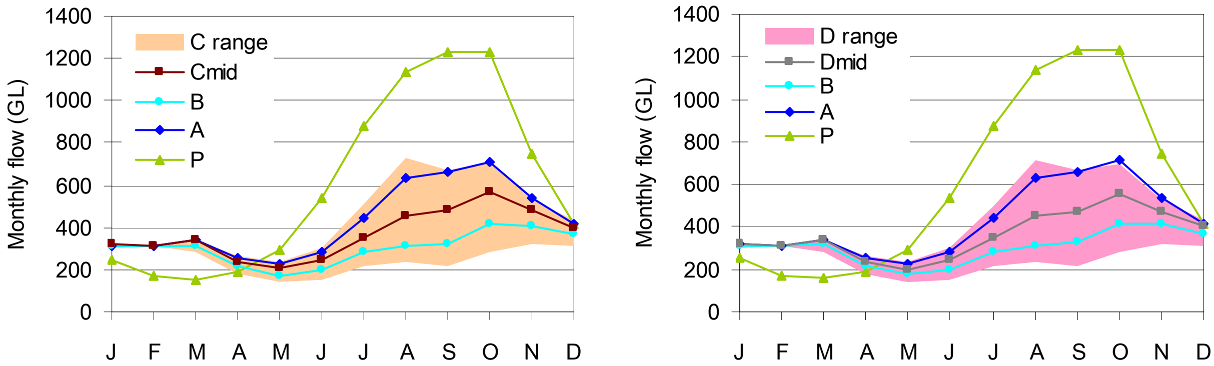


Figure 4-24. Average monthly flow at Yarrawonga Weir under scenarios P, A, B, C and D

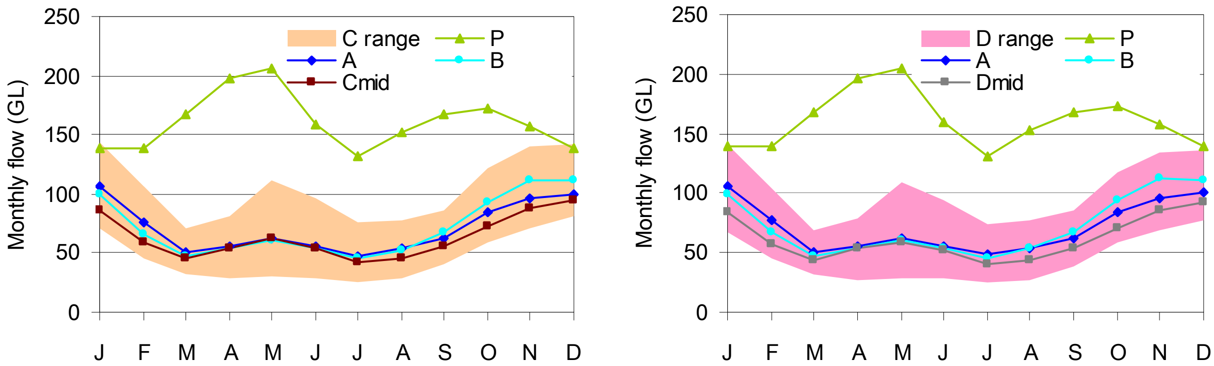


Figure 4-25. Average monthly flow at Burtundy under scenarios P, A, B, C and D

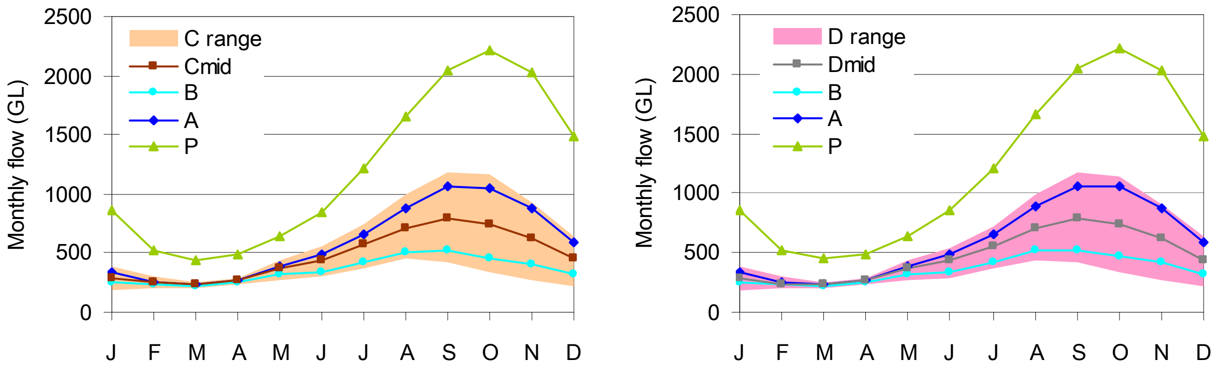


Figure 4-26. Average monthly flow at Wentworth under scenarios P, A, B, C and D

Table 4-16 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. There has been a 51 percent reduction (without-development to Scenario A) for Wentworth (38 percent for Burtundy and 36 percent for Yarrawonga) in the size of two-year events, a 49 percent reduction for Wentworth (17 percent for Burtundy and 37 percent for Yarrawonga) in five-year events and a 33 percent reduction for Wentworth (4 percent for Burtundy and 21 percent for Yarrawonga) in ten-year return interval events. This reduction in events will have significant impacts on the flooding frequency of wetlands.

Table 4-16. Daily flow event frequency under scenarios P, A, B, C and D

Return interval	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
years	ML/d		percent change from Scenario A						
Yarrawonga Weir									
2	70,307	45,163	-30%	5%	-17%	-42%	10%	-17%	-42%
5	124,834	78,227	-42%	8%	-26%	-55%	7%	-26%	-55%
10	141,471	111,024	-50%	20%	-34%	-62%	19%	-38%	-62%
Burtundy									
2	13,720	8,456	0%	0%	0%	-74%	1%	-1%	-96%
5	18,211	15,102	1%	20%	-3%	-42%	20%	-4%	-42%
10	21,722	20,782	-2%	33%	-5%	-20%	31%	-6%	-22%
Wentworth									
2	81,809	39,760	-37%	4%	-17%	-44%	3%	-18%	-46%
5	157,516	80,748	-47%	9%	-24%	-55%	9%	-26%	-56%
10	166,798	112,568	-47%	11%	-33%	-59%	9%	-34%	-59%

End-of-system (Lower Lakes and barrages) flow characteristics

Figure 4-27 shows the flow duration curves for the end-of-system (Barrage 4) under scenarios P, A, B, C and D. There has been a significant reduction in end-of-system flows across the flow range from without-development conditions to current conditions. This is further reduced across the flow range by climate change.

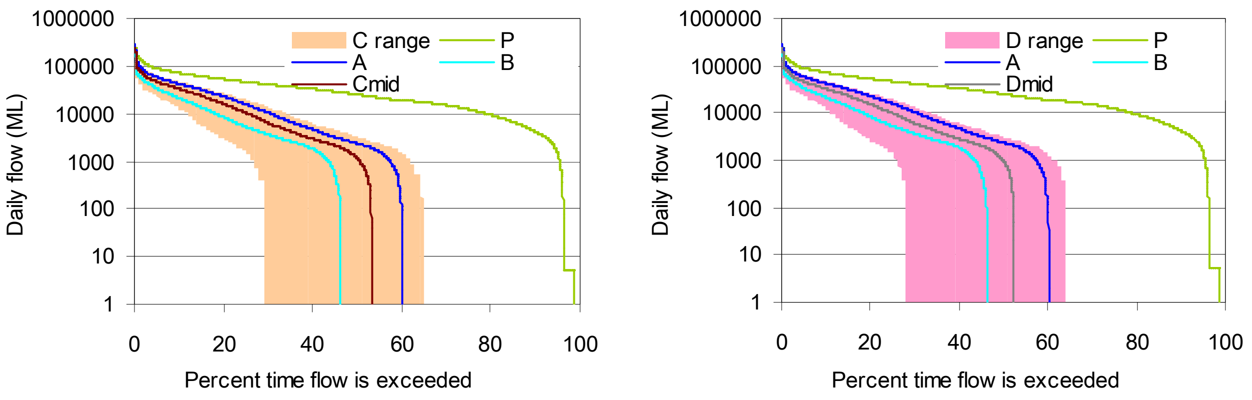
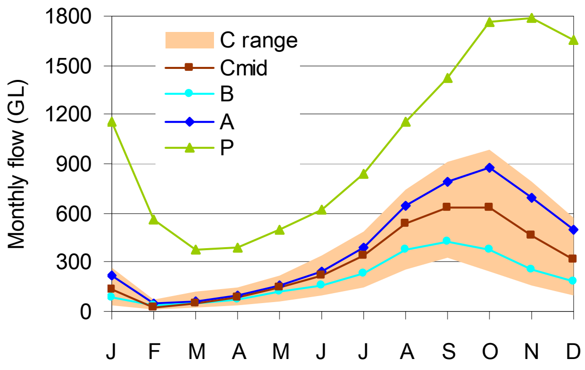


Figure 4-27. Daily flow duration curves for the end-of-system (Barrage 4) under scenarios P, A, B, C and D

Figure 4-28 shows the mean monthly flow under scenarios P, A, B, C and D for the end-of-system (the Lower Lakes Barrage 4). The seasonality at the end-of-system has been preserved but there is considerably less flow across all months and in particular flows from September to December. This will have significant impacts on the Lower Lakes flushing prior to summer.



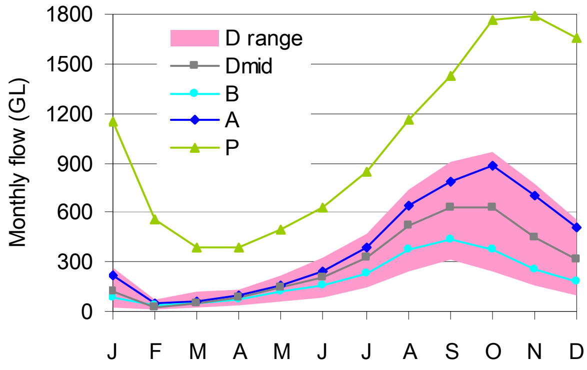


Figure 4-28. Seasonal flow curves for the end-of-system (the Lower Lakes barrages) under scenarios P, A, B, C and D

The percentage of time that flow occurs under these scenarios is presented in Table 4-17. Cease-to-flow occurs when model flows are less than 1 ML/day. Flow (greater than 1 ML/day) occurs over the barrages 99 days out of 100 under the without-development scenario. It happens only 60 percent of the time under Scenario A. Flow would cease to occur over the barrages an additional 8 percent of time under Scenario Cmid.

Table 4-17. Percentage of time flow (greater than 1 ML/day) occurs at the end-of-system (Barrage 4) under scenarios P, A, B, C and D

Outflow name	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Barrage flow	99%	60%	46%	65%	53%	30%	65%	52%	29%

Table 4-18 shows the average and lowest lake levels and areas, and the percentage of time below mean sea level under each of the scenarios. Lower Lakes levels are maintained above mean sea level for the entire 111-year period under scenarios P, A, Cwet, Cmid and Dwet. Lower Lakes levels drop below mean sea level for 3, 16, 1 and 18 percent of the time under respective scenarios B, Cdry, Dmid and Ddry.

Table 4-18. Lower Lake levels

Lower Lakes	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Average lake level (m AHD)	0.30	0.74	0.67	0.75	0.72	0.46	0.75	0.71	0.44
Minimum lake level (m AHD)	0.04	0.18	-0.86	0.22	-0.54	-1.64	0.17	-0.71	-1.65
Percentage of time below mean sea level	0%	0%	3%	0%	0%	16%	0%	1%	18%
Average lake area (ha)	59,757	63,632	63,002	63,734	63,447	61,361	63,724	63,385	61,197
Lowest lake area (ha)	57,951	58,874	51,658	59,172	54,057	43,224	58,860	52,806	43,101

Figure 4-29 shows the Lower Lakes area duration curve for the full percent of time and for the 95th percentile onwards. The flat section of the curve represents the level that is maintained by the operation of the barrages in the model. The without-development curve represents the areas of the lake without the barrages and is based on a relationship that approximates the natural flow characteristics of the Murray mouth.

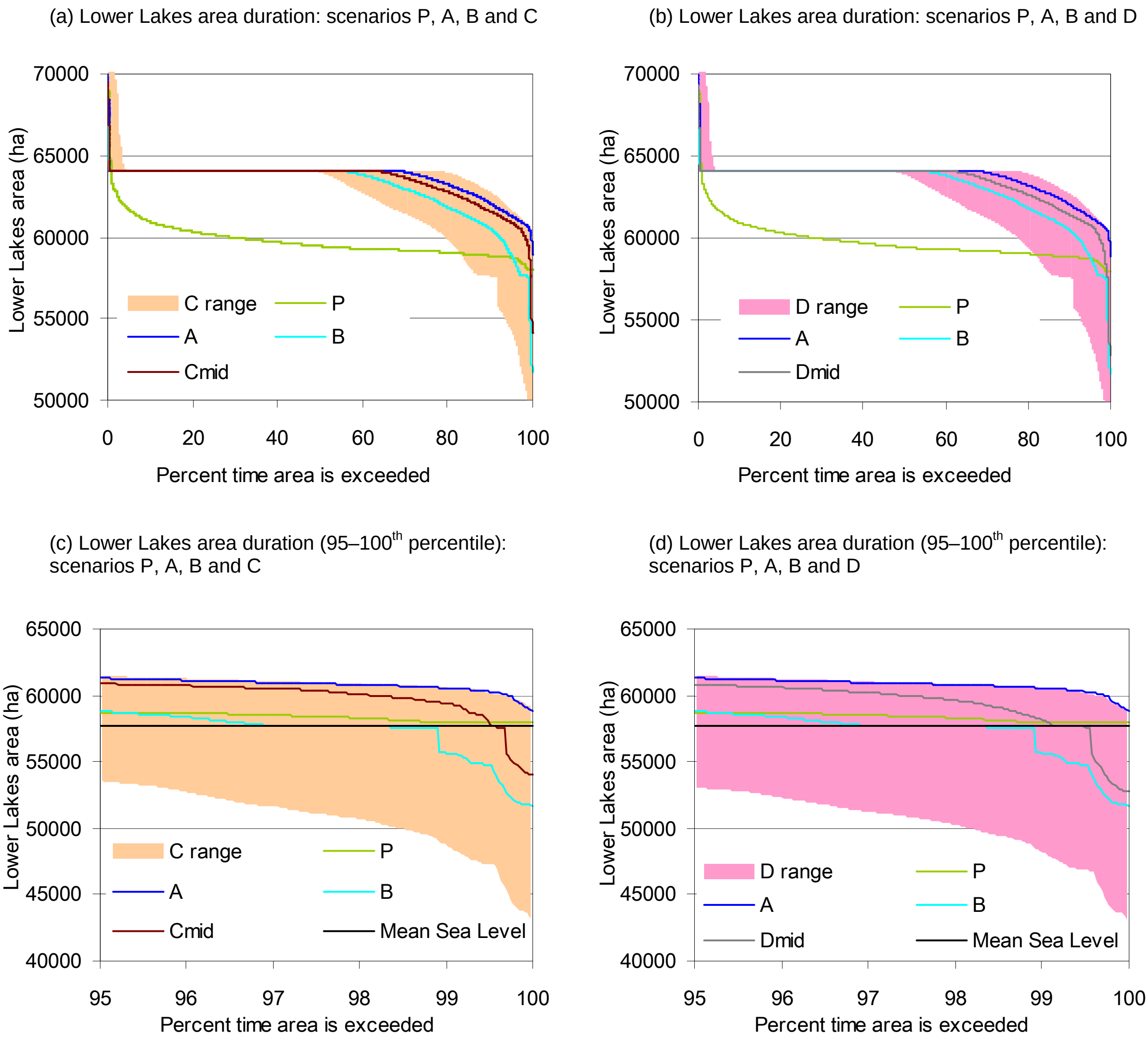


Figure 4-29. Lower Lakes area duration curve under scenarios P, A, B, C and D

4.3.6 Share of available resource

Non-diverted water shares

Table 4-19 presents four indicators for relative impact on non-diverted water for the MDB:

- the average annual non-diverted water as a proportion of the total surface water availability
- as a proportion of the total surface water availability under Scenario A
- a percentage of without-development flow to South Australia
- a percentage of without-development flow over the barrages to the sea.

Table 4-19. Relative level of available water not diverted for use under scenarios A, B, C and D for Murray-Darling Basin

Relative level of non diverted water	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	percent							
Non-diverted water as a percentage of total available water	44%	34%	47%	40%	31%	46%	39%	30%
Non-diverted share relative to Scenario A non-diverted share	100%	56%	113%	79%	45%	110%	77%	43%
Proportion of without-development cross border flows								
To South Australia	48%	29%	55%	39%	22%	54%	38%	22%
Over barrages to the sea	39%	19%	46%	29%	12%	45%	28%	12%

Combined water shares

Figure 4-30 combines the results from water availability, state use and non-diverted water for the MDB. The size of the bars indicates total surface water availability and the sub-division of the bars indicates the total state use and non-diverted fractions.

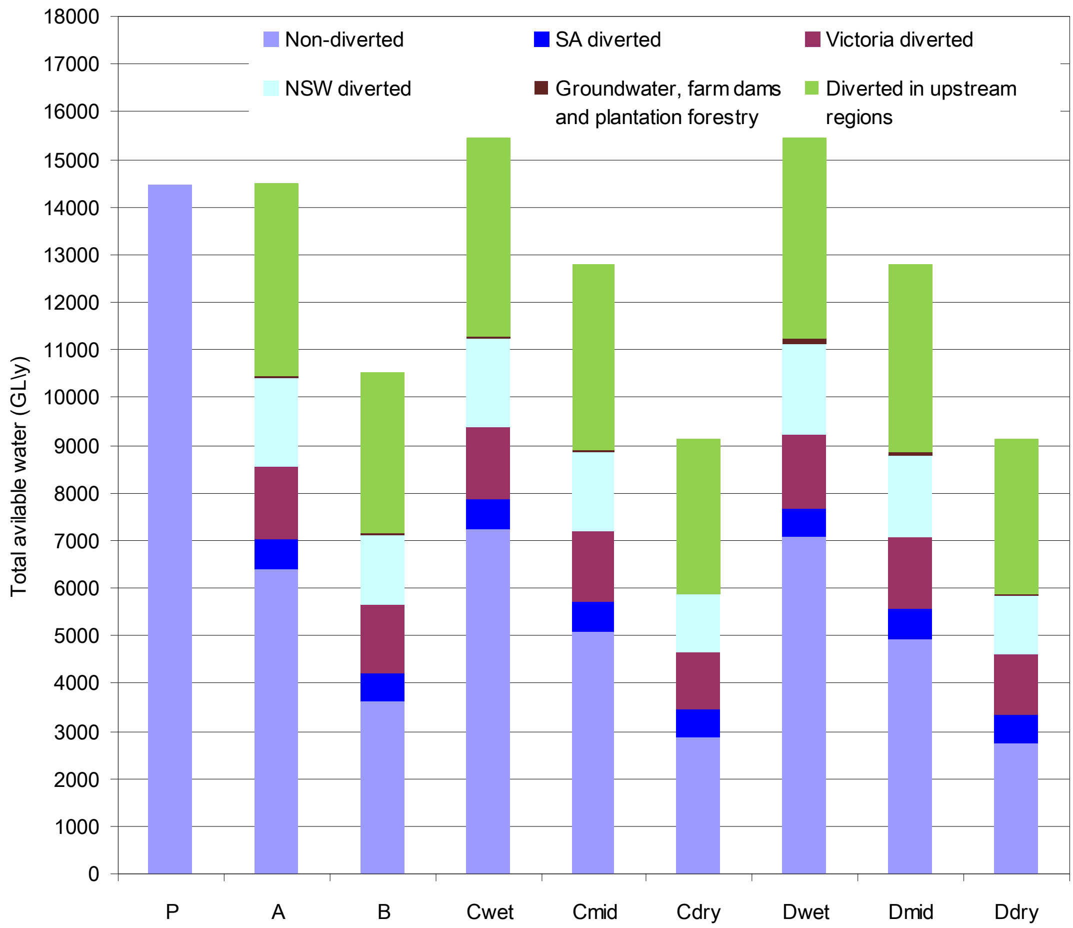


Figure 4-30. Comparison of diverted and non-diverted shares of water under scenarios P, A, B, C and D for the Murray-Darling Basin

Figure 4-31 combines the results from water availability, state use and non-diverted water for the Murray region.

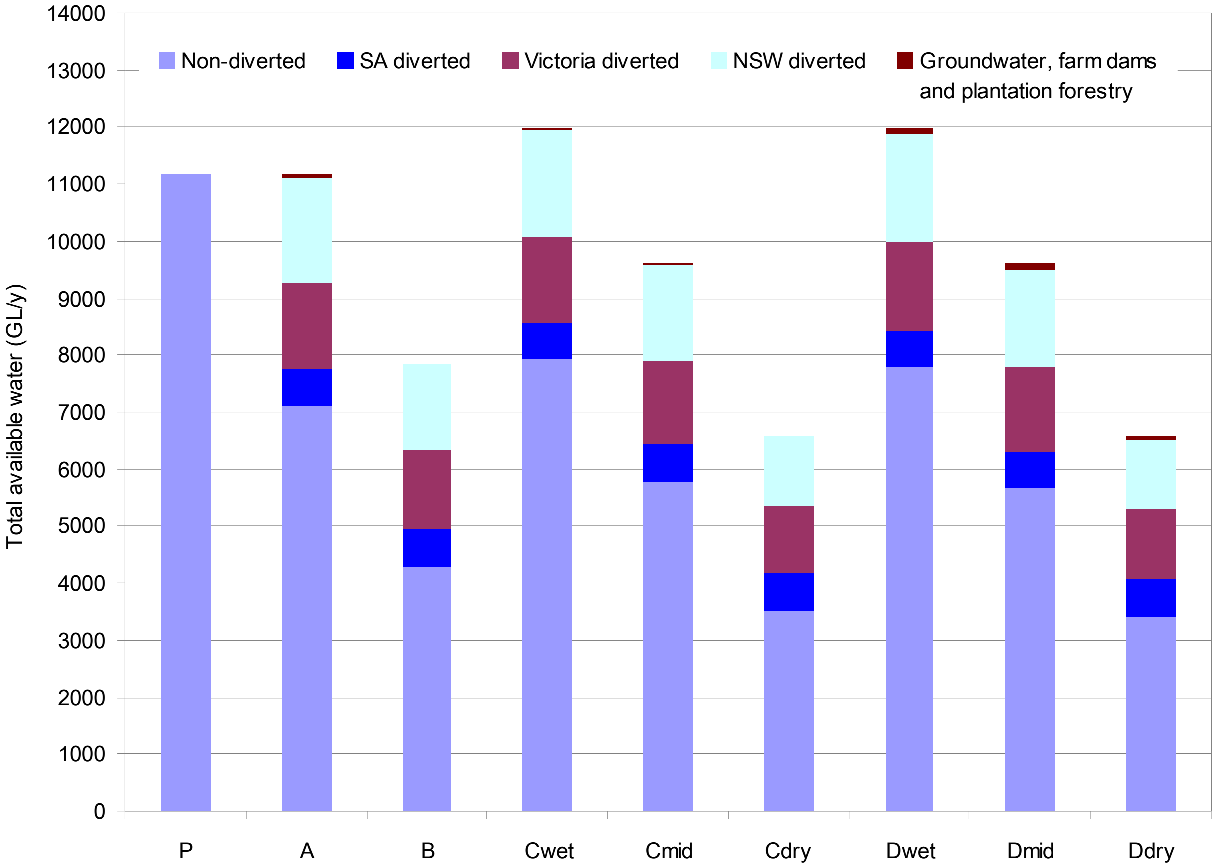


Figure 4-31. Comparison of diverted and non-diverted shares of water under scenarios P, A, B, C and D for the Murray region

4.4 Discussion of key findings

4.4.1 Scenarios

The Murray system model was originally set up by the Murray-Darling Basin Commission to operate over the period 1 May 1891 to 30 April 2006. The results from this project are presented for the common modelling period 1 July 1895 to 30 June 2006. The Murray Water Sharing Plan (WSP) (DIPNR, 2004a) is based on the different modelling period (1 January 1890 to 30 September 2000). Results presented in this report may differ from numbers published in the WSP report due to the different modelling period and reductions in inflows due to future impacts of current groundwater use. Table 4-6 shows that there is a 3 percent decrease in inflows for the common modelling period compared to the longer 1891 to 2006 period. This difference is due to the wetter conditions from 1891 to 1895.

Scenarios A0 and A are presented to consider the impacts of current levels of groundwater development reaching dynamic equilibrium. The time to reach dynamic equilibrium is discussed in Chapter 6. Table 4-6 shows a 25.8 GL/year increase in loss to groundwater that is partially offset by a 0.6 GL/year gain elsewhere in the river, making the net change 25.2 GL/year. In addition to this there is a further 24 GL/year reduction in gauged inflows due to eventual impacts of current groundwater use in upstream catchments. The results under scenarios A0 and A are similar.

Additional farm dam and commercial forestry plantation development is estimated to cause a 1.3 percent decrease in regional inflows into the system (Chapter 3). This equates to 48 GL/year less water entering the system. Future groundwater development in the headwater catchments causes a further 8 GL/year reduction in inflows (Chapter 6). The combined impact is a 0.5 percent reduction in total net diversions in the Murray region and 2 percent on end-of-system outflows. The impacts of Scenario Cmid are a 13.3 percent reduction in inflows. Consequently the combined impacts are 4.5 percent on total net diversions in the Murray region and 26.4 percent on end-of-system flows.

The results presented in this report are predominantly extracted from MSM. Daily flows and results downstream of the South Australian border are extracted from BigMod. Where these models overlap there are small differences in flows which are due to the different loss relationships in MSM and BigMod.

4.4.2 Storage behaviour

Under Scenario A, the maximum periods between spills for Hume and Dartmouth dams are 10.8 years and 14.8 years respectively and span the Federation drought. The average periods between spills are less at 1.4 years and 3.8 years respectively for Hume and Dartmouth dams which is reduced by the wetter conditions after 1950. Hume and Dartmouth dams regulate 87 percent of the inflows – a very high degree of regulation.

4.4.3 Consumptive use

The Murray irrigators are modelled to include New South Wales and Lower Darling general security access, New South Wales and Lower Darling supplementary flow access, Victorian low and high reliability water shares and South Australian entitlements. Not all of these water allocations are calibrated against observed data. However, the overall mass balance of farms is calibrated to achieve a realistic water use for the types of crops that are modelled. The volumes of these entitlements under Scenario A are New South Wales general security (1670.51 GL/year), New South Wales supplementary flows (250 GL/year), New South Wales conveyance loss including environmental flows (330 GL/year), Lower Darling general security (31.36 GL/year), Lower Darling supplementary access (250 GL/year), Victorian high reliability water shares (1270.78 GL/year), Victorian low reliability water shares including environmental flows (291.59 GL/year), Victorian loss allowance (274.82 GL/year), and South Australian entitlements (781.5 GL/year). The impact of climate on the reliability of these different water entitlements varies considerably.

Allocation made to Victorian and South Australian water users are annual and unused water can not be carried over to the next season. General security entitlement holders in New South Wales are permitted to carryover unused entitlement up to 50 percent of their entitlement. However, the maximum that can be allocated in any year (July to June) is 100 percent of entitlement. So the benefit of carryover is lost as the normal allocation approaches 100 percent. In the 2007/08 water year however, all states have used carryover to cope with extreme drought conditions, including the carryover of New South Wales high security entitlements. In this project, carryover was only modelled for New South Wales Murray general security entitlements.

The model contains many high security irrigators. The irrigators are driven by crop requirements that are a function of climate inputs. There is no significant impact on New South Wales high security users as New South Wales general security allocations are predominantly above zero (Figure 4-14). The New South Wales high security users will receive their full entitlement when there is a New South Wales general security allocation. Table 4-6 shows that the utilisation of New South Wales high security water increases under scenarios Cdry and Ddry.

4.4.4 Flow behaviour

The total inflows to the Murray River system under without-development conditions would be 16,855 GL/year. These have been reduced to 12,543 GL/year by water resource development in upstream regions (Table 4-6). The cross border average annual flow to South Australia under current conditions has reduced by 52 percent from without-development condition flow of 13,945 GL/year. Similarly, the average annual current condition end-of-system flow has reduced by 61 percent from the without-development end-of-system flow of 12,233 GL/year (Table 4-19).

The without-development average annual flow at the point of maximum flow (Wentworth) for current climatic condition over the modelling period is 13,677 GL/year. Because of the transfers from the SMHS into the Murray catchment of 526 GL/year and to the Murrumbidgee catchment of 417 GL/year, the Wentworth flow would have increased by 782 GL/year after allowing for the change in the natural losses upstream of Wentworth. Adding to this 29 GL/year for the impact of groundwater development in the upstream regions, which is implicit in the models calibration, the average total surface water resource becomes 14,484 GL/year.

The estimated flow at the South Australian border for the water year July 2007 to June 2008 is 1000 GL. This flow does not occur under scenarios P, A, Cwet, Cmid, Dwet and Dmid and highlights the extremely low inflows for this water year. Annual (water year) flow at the South Australian border occurs 1 percent of the years for Scenario B and 4 percent of the years in the dry extreme 2030 climate scenarios.

The impacts of current development on end-of-system flows for the Murray at the barrages in the Lower Lakes are greater than the impacts of the reduction in inflows under the other scenarios. There is a 39 percent reduction in the number of days in which flow (greater than 1 ML/day) occurs over the barrages under Scenario A compared to without-development conditions (Table 4-19). Under the best estimate 2030 climate, flow days would be further reduced by 10 percent and future development would cause this to increase by a further 1 percent (Table 4-17).

4.4.5 Water availability and level of use

The point of maximum water availability at Wentworth gauge (425010) is 14,484 GL/year and represents the average surface water availability for the entire MDB. This includes 782 GL/year for the net effect of SMHS transfers (via the Murray and Murrumbidgee rivers) at Wentworth and 29 GL/year of leakage induced by current groundwater use implicit in upstream model calibration. The relative level of use across the MDB integrated to Wentworth is 56 percent which is an extremely high level of use.

Considering current upstream use, the average surface water availability for the Murray region is 11,153 GL/year. The allowable level of use is not explicitly stated in the relevant New South Wales Water Sharing Plan (DIPNR, 2004a) but is implied to be about 38 percent based on the long-term average annual diversion limit for Murray region water use (4923 GL/year) and the stated average water availability (13,004 GL/year). The current average annual water use for the Murray region is estimated to be 4045 GL/year ('transferred' to Wentworth; Table 4-12), about 84 percent of which is diverted upstream of the South Australian border. This indicates the current average use in the Murray region is 36 percent of the total current average water availability of 11,153 GL/year for the Murray region.

4.4.6 South Australian entitlements, diversions and losses

The South Australian entitlement is 1850 GL/year (1154 GL/year for diversion and 696 GL/year for dilution loss entitlements). The South Australian allocation is 782 GL/year and total South Australian diversions are 635 GL/year (Table 4-2). The South Australian utilisation of 81 percent (Table 4-14) was calculated based on the South Australian allocation and diversions. South Australian system losses of 1135 GL/year (Table 4-6) are total evaporative losses in South Australia for the Murray reach from the South Australian border to the Murray mouth and differ from the loss component of the South Australian entitlement.

4.4.7 South Australian irrigation allocation practices

During the report reviewing process, the South Australian Department of Water, Land and Biodiversity Conservation advised that the function used in MSM to represent the South Australian irrigation allocations does not adequately capture South Australian allocation practice during extreme dry periods. This has not affected the usefulness of modelling results in the past and does not affect the accuracy of results for Scenario A. However, the function in MSM does not adequately represent irrigation allocations during 2007/08 – years of very low flows across the South Australian border. Similarly under dry future scenarios, the function in MSM does not adequately represent irrigation allocation practice in very dry periods.

Rerunning the river models with an improved allocation function was not practical at review stage as this would have required rerunning all of the models linked to the Murrumbidgee region, including the Murray region models and the Goulburn Simulation Model (which covers the Goulburn-Broken, Campaspe and Loddon-Avoca regions). Instead, the existing results were post-processed using existing annual cross-border flows in combination with an improved irrigation allocation function (Table 4-20) that caps the existing annual diversions during dry periods.

The improved irrigation allocation function represents South Australian allocation practice during low flow periods that are consistent with the Natural Resources Management Act 2004 Section 132(1). This states that "If, in the opinion of the Minister, the rate at which water is taken from a watercourse, lake or well (whether prescribed or not) is such that the quantity of water available can no longer meet the demand or there is a risk that the available water will not be sufficient to meet future demand; or is affecting, or is likely to affect, the quality of water in the watercourse, lake or underground aquifer; or in the case of water taken from a watercourse or lake-is having a serious effect on another watercourse or lake, or the level of water in an underground aquifer, that depends on water from the watercourse or lake for replenishment, the Minister may, by notice published in the Gazette and in a newspaper circulating in that part of the State in which the watercourse, lake or well or the surface water is situated, prohibit or restrict the taking of water from the watercourse, lake or well or the taking of surface water; or limit the quantity of water that may be taken from the watercourse, lake or well, or from any surface water" (South Australian Government, 2004).

The revised irrigation diversions based on the relationship in Table 4-20 were then used to determine additional inflows into the Lower Lakes. These inflows are assumed to arrive in the Lower Lakes without any adjustment for transmission losses or lake evaporation. The levels in the Lower Lakes were managed to a target level of 0.778 m above AHD with excess inflow assumed to be outflow from the barrages.

Table 4-20. Relationship used for improved representation of South Australian irrigation allocation practice during low flow periods

Cross-border flow to South Australia	Final irrigation allocation
GL/yr	percentage
2000	100%
1750	80%
1500	60%
1250	20%
1000	5%
900	0%

Figure 4-32 shows a comparison between observed South Australian irrigation allocations since 2001, the function used in MSM for modelling South Australian irrigation allocations and the relationship in Table 4-20 used to post-process model results to better represent South Australian irrigation allocation practice during dry periods. Note that prior to 2001 there are no observed restrictions to South Australian entitlements, and so previously this had not been considered in developing an irrigation allocation function.

Importantly, Figure 4-32 shows that the relationship of Table 4-20 does not well match the observed irrigation allocations for entitlement volumes lower than 1400 GL/year – that is, actual allocations during recent dry years did not conform to the relationship of Table 4-20. The primary reason for this is that announced irrigation allocations for South Australia were based on optimistic expectations of future cross-border flows. This situation could similarly occur in the future dry period – that is, actual irrigation allocations could be higher than the South Australian allocation practices for low flow periods would recommend, and as a result, irrigation diversions could be significantly higher than reported in Table 4-21 and Table 4-22 and the minimum levels in the Lower Lakes could be significantly lower that those reported in Table 4-23.

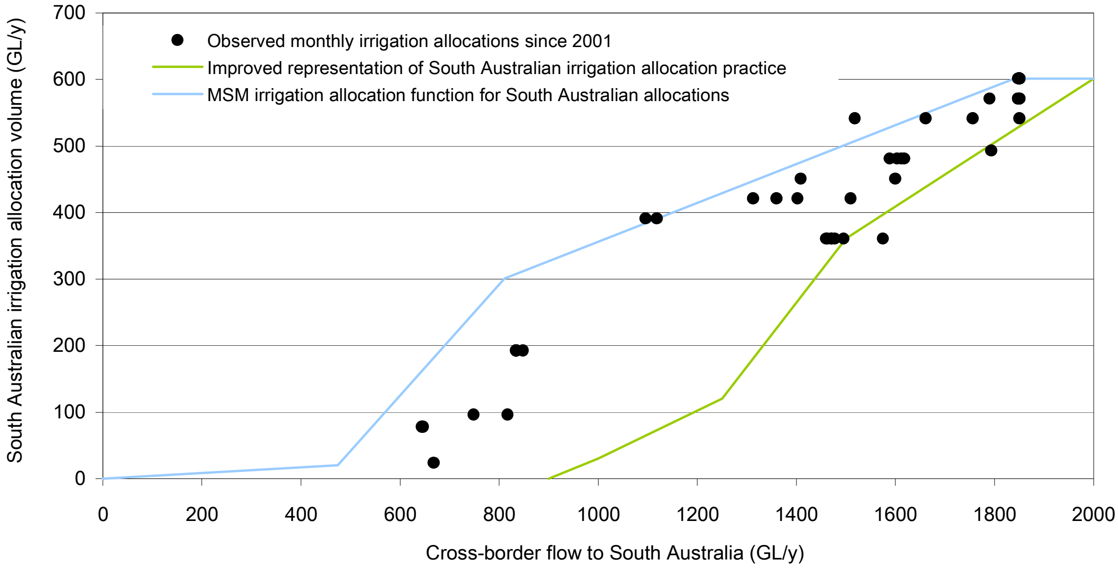


Figure 4-32. Comparison of observed recent South Australian irrigation allocations, model function for South Australian irrigation allocations and improved representation of South Australian irrigation allocation practice

Revised figures for the South Australian irrigation allocations, diversions and utilisation are shown in Table 4-21 based on the relationship of Table 4-20. The impact in dry years is shown in Table 4-22 for irrigation diversions (which includes diversions to reclaimed swamps), town water supplies (including Adelaide) and total diversions which is the sum of these two. Table 4-6 showed small reductions (between 2 and 6 percent) in South Australian total diversions in the dry future climate scenarios. Table 4-22 shows decreases of 10, 2, 23 percent in South Australia total diversions for scenarios B, Cmid and Cdry.

Table 4-22 also shows that urban and town supply is not significantly affected under any climate scenario. For urban and town supply the years of lowest use are not dry years with restrictions but are wet years in which demand is low. These actual low use years are thus different years from the low use years for irrigation. Irrigation allocations reduce to zero at a cross-border flow to South Australia of approximately 900 GL/year. This value represents the water volumes required to meet ‘critical human needs’ water and the dilution flows necessary to ensure drinking water quality. When the cross-border flow falls below around 900 GL/year, these critical human needs cannot be met with water of adequate quality. Cross-border flows fall below 900 GL/year in 3, 1 and 9 years out of 111 years in scenarios B, Cmid and Cdry respectively. In these years, although the modelling indicates there would be sufficient water volumes to meet the critical human needs’, the dilution flows would be insufficient to ensure drinking water quality.

Table 4-21. Revised values for average irrigation allocations, diversions and utilisation in South Australia under scenarios A, B, C and D based on an improved irrigation allocation relationship

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Allocated water (GL)	742.7	659.2	754.3	722.2	549.9	752.8	715.3	539.5
Diversion (GL)	630.4	568.2	628.6	616.5	483.5	628.2	611.0	475.0
Difference (GL)	112.3	91.0	125.7	105.7	66.4	124.6	104.3	64.5
Utilisation percentage	85%	86%	83%	85%	88%	83%	85%	88%

Table 4-22. Revised indicators of South Australian use (irrigation only) during dry periods under scenarios A, B, C and D based on an improved allocation relationship

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y							
Irrigation diversions (including reclaimed swamps)								
Lowest 1-year period	270.7	0.0	360.9	0.0	0.0	342.9	0.0	0.0
Lowest 3-year period	415.7	136.3	447.4	228.6	32.1	441.4	168.4	30.1
Lowest 5-year period	437.2	184.1	454.8	344.9	56.5	451.1	300.8	52.9
Average	494.6	433.7	492.8	481.4	348.3	492.5	476.0	339.8
		-12%	0%	-3%	-30%	0%	-4%	-31%
Adelaide and country town water supply								
Lowest 1-year period	67.7	68.2	67.5	68.0	70.1	67.5	68.0	70.1
Lowest 3-year period	86.8	87.3	86.8	87.2	88.9	86.8	87.2	88.9
Lowest 5-year period	98.8	99.3	98.6	99.1	101.0	98.6	99.1	101.0
Average	135.8	134.4	135.7	135.1	135.2	135.7	135.0	135.3
		-1%	0%	-1%	0%	0%	-1%	0%
Total diversions								
Lowest 1-year period	444.3	177.6	506.2	183.0	113.6	506.2	177.1	107.6
Lowest 3-year period	547.5	248.7	548.1	382.0	175.8	546.3	319.9	175.8
Lowest 5-year period	570.1	339.4	571.3	486.5	211.8	571.3	442.0	208.1
Average	630.4	568.2	628.6	616.5	483.5	628.2	611.0	475.0
		-10%	0%	-2%	-23%	0%	-3%	-23%

The revised impacts on levels and areas for the Lower Lakes are shown in Table 4-23. The table shows that the change in average lake levels and areas is small under all scenarios except for the dry climate extremes where average areas increase by approximately 2200 ha. The lowest lake areas (as a result of the improved allocation relationship) under scenarios B, Cmid, Cdry, Dmid and Ddry are 7400, 5800, 14,850, 7550 and 14,700 ha higher respectively using the improved allocation relationship and lake levels never fall below mean sea level.

Importantly, during low flow periods, levels in the Lower Lakes are very sensitive to South Australian irrigation allocations. The current modelling of South Australian irrigation allocations in MSM does not adequately reflect actual low flow irrigation allocations and so is not well suited to assessing short-term management options for the Lower Lakes. The stated South Australian irrigation allocation practice does not well match actual recent low flow allocations either, and so the relationship describing the South Australian irrigation allocation practice during low flows is also inadequate for assessing potential outcomes for the Lower Lakes.

Table 4-23. Revised levels and areas for the Lower Lakes based on an improved South Australian irrigation allocation relationship

	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Average lake level (m AHD)	0.30	0.76	0.75	0.76	0.76	0.73	0.76	0.76	0.73
Lowest lake level (m AHD)	0.04	0.37	0.20	0.42	0.33	0.05	0.40	0.41	0.01
Percent of time below mean sea level	0%	0%	0%	0%	0%	0%	0%	0%	0%
Average lake area (ha)	59,757	63,863	63,754	63,892	63,817	63,527	63,895	63,810	63,494
Lowest lake area (ha)	57,951	60,098	59,048	60,442	59,850	58,078	60,340	60,350	57,785

4.5 References

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Close AF (1996b) The BigMod model of flow in the River Murray. MDBC Technical Report 96/12. Murray-Darling Basin Commission, Canberra.

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5 Uncertainty in surface water modelling results

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

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

5.1 Summary

The uncertainty that is internal to river models (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) river model results 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 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 model might predict future patterns of flow.

5.1.1 Issues and observations

- The hydrology of the Murray surface water system is generally well gauged. The density of gauging is slightly less than the average network density for the Murray-Darling Basin. Streamflow gauging is concentrated in the Murray, Darling, Edward and Kiewa rivers.
- Water accounts could be established for 29 reaches: 18 reaches on the Murray River, one on the Mitta Mitta River, two on the Kiewa River, three on the Darling River and Great Darling Anabranch, and five in the Edward-Wakool system.

5.1.2 Key messages

The assessment of uncertainty in the surface water modelling results indicates:

- The models are generally well suited for the purposes of this project and reproduces the observed streamflow patterns in most of the system very well.
- The models provide strong evidence of changes in flow pattern due to water resource development in the regulated part of the system.
- The models provide strong evidence of a change in flows under a medium or dry 2030 climate, but the projected changes under a wet 2030 climate are the same order of magnitude as river model uncertainty.
- Uncertainties associated with forestry, further groundwater extraction and farm dam development are all small when compared to climate scenario uncertainty and internal model uncertainty.
- Some caution is recommended when interpreting predictions of absolute as well as relative changes in flow patterns and average flows in the Murray between the offtakes of the Edward system and Barmah, the Edward-Wakool system itself and the Great Darling Anabranch.

5.2 Approach

5.2.1 General

River models are used 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, and
- *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's performance in simulating observed stream flow patterns
- the projected changes in flow pattern under the scenarios compared to the performance of the model in reproducing historic 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, and
- 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 the river model 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 no attempt is made 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), Pinneena 8 Database (provided on CDROM by New South Wales Department of Water and Energy (DWE)), South Australian Department Water, Land, Biodiversity and Conservation (departmental website http://e-nrims.dwlbc.sa.gov.au/swa/default.aspx), and the Victorian Water Resources Data Warehouse (www.vicwaterdata.net). Information on the MSM-BigMod river model was provided by the Murray-Darling Basin Commission (MDBC, 2002 and 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 was adequate for water accounting of the years from 1990/91 to 2005/06. This period is the same as used for the other regions, and represents a compromise between the length of the period and a greater numbers of gauges in a shorter, more recent period. Water accounts were established for a total of 29 reaches: 18 reaches on the Murray River, one on the Mitta Mitta River, two on the Kiewa River, three on the Darling River and Great Darling Anabranch, and five in the Edward-Wakool system. The MSM-BigMod model results were available for eight reaches, seven of which were compared to a combination of water balance accounting reaches. Figure 5-1 shows associated catchment areas, accounting reaches and contributing catchments. Ephemeral water bodies and floodplain areas are 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 runoff modelling.

Water accounting reach	Subcatchment code(s)	Description (main stem d/s gauge)	River model reach
1	4012041	Mitta Mitta River @ Tallandoon	–
2	4090161	Murray River @ Hume Dam	–
3	4022221	Kiewa River @ Main Station	–
4	4022051	Kiewa River @ Bandiana	–
5	4090171	Murray River @ Doctor's Point	–
6	4090021, 4090423	Murray River @ Corowa	A) Albury–Yarrawonga
7	4090251	Murray River @ Yarrawonga Weir	A) Albury–Yarrawonga
8	4092021	Murray River @ Tocumwal	B) Yarrawonga–Torrumbarry
9a, 9b	4090061	Murray River @ Picnic Point, Edward River @ Offtake	B) Yarrawonga–Torrumbarry
10	4042101	Murray River @ Barmah	B) Yarrawonga–Torrumbarry
11	4092071	Murray River @ Torrumbarry Weir	B) Yarrawonga–Torrumbarry
12	4090051	Murray River @ Barham	D) Torrumbarry–Wakool
13	4072160, 4092041	Murray River @ Swan Hill	D) Torrumbarry–Wakool
14	4090471	Edward River @ Toonalook	C) Edward Gulpa–Stevens Weir
15a, 15b	4090231	Edward River @ d/s Steven Weir, Wakool River @ Offtake Regulator	C) Edward Gulpa–Stevens Weir
16	4090582, 4090141	Edward River @ Moulamein	E) Stevens Weir–Kyalite*
17	4090351	Edward River @ Leiwah	E) Stevens Weir–Kyalite*
18	4090131	Wakool River @ Stoney Crossing	E) Stevens Weir–Kyalite*
19	4142001	Murray River @ Wakool Junction	D) Torrumbarry–Wakool
20	No area	Murray River @ Boundary Bend	F) Wakool–Wentworth
21	4142031	Murray River @ Euston Weir	F) Wakool–Wentworth
22	4142071	Murray River @ Colignan	F) Wakool–Wentworth
23	4250121	Darling River @ Weir 32	–
24a, 24b	4250071, 4250131	Darling River @ Burtundy, Great Darling Anabranch @ Wycot	G) Menindee–Murray
25	4250111	Great Darling Anabranch @ Bulpunga	G) Menindee–Murray
26	4250101	Murray River @ Wentworth (Lock 10)	F) Wakool–Wentworth
27	4265051	Murray River @ Lock 9	–
28	4265281	Murray River @ Overland Corner	–
29	4269031	Murray River @ Lock 1	–
Not assessed		Reason	
	4012240, 4012111	Upstream inflow to reach 1	
	4012011, 4015600, 4015610, 4015650, 4015710	Upstream inflow to reach 2	
	4022030	Upstream inflow to reach 3	
	4265273, 4265328, 4265329	Downstream of the lowest gauging station with data	

* The downstream gauge in accounting was the Edward River @ Leiwa, and therefore there is some mismatch between these reaches.

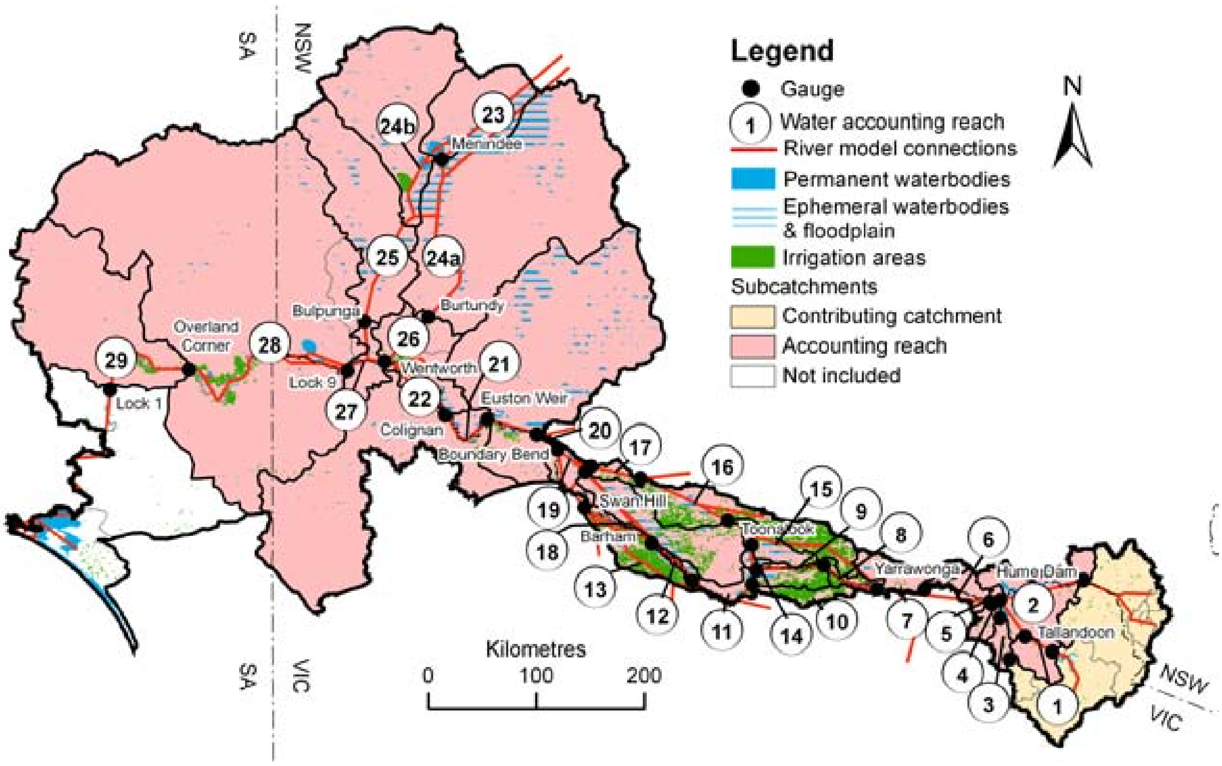


Figure 5-1. Map showing the subcatchments used in modelling, and the water accounting reaches

5.2.4 Diversion data

Wetland and irrigation water use

The results of the remote sensing analyses (Chapter 1) are in Figure 5-1. It shows irrigation is particularly concentrated between Yarrawonga and Euston Weir and the South Australian border and Lock 1. Several reservoirs, lakes, weir pools, ephemeral wetlands and floodplains occur along the Murray and Darling rivers. Streamflow and diversion data were sourced from Sinclair Knight Merz for Victoria, the Murray-Darling Basin Commission's Water Audit Monitoring Reports for South Australia and the New South Wales Department of Water and Energy.

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

The river model 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 Van Dijk et al. (2008). Calculations were made for each reach separately but summary indicators were compared between reaches.

Completeness of hydrological observation network

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

- the volumes of water measured at gauging stations and 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 as modelled by the baseline river model (Scenario A) and as accounted. Large divergence is likely to indicate large uncertainty in reach water fluxes and therefore uncertainty in the river model and water accounts.

Climate range

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

Performance of the river model in explaining historical flow patterns

All the indicators used in this analysis are based on the Nash-Sutcliffe model efficiency (NSME; Nash and Sutcliffe, 1970). NSME indicates the fraction of observed variability in flow patterns that is accurately reproduced by the model. In addition to NSME values for monthly and annual outflows, values were calculated for log-transformed and ranked flows, and high (highest 10 percent) and low (lowest 10 percent) monthly flows. NSME cannot be calculated for the log-transformed flows where observed monthly flows include zero values or for low flows if more than 10 percent of months have zero flow. 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 fuller description of the method in a project methods report (Van Dijk et al., 2008).

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

Scenario change-uncertainty ratio

Streamflow patterns simulated for any of the future scenarios can be compared to those for the baseline scenario. If these future scenarios explain historically observed flows about as well or better than the baseline scenario, then it may be concluded that the future scenario changes are within model ‘noise’, that is, smaller or similar to model uncertainty.

Conversely, if the agreement between future scenario and historically observed flows is poor – much poorer than between the baseline scenario 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 a future scenario to that for the baseline scenario (Scenario A). A value of around 1.0 or less suggests that the projected change under a future scenario is not significant when compared to river model uncertainty.

A ratio that is considerably greater than 1.0 indicates that the future scenario is much poorer at producing historical observations than the baseline scenario, suggesting that the future scenario leads to significant changes in flow. The change-uncertainty ratio is calculated for monthly and annual values. In this case the baseline scenario 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.

A fuller description of the method is in a project methods report (Van Dijk et al., 2008).

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 Murray region is the largest of the 18 regions and covers a fifth of the MDB. It is the sixth most sparsely gauged region in the MDB. The density of the streamflow, rainfall and evaporation gauging networks is slightly less than the average density across the MDB. Streamflow gauging is concentrated on the Murray, Darling, Edward and Kiewa rivers. Rainfall and evaporation gauges are concentrated in more densely populated areas along the Murray River and the Lower Murray area.

Table 5-3. Some characteristics of the gauging network of the Murray region (207,667 km^2) compared with the entire Murray-Darling Basin (1,062,443 km^2)

Gauging network characteristics	Murray		Murray-Darling Basin	
	Number	per 1000 km^2	Number	per 1000 km^2
Rainfall				
Total stations	861	4.15	6,232	5.87
Stations active since 1990	431	2.08	3,222	3.03
Average years of record	49		45	
Streamflow				
Total stations	174	0.84	1,090	1.03
Stations active since 1990	151	0.73	881	0.83
Average years of record	20		20	
Evaporation				
Total stations	34	0.16	152	0.14
Stations active since 1990	26	0.13	104	0.10
Average years of record	27		27	

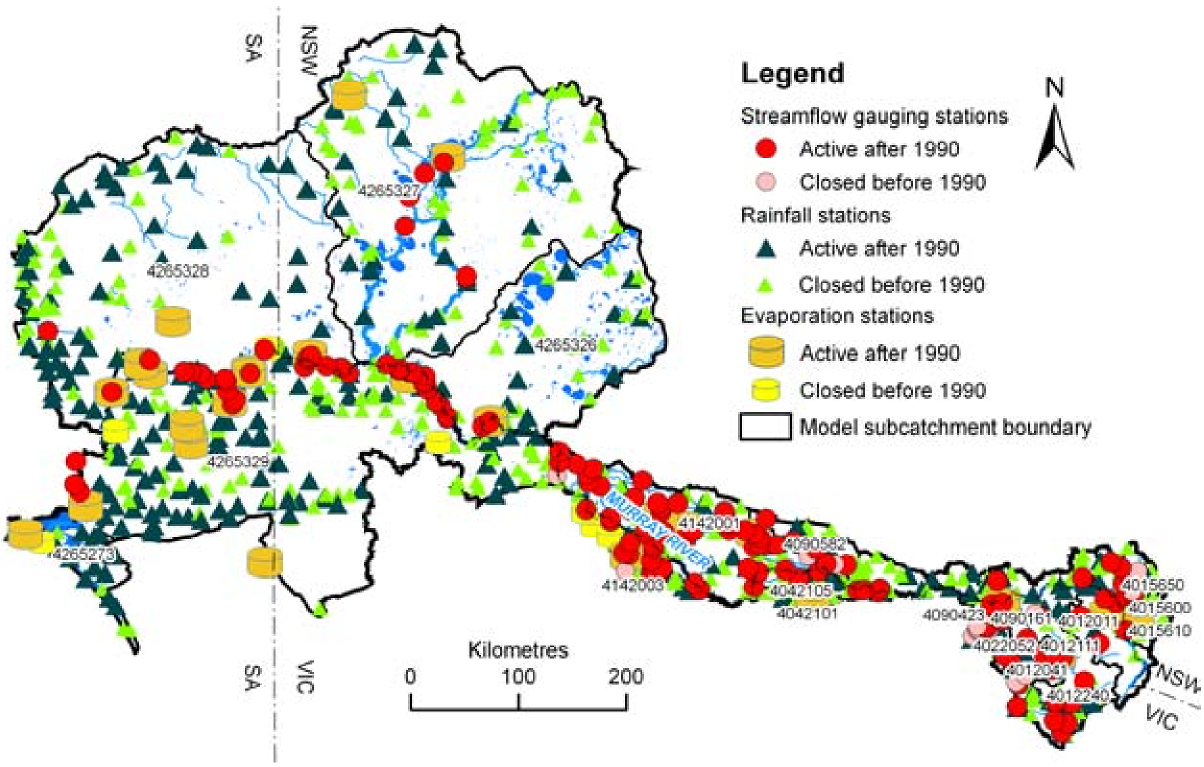


Figure 5-2. Map showing the rainfall, stream flow and evaporation observation network, and the subcatchments used in modelling

5.3.2 Review of model calibration and evaluation information

This section provides a summary of the river models, the data and procedure used in calibration and performance assessment, and identified areas of weakness, based on MDBC (2002 and 2007).

Model description

The MSM-BigMod models provide the capability to simulate daily stream flow for the Murray system from Dartmouth Dam to the barrages in South Australia including the Lower Darling from the Menindee Lakes on a daily basis (as well as salinity from Hume Dam downstream (MDBC, 2002)).

The Monthly Simulation Model (MSM) was developed initially in 1965 to accord with the water sharing arrangements under the Murray-Darling Basin Agreement. It was used for simulating the Murray and Lower Darling River System from Dartmouth Dam to the South Australian border. The model was revised in 1979 to allow water accounting between states. The model has been updated and its capabilities since enhanced to inform water management and various policy options. The model is a monthly time step model (with the exception of the Menindee Lakes system which is modelled at a daily time step) that simulates resources available and allocations by states, demand for water in the key areas throughout the system, water accounting, transfers between storages to ensure that the demands can be met, operation of various dams and structures including orders and pre-releases from each storage for flood mitigation (MDBC, 2007).

BigMod was developed for daily simulation (MDBC, 2002). The two models are run sequentially; some of the MSM outputs (irrigation demands, resource assessment, water accounting and storage pre-release targets) are disaggregated to daily data and used as inputs to BigMod. BigMod simulates flow and salinity routing for each river reach as well as losses, inflows, extractions, the operation of storages and weirs based on specified rules and the diversion of water into branches. The model extends from Dartmouth Dam beyond the South Australian Border to Lake Alexandrina.

The Murray and Lower Darling River system was divided in MSM into eight river reaches and a number of major structures, inflows, regulators, diversions and anabranches. Unregulated catchment flows were synthesised as flows under natural conditions. These inflows for the Kiewa and Ovens rivers were adjusted for diversions. Unregulated diversions (estimated at about 28 GL/year) in the NSW catchments were included in unspecified losses. Water balance simulation was done for four storages (Dartmouth and Hume Dams, Menindee Lakes and Lake Victoria) but not for the Yarrawonga, Torrumbarry, Euston and Stevens weir pools because of their low storage volumes. However, their effect on routing is simulated in BigMod.

Surface-groundwater exchanges were not modelled in MSM originally but were addressed as part of this project.

The process of assessing water availability for allocation to each State and to their water users is simulated in MSM. It involves estimation of water available in storages, expected inflows until the next 31 May (under a specified risk level), and losses that would occur in the whole system while supplying water to various users. MSM simulates water sharing arrangements between states in the Murray and Lower Darling rivers according to the rules specified in the Murray Darling Basin Agreement (MDBC, 2006).

MSM includes rules for releases from Hume and Dartmouth dams at each time step for flood mitigation and resource assessment. MSM covers transfer of water from Dartmouth Dam to Hume Dam, Hume Dam to Lake Victoria and Menindee Lakes to Lake Victoria for optimal resource management. It also considers constraints on discharge imposed by two narrow points in the system (the Mitta Mitta River and the Barmah Choke in the Murray River). BigMod simulates operation of the four lakes in the Menindee Lakes system for optimal flow and salinity management on a daily time step, then monthly totals are supplied to the MSM model domain downstream (MDBC, 2007). This ‘optimal’ operation of the lakes has not always been achieved (MDBC, 2007). MSM also simulates operation to fulfil environmental flow allocations on the Murray System for Barmah-Millewa Forest, minimum flow requirements and Lower Darling demands.

Data availability

The models use rainfall and evaporation data to estimate losses or gains in river reaches and storages and to calculate irrigation demand. The model generally uses monthly values for net evaporation estimation that were computed separately and used as model input data.

Six rainfall stations with long-term data (more than 80 years, except for the Mildura station) and four evaporation stations (at Dartmouth and Hume reservoirs, Lake Victoria and Menindee) were used to estimate evaporation losses. Nine rainfall stations were used in the calibration of BigMod to enable it to cover a larger area. Large differences between the various rainfall and evaporation stations and between years were noted by MDBC (2007).

Historical data for all tributary inflows and drain inflows were used for calibration of MSM. Data quality was controlled by various visual and statistical analyses to detect outliers (rating curves are reviewed on an ongoing basis). Data gaps up to 30 days were filled in by linear interpolation of model input flows. Gaps were not filled where flow observations were used in calibration. Some of the inflow data were reconstructed from multiple data sources. The approach for gap filling or data synthesis included correlation with nearby stations, water balances on dams, and routing of historical flows using BigMod. Monthly data from the Goulburn and Campaspe REALM model were disaggregated to daily using data from relevant gauging stations. Measurement of inflows from drains was very limited (MDBC, 2007). Available data were included; otherwise mean monthly values were estimated.

The demand model in MSM was calibrated to diversion data supplied by state agencies (or in the Murray-Darling Basin Commission database). MSM estimates of diversions were disaggregated to daily time step for BigMod using historical recorded daily data. Gaps in daily recorded data values were in-filled using linear interpolation or by regression with data from neighbouring sites to generate a continuous record of the daily data pattern. Regression relationships were developed where daily data were not available between the fraction of the monthly diversion occurring on any day and rainfall.

Model calibration and validation

MSM was revised and recalibrated over past decades. Values for the parameters relating to operational rules, storage capacities, irrigation demands, system losses, and resource assessments were updated. The period for MSM model calibration was 1983 to 2000, and the period for model testing was 1982 to 2005. Therefore the period 2000 to 2005 is a period of independent validation. Model calibration and validation was done in four steps: (1) demand calibration, (2) loss calibration, (3) operational loss calibration and (4) model testing.

Demand calibration involved development, calibration and testing of empirical regression equations to estimate irrigation demand from rainfall, temperature, and water availability, and match historical water use data. Historical data at some locations showed increasing or decreasing water use trends due to changes in crop or irrigation practices and climate trends. Observed storage releases were used at this stage.

Loss calibration involved developing and testing equations to estimate transmission losses in various river reaches and for various flow ranges. This was done by comparing the flows at gauging stations along the river using historical data on storage releases and diversions. Empirical loss equations were developed and calibrated to maximise the match with observed streamflow (MDBC, 2007).

Operational loss calibration allowed for storage release in addition to historical releases and reflected the planning purpose of MSM. Operational loss covers the river operation uncertainty associated with differences between water orders and the actual diversions, estimates of system losses, environmental flow needs and tributary inflows. It incorporates a conservative calculation that reduces the risk of failing to meet the requirements. Operational losses were estimated by subtracting modelled orders from historical releases from Hume Dam and developing empirical regression equations that best described differences.

Model testing was done by comparing simulated and historic streamflow at selected locations, storage volumes and resource assessments. The main performance indicators considered were irrigation demands and returns, losses, storage volumes, resource assessments, off-allocation declaration, Dartmouth – Hume transfers, Hume – Lake Victoria transfers, and Edward-Gulpa Offtakes (bulk diversions).

BigMod was calibrated originally for 1979 to 1990 and validated for 1990 to 1996 (MDBC, 2002). BigMod calibration and testing was done in five stages: (1) flow routing and transmission losses calibration, (2) storage and weir calibration, (3) salinity routing calibration, (4) estimation of salt inflow in various reaches and (5) model testing.

Flow routing and transmission loss calibration was done by estimating flow routing parameter values and loss estimates for various flow regimes. Calibrated parameters described the relationship between flow and travel time through the river reach and the flow versus loss relationship. A sequential run of MSM and BigMod was done to test the accuracy of the linked model to reproduce historical flows and salinities at the gauging stations along the Murray River.

Historical inflow data (1975 to 2000) were used in this run in MSM. Diversions were calculated by including observed trends and the river system operating rules were varied during the simulation period where necessary. Monthly MSM outputs were disaggregated and used as input for BigMod. These results accumulate all errors including those from both the MSM and BigMod model structures, the procedure to disaggregate monthly data, routing parameters, and gap-filling (MDBC, 2002). The performance of MSM-BigMod was assessed for the period May 2000 to April 2003. Modelled and observed flow, salinity and salt load were compared for this period.

Model performance

Model performance assessment included comparison of observed and simulated time series in terms of mean, standard deviation, root mean square of errors (RMSE), standard error of estimate (SEE) and correlation coefficient. A value of ±5 percent net difference between simulated and observed means was considered as the maximum allowable limit unless the difference was caused by an explainable event. A correlation coefficient of more than 0.70 for irrigation diversions and more than 0.90 for streamflow in the Murray and Lower Darling rivers was considered satisfactory. If the correlation coefficient was lower than 0.70 than the result was still considered acceptable if the SEE was less than 5 percent of the mean. Visual inspection time series graphs, flow duration curves, scatter and deviation-from-the-mean plots were used to identify any systematic error and to assess the quality of calibration in different flow ranges (MDBC, 2007).

The model simulated irrigation diversions for both New South Wales and Victorian irrigators with reasonable accuracy. Victorian demands were simulated better than New South Wales demands both in terms of variability and on average. The New South Wales demands (especially for Murray Irrigation Limited, the largest user) were highly variable and some of the peak demands observed in January and March were not reproduced well by the model. The measurement accuracy of some of these large diversions was also questioned by MDBC (2007).

Victorian irrigation demand was overestimated for two years (2004 and 2005) by the model. This was attributed to changes in allocation rules in recent years.

Predictions of New South Wales diverter demands downstream of the Murrumbidgee confluence and Broken Hill pumping were not reproduced as accurately as other diverters. The demand estimates for these locations were still considered acceptable considering the limited quality of historic data and the low SEE (MDBC, 2007).

Comparison between observed and modelled diversions showed unsatisfactory results for the lower Darling. The main reason for this was the variability in the timing and volume of releases to the Great Darling Anabranch and off-allocation diversions by Tandou Irrigation Limited. The on-allocation release to the Great Darling Anabranch of 50 GL/year occurs in July in the model whereas in practice both the timing and volume of on-allocation releases have varied. The accuracy of the lower Darling predictions could be improved if additional information on farm water management and cropping practices for the Tandou district were available.

The model reproduced historical behaviour for Dartmouth and Menindee lakes storage volumes well. Simulated water levels in the lower lakes showed rising and falling trends that agreed well with observations. Observed daily fluctuations were not reproduced.

Overall the results of calibration for flow and salinity from the MSM-BigMod model were good considering the accumulation of errors in the linked model (MDBC, 2002). The model reproduced streamflow patterns reasonably well at all major gauging stations (MDBC, 2007).

Simulated flows downstream of Yarrawonga Weir and Torrumbarry Weir agreed well with flood timing, peak and volume observations. The match was poorer for low, regulated flow conditions. Flows were overestimated at Swan Hill and under-estimated at Kyalite during major floods. An attempt to include flood runners from the Murray into the Wakool River did not improve the water balance. Errors in the Swan Hill and Kyalite rating curves for high flows, poor drainage flow data and patchy data in general may explain the uncertainty. The calibration at Torrumbarry was also affected by low quality drainage data. The agreement between simulated and recorded flows at Weir 32 in the lower Darling was poor during low flows but was reasonably good for flows greater than 10,000 ML/day (MDBC, 2002).

Flows into South Australia were exceptionally close to recorded values as errors in low flow data near Lake Victoria get corrected by the Lake Victoria inflow and outflow simulations. The match between the simulated and observed flood flows upstream of Lake Victoria was also very good.

The timing as well as shape of the flood hydrographs in the lower Murray River at Lock 1 was reproduced well by the model. The variability in simulated flows during the low regulated flow periods was less than the observed data due to the model distributing diversions evenly over each month and maintaining steady water levels at the locks. In practice operation of the locks generates flow fluctuations.

The model simulated flow with a reasonable degree of accuracy on the main stem of the River Murray and Lower Darling River. Modelling of the Edward-Wakool system was not as good and was ascribed to the complexity of the system and a lack of data (MDBC, 2002).

Identified areas of weakness or improvements

Several areas of improvement were identified by MDBC (2007).

Data for 17 years (1983 to 2000) were used for the development of demand equations. There were changes during this period in the level of irrigation development as well as in crop mix and an increasing adoption of efficient water application technologies. The empirical regression equations in the model may not have represented these changes correctly even after trend analysis. Some of the recent extreme climate conditions were not covered by the data.

Estimating demands using simulation of the soil moisture balance, crop mixes, annual area planted, and irrigation water application method may give better estimates of crop water use under these changing conditions. This would require comprehensive additional data collection as well as a modelling time step of less than a month.

Recent changes in allocation rules for diversions in Victoria have not yet been implemented in the model.

Evaporation losses (as well as salinity) from the Menindee Lakes system are sensitive to how the water is distributed between the four lakes when they are not full. Menindee and Cawndilla lakes are not well connected to the river and it is not possible to draw them down rapidly. There is a discrepancy between this physical constraint and the assumptions and simulations in the model during periods of low water availability (MDBC, 2007). The model calibration for the Tandou and Great Darling Anabranch releases could be improved if additional data on diversions and diversion rules were available.

River operation decisions are made in real time based on information on climate, irrigation demand and system losses. Some of the logic used by the river operators is not built into the model and documentation of the decision making processes may improve model performance (MDBC, 2007). The capability of the MSM model to simulate rain rejection, high flow losses and operational loss estimates could be improved by moving the model to a shorter time step. Estimates of rain rejection and operational losses by the model reflect long-term extra releases from storages and can be in error for individual events. Rain rejections are managed proactively by the river operators in practice who consider additional information on rainfall and flow in the upstream parts catchments. This decision making process is not simulated in the model.

Estimates of transmission losses and operational losses could be improved but would require more detailed studies of floodplain behaviour (MDBC, 2007). Losses in the Barmah-Millewa Forest could depend on antecedent conditions. Using a loss estimation approach that takes the time since previous flooding or rainfall into account was considered a feasible and important improvement and might also benefit from daily modelling.

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. Conclusions follow:

- Gains are gauged very well to excellent (>80 percent gauged; Figure 5-3a) in most of the reaches because main stem inflows are very high compared to ungauged local inflows. The Kiewa and upper Murray river reaches are gauged well to reasonably well (Reach 1 to 4, 66 to 78 percent gauged) due to considerable local inflows. Inflows to the Edward River are fairly well gauged (49 percent; Reach 14) but do not include several anabranches, and inflows into the lower Wakool system are very poorly gauged (6 percent; Reach 18) due to ungauged tributary inflows).

- Outflows and losses are generally well to excellently gauged (>75 percent gauged). Notable exceptions in the Murray River include the reaches between Picnic Point and Tocumwal (Reach 7) and between Lock 9 and Wentworth (Reach 27; 71 percent gauged in both cases). This is attributed to unaccounted overbank flows into wetlands and distributaries. Losses in the Darling are less well gauged (29 to 79 percent gauged).
- On average 83 percent of the total water balance appears to be gauged in the various reaches. Gauging is more complete in the Murray River and less complete in the Edward-Wakool and Darling systems.
- Attribution of gains and losses using SIMHYD estimates of local runoff, diversion data and remote sensing generally help to explain a large part of ungauged gains and losses in the Kiewa and Murray rivers (more than 88 percent of the combined reach gains and losses). Reach 2 in the Murray River is an exception as this is associated with insufficiently accounted changes in Hume Dam storage.
- Attribution of ungauged flow components was less successful in the Edward-Wakool system (particularly in the lower Wakool (Reach 18)) and the Darling River (78 to 91 percent of water balance gauged).
- Most gains and losses are gauged or can be attributed and so the water balance of the Murray River system is well gauged. Exceptions are the upper Edward and lower Wakool reaches and the Darling system where hydrology is more complicated due to the anabranching stream network.

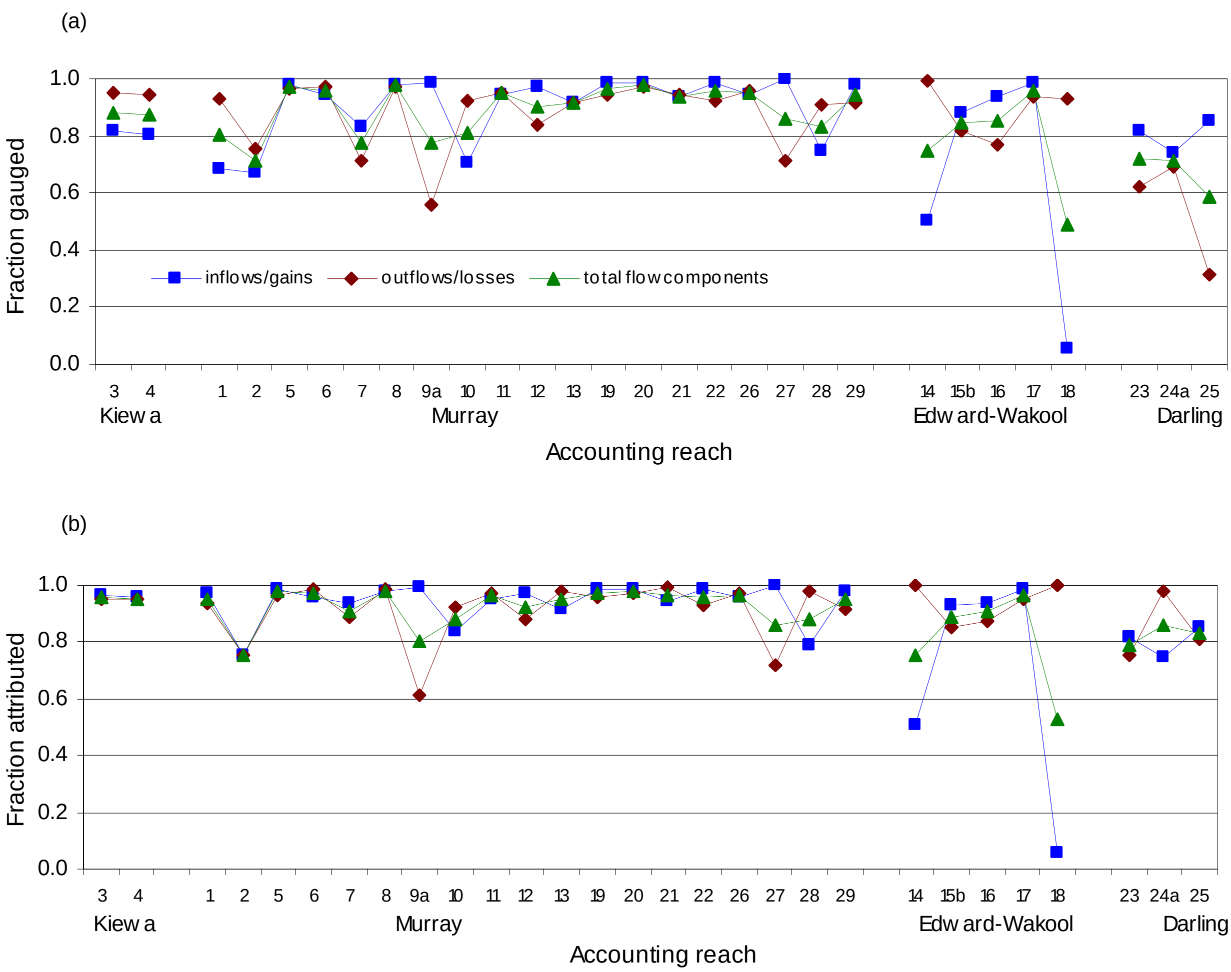


Figure 5-3. Patterns along the length of the river of indicators of the fraction of inflows/gains, outflows/losses and the total of water balance components that is (a) gauged or (b) could be attributed in the water accounts

Comparison of modelled and accounted reach water balance

A summary water balance for both reaches as simulated by the river model and derived by water accounting can be found in Appendix C. The water balances are combined in Table 5-4.

Table 5-4. 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 (gains)				
Main stem inflows	5297	5434	-137	-3%
Tributary inflows	5706	4863	843	17%
Local inflows	0	1823	-1823	-100%
Subtotal gains	**11003**	**12121**	**-1118**	**-9%**
Unattributed gains and noise		7497		
Outflows (losses)				
End of system outflows	5790	6156	-366	-6%
Distributary outflows		0	0	n/a
Net diversions	3648	4007	-359	-9%
River flux to groundwater	21	0	21	n/a
River and floodplain losses	1564	2401	-837	-35%
Other losses	-21	0	-21	n/a
Subtotal losses	**11003**	**12564**	**-1562**	**-12%**
Unattributed losses and noise		8040		

An interpretation follows:

- The overall water balances of the model and the accounts are similar. However, the accounts show higher inflows and outflows than the model as the accounts cover (in some cases) a shorter reporting period where gauging is incomplete.
- The accounting water balance contains a mass balance error (the gains and losses in the table did not sum to zero) due to different reaches having different periods of accounting.
- The accounting water balance contains large unattributed gains and losses (the sums of the mass balance errors for each month in each accounting reach) and indicates uncertainty in the overall water balance.
- The end-of-system outflows (the values at Lock 1) are greater than the true end-of-system outflows (at the barrages or the Murray mouth). The true value is around 1000 GL/year less than that at Lock 1.

Climate range

The 17-year period from 1983 to 2000 represented the calibration period. Eleven years in the entire 111-year record used in modelling were drier than those included in the calibration period. Three years were wetter. The average rainfall for the calibration period (371 mm/year) was 10 percent higher than the long-term average (341 mm/year). The historical 111-year rainfall record had seven years that were drier and three years that were wetter than the extremes during the period of water accounting (1990 to 2006). Overall, the period of calibration provides a good representation of the longer climate record. The water accounting period also provided a good representation of long-term climate variability.

Performance of the river model in explaining historical flow patterns

The better the baseline model simulates streamflow patterns, the greater the likelihood is that it represents the response of river flows to changed climate, land use and regulation changes (notwithstanding the possibility that the model is right for the wrong reasons through compensating errors). Appendix C lists indicators (reach by reach) of the models reproduction of different aspects in historically measured monthly and annual flows (all are variants of Nash-Sutcliffe model efficiency – NSME). Appendix C gives NSME values of model performance. These are also shown in Figure 5-4a and b. A comparison between simulated and observed average flow is shown in Figure 5-5.

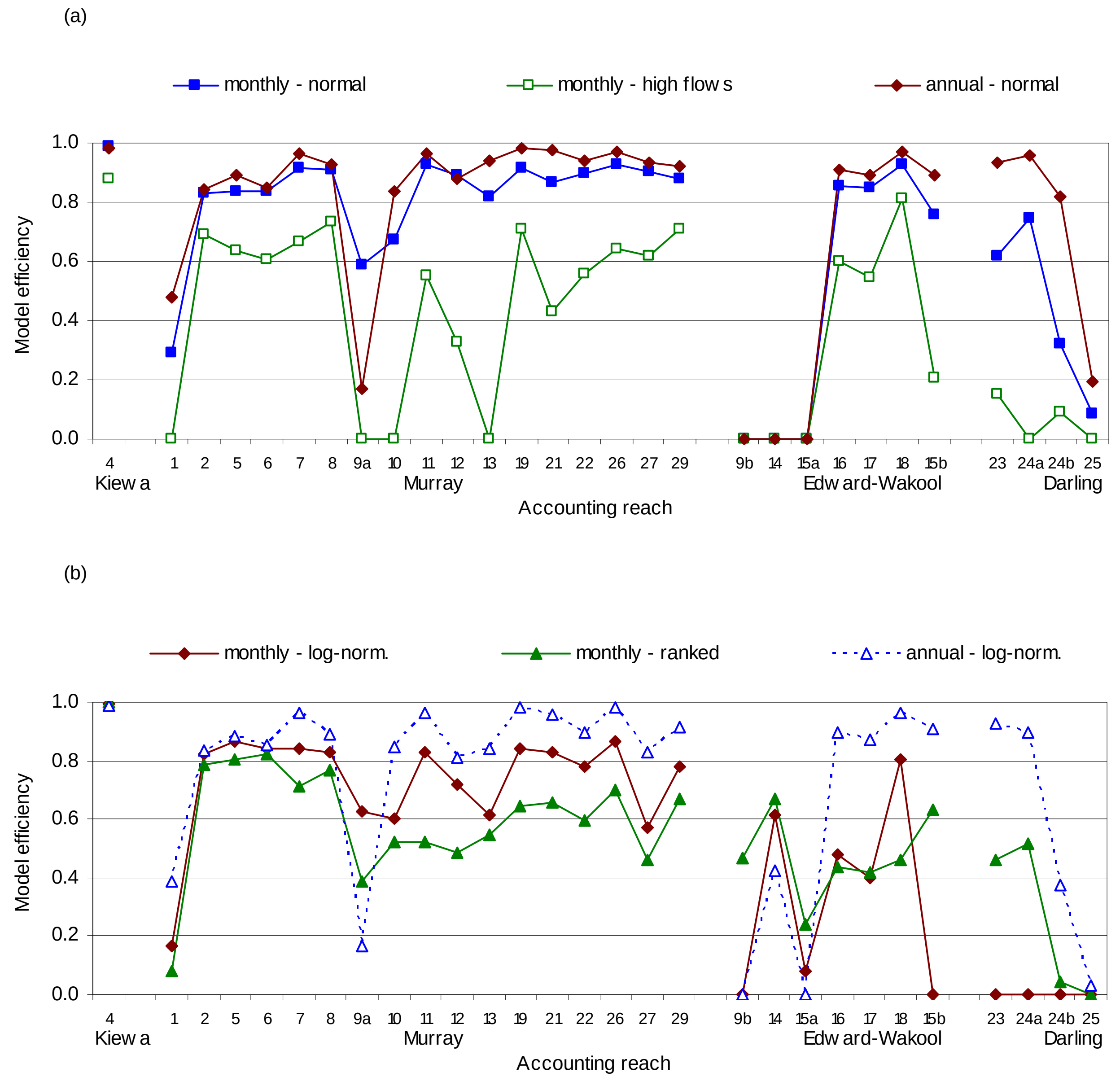


Figure 5-4. Changes in different measures of model efficiency (the performance of the river model in explaining observed streamflow patterns) along the length of the river (numbers refer to reach)

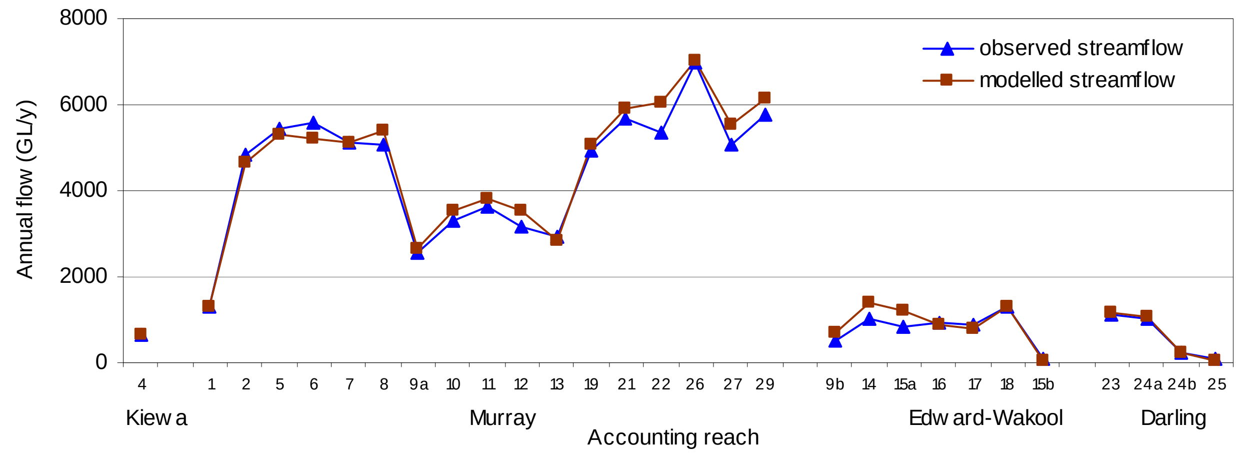


Figure 5-5. Comparison of baseline simulations and observations of average annual streamflow along the length of the river (numbers refer to water balance accounting reaches)

Observations follow:

- The performance of the model in reproducing totals is excellent for the Kiewa River (Reach 4, NSME=0.99 for monthly and 0.98 for annual flows) but poor for the Mitta-Mitta reach (Reach 1, NSME=0.29 and 0.48). The first result is because modelled flows are directly based on recorded flows. The second result is attributed to difficulty in simulating human decisions on releases from Dartmouth Dam (Appendix C). Other streamflow performance indicators showed the same patterns (Figure 5-4b) and average flows are reproduced extremely well (within 1 percent or 10 GL/year; Figure 5-5).
- Model performance in reproducing annual flows is very good to excellent (NSME=0.85–0.98) in the Murray River main stem and tends to increase downstream. Model performance for monthly flows shows an increasing trend (NSME=0.83–0.93). However, model performance is fair (NSME=0.59–0.67) in reaches 9a (Picnic Point) and 10 (Barmah) as these stations are affected by the Edward-Gulpa Offtakes and the Barmah Choke.
- Performance for high flows is lower than monthly flows (Figure 5-4a) except at Swan Hill (Reach 13) where overall flow patterns are reproduced well but recorded high flows are systematically greater than modelled. Performance is better at gauges upstream and downstream of this site. Figure 4-5b shows that the relative flow patterns between Hume Dam and Lock 1 are simulated reasonably well (NSME=0.52–0.82 for ranked monthly flows), performance deteriorates beyond the Edward-Gulpa Offtakes (Reach 9a) and then gradually increases again.
- Average flows are reproduced well in relative terms (within 12 percent) although a difference of up to 711 GL/year occurred (Reach 22, Colignan) (Figure 5-5). Flows are underestimated above Yarrawonga Weir and overestimated below for unknown reasons.
- Model performance is poor for the Edward River above Stevens Weir (Reaches 9b, 14 and 15a; Figure 5-4a) and coincided with systematic overestimation of recorded flows by 37 to 43 percent or 203 to 370 GL/year (Figure 5-5). Relative patterns are reproduced slightly better (Figure 5-4b). The lack of consistency may have been associated with ungauged flows in anabranches parallel to the Edward River that are not gauged but are simulated by the model. Model performance below Stevens Weir is good to excellent for monthly flows (NSME=0.76–0.93), annual flows (NSME=0.89–0.97) and (in some cases) good for high flows (NSME=0.20–0.81) (Figure 5-4a). Average flows are also consistent (within 4 to 9 percent or 41 to 75 GL/year).
- Monthly streamflow patterns in the lower Darling River are reproduced reasonably well for the main stem which carries most of the streamflow (NSME=0.62-0.74 for monthly; Reaches 23 and 24a; Figure 5-4a), very well for annual patterns (NSME=0.93–0.96) and average flows (within 2 to 5 percent or 23 to 52 GL/year). Results for flow patterns and average flows deteriorate down the smaller Great Darling Anabranch (from NSME=0–32–0.82 and a 6 percent or 14 GL/year difference for Reach 24b, to NSME=0.09–0.20 and a 35 percent or 29 GL/year difference for Reach 24a). However combined flows from the main stem and anabranch (Reaches 24a and 25) agree extremely well (within 1 percent or 6 GL/year).
- Performance in reproducing the 10 percent lowest flows is poor in all cases (NSME<0). The Mitta-Mitta, Murray and the Edward-Wakool system minimum flows are managed through regulation and are estimated well by the model. However, the 10 percent lowest flows in the 1990 to 2006 historical record include several months when flow falls below this ‘normal’ minimum flow (for unknown reasons) and the model does not reproduce these events (Appendix C). The model tends to underestimate minimum flows in the Darling River main stem (Reaches 23 and 24a) (Appendix C). The Great Darling Anabranch (Reach 25) is dry for more than 10 percent of months so the low flow model performance metric was not calculated.

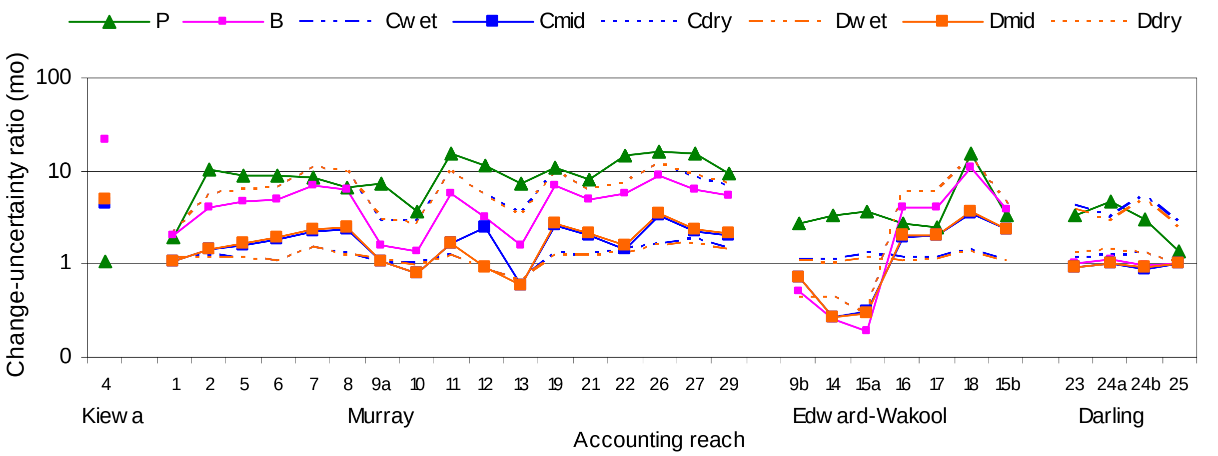
Conclusions follow:

- Model performance in reproducing annual and monthly flow patterns is good for most of the region. However, the model has difficulty reproducing flows between the offtake of the Edward-Wakool system down to the Murray River at Barmah, the Edward River at Stevens Weir and flows in the Great Darling Anabranch.
- Model performance in reproducing high flows is less good than overall model performance and shows similar relative differences between locations.
- River operations determine overall flow patterns in the Mitta-Mitta River and low flow patterns in the rest of the system. The average results of operations are generally well reproduced by the model but where occasional departures occur in the record are not modelled.

Scenario change-uncertainty ratio

A high change-uncertainty ratio (CUR) corresponds with a change in flows related to a scenario that is likely to be significant given the uncertainty in the model. A value of around one means that the modelled change is similar to the uncertainty in the model. The patterns of CUR along the river system are shown in Figure 5-6.

a)



b)

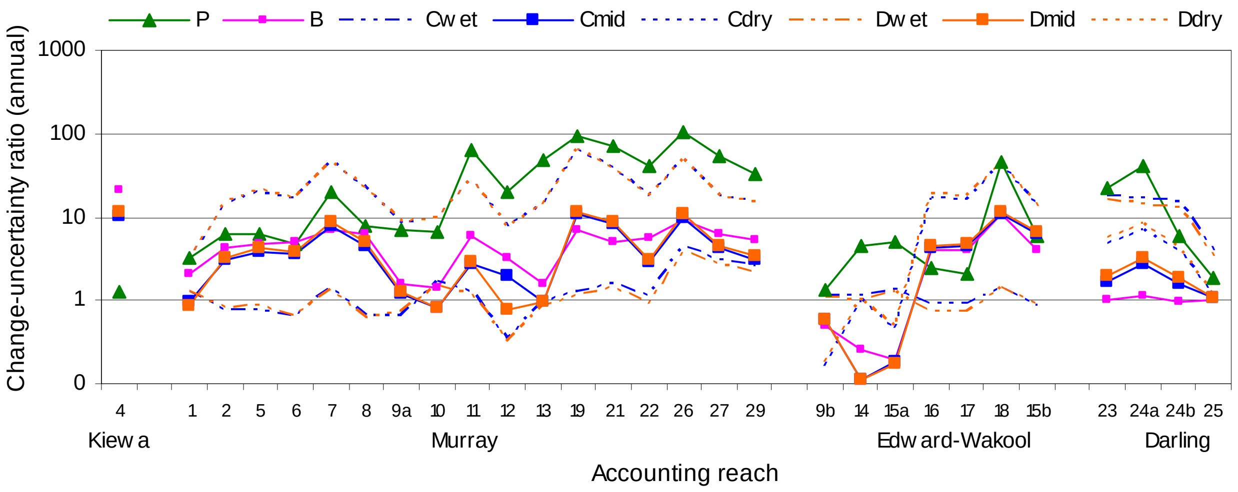


Figure 5-6. Pattern along the river of the ratio of the projected change over the river model uncertainty for the different scenarios modelled for (a) monthly and (b) annual flows

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.
- The predicted without-development flows are significantly different to current flows. The predicted change from the current pattern is larger than the uncertainty in the modelling of current flows. The change to uncertainty ratios are greater than almost everywhere except in the Murray uplands (Kiewa and Mitta-Mitta rivers) and the lower Great Darling Anabranch (Reach 25). Predicted annual without-development flows in the Murray River are significantly different from current flows between Hume Dam and Lock 1 (CUR=7–104). Monthly streamflow patterns above Yarrawonga Weir change more than annual totals. They are less variable due to the operation of Hume Dam (Appendix C) and the seasonality in flows reversed (Chapter 4). This is opposite below Torrumbarry Weir as annual flows change more than monthly flows and without-development high and medium flows are reduced due to regulation (Appendix C). Flows in the Edward-Wakool system change substantially (CUR=2.5–46). Flows in the Darling system also change (CUR=3.1–40).
- The projected changes in current flow patterns under Scenario Cdry are generally greater than model uncertainty by a high to very high margin (CUR for annual or monthly flows greater than 5 in 22 out of 29 reaches; Figure 5-6). The projected changes under Scenario Cmid are larger than model uncertainty by a moderate margin (CUR for either annual or monthly flows greater than 2 in 19 reaches). The projected changes under Scenario Cwet are slightly greater than model uncertainty (CUR values are less than 2 in 22 reaches). The projected changes in annual flows under Scenario B are generally greater than model uncertainty by a moderate margin and projected changes to monthly flows are greater than model uncertainty by a high margin (Figure 5-6).
- The evidence that flow will change under the different climate scenarios is strongest in the Kiewa River (Reach 4) and the Murray River below Swan Hill (Reach 19). Evidence is weakest in the Murray River between Tocumwal and Barmah (9a and 10), the upper part of the Edward-Wakool system (Reaches 9b, 14 and 15a) and the Darling system. This is because the model performs less well in these reaches rather than because predicted flow changes are smaller.
- The projected changes due to Scenario C and D have very similar CUR values. Differences between scenarios D (associated with plantation forestry, further groundwater extraction and farm dam development) and C are less than 1 percent of overall system inflows (Chapter 4).

Conclusions follow:

- There is strong to very strong evidence for changes in flow pattern due to past development in most of the regulated part of the system.
- The evidence that flow patterns would change under scenarios Cdry or Cmid is strong and moderately strong, respectively. Projected changes under Scenario Cwet are closer to model uncertainty.
- The projected impact from development is very small (<1 percent) compared to the projected impact from climate change and the uncertainty around development is smaller than the uncertainty from other sources.
- The river model uncertainty is generally small compared to the projected changes. Exceptions are the Murray between Tocumwal and Barmah and the Edward system above Stevens Weir. This is due to systematic biases between modelled and observed flows associated with incomplete gauging. There is also uncertainty in projections for the Great Darling Anabranch.

5.4 Discussion of key findings

5.4.1 Gauging and understanding of the hydrology of the Murray region

The hydrology of the Murray region surface water system is well gauged. The density of gauging is slightly less than the average network density for the MDB. Streamflow gauging is concentrated in the Murray, Edward and Darling rivers. Water accounts could be established for 29 reaches: 18 reaches on the Murray River, one on the Mitta Mitta River, two on the Kiewa River, three on the Darling River and Great Darling Anabranch, and five in the Edward-Wakool system. The Murray River is gaining above Doctors Point, and alternatively losing and gaining below it due to offtakes and tributary inflows. The Darling system is losing over the length considered. Overall, the region appears to be sufficiently well gauged and understood for reliable modelling.

The conceptual understanding of the current hydrology is good. Groundwater interactions appear to play a minor role in the accounted section of the Murray surface water system (Chapter 4). Uncertainty associated with unanticipated changes in river regulation, irrigation and development is possible.

Prior river model evaluation suggested that the least well understood parts of the system are the hydrology of the Edward-Wakool and Darling river systems (Section 5.3.2). Both are characterised by a relatively complicated anabranching river network and incomplete gauging.

The effect of the wetlands and overflows of the Murray and Edward rivers on Murray hydrology is also recognised as uncertain. This uncertainty does not affect the reproduction of the hydrological behaviour of other parts of the Murray River system.

There may be more internal model uncertainty in assumptions about runoff generation that are implicit in the river modelling methodology. Uncertainty associated with further groundwater development and forestry are estimated to be negligible and the impact of farm dam increases is estimated at less than 1 percent of average annual flow (Chapter 4). These are therefore small compared to other uncertainties and climate in particular.

5.4.2 Model performance in explaining observations and comparison to water accounts

Overall model performance in reproducing annual and monthly flow patterns is good for most of the region. The models have difficulty reproducing flows between the offtake to the Edward-Wakool system down to the Murray River at Barmah, the Edward River at Stevens Weir and flows in the Great Darling Anabranch. This assessment largely confirms the results of prior model evaluation.

Model performance in reproducing high flows is poorer than overall model performance and shows similar relative differences between locations. River operations determine overall flow patterns in the Mitta-Mitta River and low flow patterns in the rest of the system. The average results of operations are generally well reproduced by the models but occasional departures occurred in the record and are not modelled. Although the calibrated climate range is short, it provides a good mix of wet and dry years that further increases confidence in the reliability of the models under climate change scenarios.

The overall water balances of the model and the accounts are similar. The accounts show higher inflows and outflows than the model due to a shorter reporting period for the accounts, in some cases.

5.4.3 Uncertainty assessment and implications for the use of results

Based on the model assessment it is concluded that:

- The models generally reproduce observed streamflow patterns very well.
- The models provide strong evidence of changes in flow pattern due to prior development of the regulated part of the system.
- The models provide strong evidence of a change in flows under Scenario Cmid and Cdry but the projected changes under Scenario Cwet are similar to river model uncertainty.
- Uncertainties associated with commercial forestry plantation, further groundwater extraction and farm dam development are all small compared to climate scenario uncertainty and internal model uncertainty.

The models are well suited for the purposes of this project. Caution is recommended when interpreting predictions of absolute as well as relative changes in flow patterns and average flows in the Murray between the offtakes of the Edward system and Barmah, the Edward-Wakool system itself and for the Great Darling Anabranch.

5.5 References

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6 Groundwater assessment

This chapter describes the groundwater assessment for the Murray region. It has nine sections:

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

6.1 Summary

6.1.1 Issues and observations

There are 16 groundwater management units (GMUs), two unincorporated areas and two other stock and domestic areas that cover the entire Murray region. The assessments for the Lower Murray Alluvium GMU (New South Wales) and the Katunga Water Supply Protection Area (WSPA) GMU (Victoria) are based on the Southern Riverine Plains groundwater model – a groundwater model that covers a much broader area across multiple regions which was developed specifically for this project. Assessments for the lower priority GMUs were based on simpler water balance analyses. Parts of several GMUs fall within the Murray region but are assessed in other region reports.

6.1.2 Key messages

- Total groundwater extraction in the Murray region for 2004/05 is estimated at 233 GL and represents 13.5 percent of groundwater use in the Murray-Darling Basin (MDB). This extraction volume represents 5 percent of total water use within the region and around 8 percent of total water use in years of lowest surface water diversion. The majority (83 percent) was from the Katunga WSPA, Lower Murray Alluvium, Upper Murray Alluvium and South Australia–Victoria Border Zone GMUs.

- The eventual total net streamflow loss to groundwater as a result of the current level of groundwater extraction is estimated to be 101 GL/year. This includes 73 GL/year of streamflow loss from rivers and drains across the modelled Southern Riverine Plains area and 28 GL/year of streamflow loss across non-modelled GMUs. The total eventual net streamflow loss to groundwater as a result of projected future (2030) groundwater extraction is estimated to be 123 GL/year. This includes 83 GL/year of streamflow loss from rivers and drains across the modelled Southern Riverine Plains area and 40 GL/year of streamflow loss across non-modelled GMUs.

- Groundwater modelling indicates that current groundwater extraction across the entire Murray region portion of the Southern Riverine Plains model area is 166 GL/year and represents 84 percent of total diffuse recharge or 45 percent of combined diffuse and river recharge. About one-quarter of the extraction in the modelled area within the region is outside the Lower Murray Alluvium and Katunga WSPA GMUs. Under a long-term continuation of the recent (1997 to 2006) climate there would be a 7 percent reduction in recharge and an 11 GL/year decrease in the net streamflow loss to groundwater. Under the best estimate 2030 climate, both recharge and net streamflow loss would fall slightly. Groundwater extraction across the entire modelled area in the region is projected to increase to 193 GL/year leading to minor changes in the overall water balance.

- For the Lower Murray Alluvium GMU (parts of which lie outside the Murray region), modelling indicates that current extraction – which is essentially equivalent to the long-term average extraction limit – represents

29 percent of total groundwater recharge. This is a low level of development which can be supported by the existing distribution of bores. Total recharge exceeds extraction in all years. Leakage from the more saline Shepparton Formation to deeper aquifers is 109 GL/year and is a large component of the water balance and thus represents a salinisation risk for the deeper aquifers. Under a long-term continuation of the recent (1997 to 2006) climate, total recharge would fall by 12 percent but would still exceed extraction. Under the best estimate 2030 climate the water balance would essentially remain unchanged.

- For the Katunga WSPA GMU which is entirely within the Murray region, modelling indicates that current extraction represents 42 percent of total groundwater recharge. This is a moderate level of development which can be supported by the existing distribution of bores. Total recharge exceeds extraction for 100 percent of the time. Under a long-term continuation of the recent climate there would be no change in recharge and under the best estimate (median) 2030 climate the water balance would essentially remain unchanged. The modelling indicates that although current extraction is less than half the long-term average extraction limit; this level of extraction essentially represents the maximum yield of the GMU under current extraction rules.
- Simple water balance analyses for the 20 lower priority GMUs indicate that total current extraction outside of the Southern Riverine Plains model area is 67 GL/year. Several GMUs in the Mallee region have either been recharged thousands of years ago or modern recharge is associated with high salinity. For the eight lower priority GMUs where rainfall recharge is significant, current extraction is less than one-fifth of recharge. For the Upper Murray Alluvium GMU extraction is nearly eight times the rainfall recharge. Under a long-term continuation of the recent climate there would generally be only minor changes to the ratios of extraction to recharge. The best estimate 2030 climate would have little effect on the ratios of extraction to recharge. Future (2030) groundwater extraction across the 20 lower priority GMUs is estimated to be 508 GL/year outside of the Southern Riverine Plains model area meaning total groundwater extraction in the region at 2030 would be 701 GL/year on average. This level of groundwater extraction would represent 15 percent of total future water use on average and 24 percent in years of lowest surface water use. At this future extraction level and under the best estimate 2030 climate extraction would be less than half of the rainfall recharge volume for all GMUs with significant recharge except the Upper Murray Alluvium GMU where extraction would be more than ten times the rainfall recharge under the best estimate climate. Neither the current nor the projected future level of extraction from the Upper Murray Alluvium GMU are likely to be sustainable.

6.1.3 Uncertainty

The priority of each GMU was ranked in the context of the overall project and the analysis method for the GMU. Ideally, the ranking of the GMU priority and the GMU analysis method match, so that GMUs likely to influence MDB-wide outcomes have reliable information on groundwater availability and the level of development. The ranking criteria for analysis methods are: minimal (hydrogeological description); simple (simple water balance); and medium to very thorough (numerical modelling). The ranking of numerical modelling is based on (i) the quality of monitoring data (length of period and spatial distribution); (ii) the quality of extraction data (metered versus estimated); (iii) complexity of process representation; (iv) availability of field data independent of calibration; (v) explicit representation of surface–groundwater connectivity; and (vi) level of independent peer review. Since at least three of these criteria are based on availability or quality of data, a good calibration fit in line with the best modelling guidelines may still not rank well. Also, the more mature a model, the more opportunities there are for obtaining a higher ranking because of data availability and peer review. A very thorough model should provide very good reliability in addressing issues of groundwater balance and hence extraction limits.

The modelling approach for the project uses a very long modelling time period (222 years) and any models that (i) have not previously been calibrated under steady state conditions or (ii) have small model extent, may not be fit for this purpose. If the first of these conditions is not met, the modelled watertable levels may show drifts that are more associated with the calibration process than hydrological processes. If the second condition is not met, the boundary conditions imposed on the model may overly affect the groundwater balance and lead to spurious results. The long modelling period is required to bring the groundwater system to a ‘dynamic equilibrium’ over the first 111 years and to run in sequence with surface water models to provide input to surface–groundwater interactions for the second 111 years. Dynamic equilibrium is not reached within 111 years in some cases. The most likely cause for this is that extraction exceeds recharge from all sources for some or all of the model area and the water tables gradually fall, indicating that the modelled spatial pattern of extraction is not sustainable. The modelling results in such cases will have implications beyond the project and in particular for the sustainable extraction limit. Thus, the ranking of the assessment methodology must describe the reliability of such information. A model for assessing water availability at the larger scale may be fit for the purpose for this project but less than adequate for addressing local management issues.

The analysis using the Southern Riverine Plains groundwater model developed for the project has been ranked as thorough in the Murray region and is consistent with the high and medium priority of the Lower Murray Alluvium and Katunga WSPA GMUs respectively. The simple water balance analyses used to assess the lower priority GMUs were consistent with their priority ranking, except for the Upper Murray Alluvium GMU where information used to determine the priority ranking originally available to the project changed during the course of the project. However, a previously developed Upper Murray groundwater model (Mampitya, 2006) was used as background for determining stream loss to groundwater in relevant lower priority areas including the Upper Murray Alluvium GMU.

While these assessments are appropriate given the constraints and terms of reference of this project, additional work is probably required for local management of groundwater resources.

The Southern Riverine Plain groundwater model was run in a without-development calibration. The model has been peer-reviewed but it has not received widespread scrutiny. Monitoring and extraction data is not as good as in some other MDB regions. Lateral flows from outside the model area are small. The model was assessed as thorough and hence is adequate for providing information on water availability in the context of this project, but is less reliable for local management requirements. The model reached a dynamic equilibrium under all scenarios. The level of reliability of predictions could be improved to very thorough by recognising the importance of the Lower Murray Alluvium and Katunga WSPA GMUs as groundwater resources and the requirement for a more robust water allocation model for future decisions.

The streamflow impact from groundwater extraction in the non-modelled areas is reliant on the value of the ‘connectivity factor’. For the fractured rock areas, a value of 30 percent has been used. For such steep terrain, this is considered low, but is consistent with that used for other regions representing a wider range of terrain. A value of 80 percent has been used for the alluvial fill, consistent with those inferred from modelling studies for similar hydrogeological units.

There is considerable uncertainty in the groundwater development projections in the lower priority GMUs but the estimates do show their importance. Low priority areas are categorised due to a generally low level of impact and/or limited information. The groundwater resources in these areas may be well developed but borehole, extraction and groundwater level data are variable in quality so aquifer parameters are usually only estimated. Extraction data are often estimated and there is generally no detailed assessment of groundwater flows, recharge or other water balance components. 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 in the region

6.2.1 Location

There are 16 GMUs, two unincorporated areas and two other stock and domestic areas covering the entire Murray region. The GMUs may be separated by unincorporated areas and are sited along the Murray River at various locations within New South Wales, Victoria and South Australia as shown in Figure 6-1. The Murray region also contains portions of a number of other GMUs (indicated on Figure 6-1) that are assessed in other region reports:

- the Lower Lachlan Alluvium GMU (N12), assessed as part of the Lachlan region (CSIRO, 2008d)
- the Lower Murrumbidgee Alluvium GMU (N02), assessed as part of the Murrumbidgee region (CSIRO, 2008a)
- the Barnawartha GMU (V36), assessed as part of the Ovens region (CSIRO, 2008c)
- the Kialla (V40) and Shepparton WSPA (V43) GMUs, assessed as part of the Goulburn-Broken region (CSIRO, 2008b)

- the Eastern Mount Lofty Ranges (S14) and Marne-Saunders (S23) GMUs, assessed as part of the Eastern Mount Lofty Ranges region (CSIRO, 2007).

The region can be subdivided into three areas: the Murray Uplands; the Riverine Plain; and the Mallee and Lower Lakes. The Murray Uplands includes the Lachlan Fold Belt GMU (N811) in New South Wales and an unincorporated area of limited highland aquifers in Victoria. It also includes the alluvial deposits along both sides of the Murray River from the Hume Dam in the east to Corowa in the west. This area is represented by the Upper Murray Alluvium GMU (N15) in New South Wales and Mullindolingong GMU (V35) in Victoria.

Downstream the region passes into the Riverine Plain, a broad area of alluvial plains between Corowa and Swan Hill. This area is represented by the Lower Murray Alluvium GMU (N16) in New South Wales that covers all groundwater resources deeper than 12 m below the surface and Katunga WSPA GMU (V39) in Victoria that covers groundwater contained in the Calivil Formation and Renmark Group. The Mallee and Lower Lakes area extends downstream of Swan Hill. GMUs cover all areas of New South Wales and in the Murray region these include the Lower Darling Alluvium (N45), the Western Murray Porous Rock (N612), Kanmantoo Fold Belt (N817) and the Adelaide Fold Belt (N818) GMUs.

In Victoria and South Australia several GMUs located near the border concentrate on the Murray Group Limestone and the availability of good quality groundwater. In Victoria these include the Murrayville WSPA (V49), Telopea Downs (V50, specific to the Murray Group Limestone), and Kaniva (V51, specific to the Renmark Group) GMUs. These GMUs are overlapped by the SA/Vic Border Zone (V63) – established under the Groundwater (Border Agreement) Act 1985 (South Australian Government, 1985) – designed to cooperatively manage related groundwater resources (BGARC, 2006). The South Australian portion of the Mallee is represented by the Mallee Prescribed Wells Area (PWA) (S20), Noora PWA (S50) and the Peake, Roby and Shelock PWA (S53) GMUs.

6.2.2 Ranking

Table 6-1 shows the GMU priority ranking and the assessment ranking for the project. The priority ranking helps focus efforts on those GMUs which 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 groundwater assessments vary for different GMUs to reflect the availability of data and analysis tools and the priority of the GMU. Assessments range from minimal to very thorough. A simple ranking for the GMUs in the Murray region denotes a simple water balance approach while thorough denotes a calibrated numerical groundwater model (for the purposes of this project). The analysis method is consistent with the priority ranking for all of the GMUs listed in Table 6-1, except for the Upper Murray Alluvium GMU where information used to determine the priority ranking originally available to the project changed during the course of the project.

The main groundwater indicator used is the E/R ratio. This is used to indicate the level of groundwater development under the classifications: low (0.0–0.3), medium (0.3–0.7), high (0.7–1.0) and very high (>1.0). Streams can contribute to recharge in alluvial GMUs and groundwater extraction can induce further recharge. The impact of groundwater extraction on streamflow is also assessed.

While these assessments are appropriate given the constraints and terms of reference of this project, additional work is probably required for local management of groundwater resources.

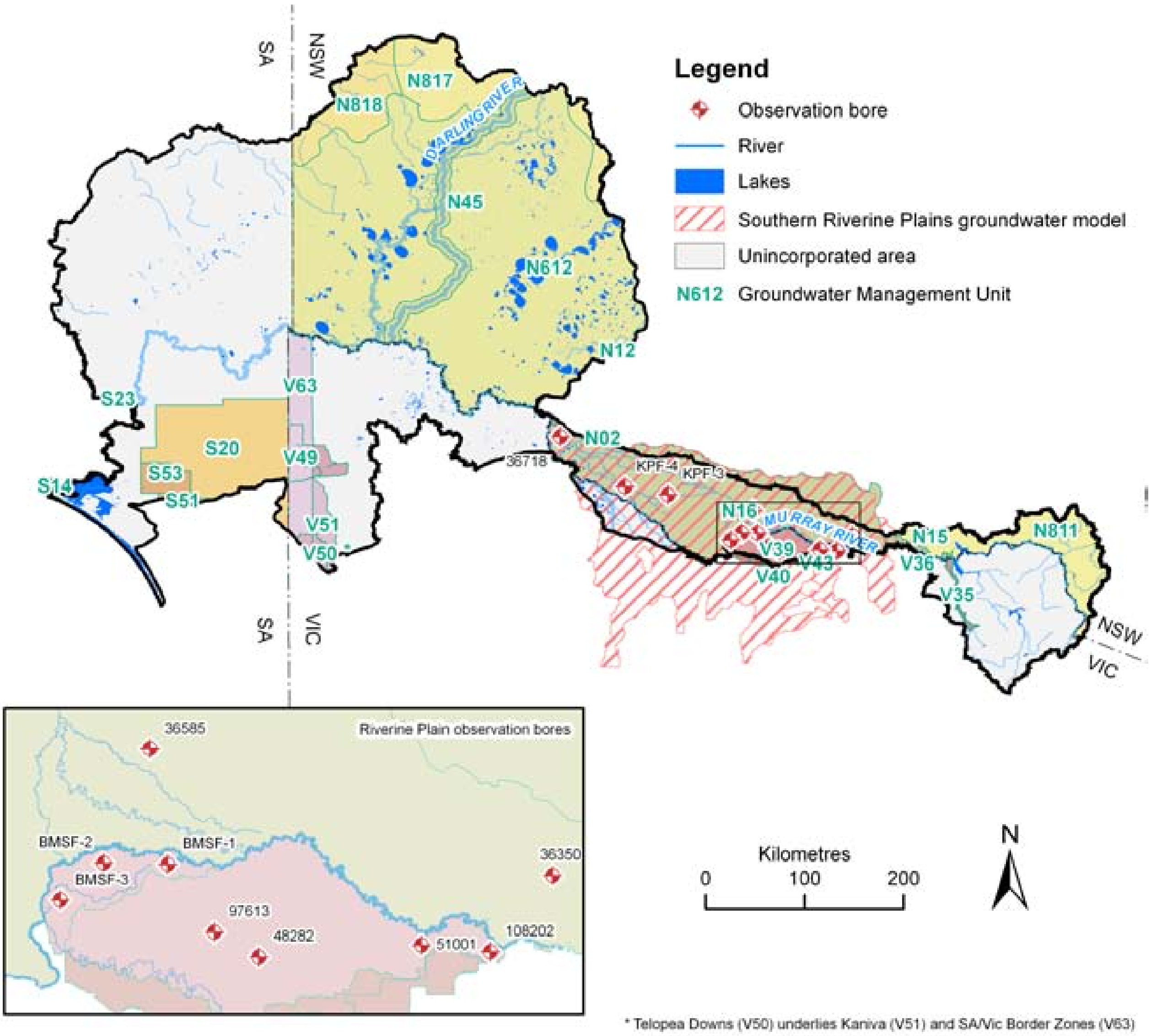

Figure 6-1. Map of groundwater management units in the Murray region showing the extent of the Southern Riverine Plains groundwater model and locations of key indicator bores, with inset showing locations of key indicator bores on the Riverine Plain

Table 6-1. Priority and assessment rankings of groundwater management units in the Murray region

Code	Name	Priority	Assessment	Current extraction	Current entitlements	Extraction limit [1]	Maximum likely extraction without plan revision
				GL/y			
N15	Upper Murray Alluvium	very high	simple	[2]30.5	[2]40.5	[2]38.6	[2]40.5
N16	Lower Murray Alluvium (Calivil/Renmark)	high	thorough	[2]73.9	[3]85.2	[3]83.7	[2]83.7
na	Lower Murray Alluvium (Shepparton)	na	na	18.0	na	59.9	59.9
N45	Lower Darling Alluvium	low	simple	[2]2.0	[2]3.7	[2]9.3	[2]4.7
N612	Western Murray Porous Rock	low	simple	[2]4.5	[2]7.6	[2]663.8	[2]331.9
N811	Lachlan Fold Belt	low	simple	[2]5.2	[2]8.6	[2]69.4	[2]17.4
N817	Kanmantoo Fold Belt	very low	simple	[2]0.3	[2]0.3	[2]36.0	[2]18.0
N818	Adelaide Fold Belt	very low	simple	[2]0.9	[2]1.7	[2]30.4	[2]18.3
V35	Mullindolingong GMA	very low	simple	[4]1.2	1.3	7.0	1.8
V39	Katunga WSPA	medium	thorough	[4]27.4	59.8	46.5	40.5
V49	Murrayville WSPA	very low	simple	[4]0.6	1.8	10.9	1.0
V50	Telopea Downs	na	simple	[4]0.7	1.5	7.5	1.5
V51	Kaniva	very low	simple	[4]0.0	0.0	3.7	0.0
S20	Mallee PWA	low	simple	14.9	32.2	[5]52.8	32.2
S50	Noora PWA	very low	simple	NA	0.0	[6]5.1	0.0
S53	Peake, Roby & Sherlock PWA	na	simple	1.1	2.4	na	2.0
V63	South Australia–Victoria Border Zone PWA	na	simple	24.8	38.2	[7]55.0	31.1
na	Upper Murray unincorporated areas	na	simple	2.3	4.1	None set	4.5
na	Kiewa unincorporated areas	na	simple	0.9	0.8	None set	1.7
na	Salt interception schemes	na	na	23.3	na	na	35.8
na	Vic stock and domestic	na	na	0.2	na	na	0.2
na	Stock and domestic (Mallee, Noora, Peake-Roby-Sherlock)	na	na	0.7	na	na	0.7

[1]Extraction limit refers to:
- long term average extraction limit for NSW GMUs
- licensed entitlement for Victorian GMUs
- allocation for South Australian GMUs

[2]Sourced from data supplied by NSW DWE
[3]Source: DIPNR, 2006
[4]Source: DSE, 2006
[5]Source: MWRPC, 2000
[6]Source: RMCWMB, 2001
[7]Source: BGARC, 2006
NA – not available

6.2.3 Hydrogeological context

A summary of the hydrogeological context detailed in Chapter 2 is provided here. Groundwater occurs in fractured rock landscapes of the highland regions in a range of different geologies with local and intermediate groundwater flow systems. These aquifers form important water sources in the eastern portion of the Murray Valley. Groundwater quality is generally very good, however, these consolidated sediments have low permeability and groundwater is typically restricted to stock and domestic purposes. A series of valleys formed by palaeochannels eroded into the fractured rock basement contain significant alluvial deposits referred to as the Lachlan and Cowra formations. The Cowra Formation overlies the entire extent of the Lachlan Formation. The Cowra Formation receives a large amount of recharge from stream leakage and flood induced recharge but is largely utilised for stock and domestic purposes. The Lachlan Formation occurs in the base of valleys of the upper Murray River and Billabong Creek where it supplies groundwater for irrigation and town water. Increased extraction from the Lachlan Formation will induce recharge from the overlying sediments and stream leakage.

The Renmark Group is the basal aquifer within the Riverine Plains. It is composed of alluvial sands and gravels with inter-bedded carbonaceous clay-rich units, hydraulically connected with the overlying Calivil Formation and used for irrigation across the eastern portion of the Riverine Plains. The Calivil Formation is up to 80 m thick and consists of quartz sand and gravel – often yielding large volumes of high quality groundwater. The Calivil Formation is the primary aquifer used to provide irrigation water supply in some areas.

The Shepparton Formation overlies the Calivil Formation and usually forms the watertable aquifer in the Riverine Plains. It is composed of river and lake deposited sediments. The Shepparton and Calivil Formations on the Riverine Plain are loosely correlated with the Cowra and Lachlan formations respectively and are contiguous at the boundary between the Murray Uplands and the Riverine Plains. Groundwater in the Shepparton Formation is generally saline and there is a threat from shallow saline watertables. Within Victoria the Shepparton Irrigation Region Catchment Strategy (GBCMA, 2007) controls the groundwater contained within the Shepparton Formation. The strategy is designed to protect the region's agricultural and natural resources from salinity by regular pumping of groundwater to provide salinity control.

A range of geologies, including metamorphic and consolidated sediments that form fractured rock aquifers, extend around and beneath the margins of the Mallee and Lower Lakes area. They include the Barrie, Olary and northern Mount Lofty Ranges. The Renmark Group is the basal aquifer within the sedimentary Murray Geological Basin of the Mallee and Lower Lakes but is not generally used due to availability of better quality groundwater in the overlying Murray Group Limestone. The Murray Group Limestone overlies the Renmark Group and is the primary aquifer in the western part of the region supporting town water supplies and potato, olive and pistachio crops but becomes too saline for use in regions closer to the Murray River. The Loxton-Parilla Sands overlie the Murray Group Limestone, consist of fine to coarse sand and form the watertable aquifer in the central part of the Mallee region.

The Murray Trench is a geomorphic feature that commences near Swan Hill and represents the course taken by successive Murray River systems across the Mallee region to the coast in South Australia. The basal coarser material is referred to as the Channel Sands. These are intermittently hydraulically connected to the underlying and adjacent saline aquifers and groundwater mounds can develop in these sediments beneath or adjacent to irrigated areas. Saline inflows to the river are intercepted by salt interception schemes such as the Waikerie, Woolpunda and Mildura-Merbein interception schemes.

6.2.4 The 'Achieving Sustainable Groundwater Entitlements' structural adjustment program

The 'Achieving Sustainable Groundwater Entitlements' structural adjustment program announced in June 2005 (DNR, 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 in the groundwater systems of these areas was reduced to equal the long-term average extraction limit (LTAEL) within the water sharing plans. The level of entitlements to each source will be gradually reduced from the current levels of the LTAEL over the ten years of each water sharing plan. The LTAEL forms the assumed levels of extraction under scenarios A and D for the Lower Murray Alluvium GMU.

6.2.5 Salt interception schemes

Salt interception schemes exist or are being built within the southern parts of the MDB to intercept saline groundwater that would otherwise discharge to the Murray River. The majority of schemes are in the Sunraysia region of New South Wales and Victoria near Mildura, or between Waikerie and Renmark in the South Australian Riverland. These schemes are particularly important in South Australia where there is a heavy reliance on river water to supplement supplies. The schemes generally involve bores constructed in or adjacent to the floodplain alongside the river and they intercept saline groundwater entering the river and pump this to specified disposal basins.

Groundwater extraction from all interception schemes along the Murray River upstream from Morgan in South Australia are summarised in Table 6-2. Groundwater extraction to control the quality of the Murray River in 2004/05 is estimated to be 23 GL. Saline groundwater extraction projected to 2030 is estimated to be 32 GL based on continued operation of the current schemes and the addition of various schemes currently under construction. The construction of additional planned schemes would increase this extraction.

Table 6-2. Summary salt interception scheme, current and future groundwater extraction volumes for the Murray River upstream of Morgan.

Scheme Ref Number[1]	Groundwater Interception Scheme	Current extraction (2004/05)	Estimated future extraction (2030)	Status
		GL/y		
1	Waikerie	4.34	3.30	existing scheme
2	Woolpunda	5.25	4.80	existing scheme
4	Bookpurnong	NA – commissioned 2006	1.70	existing scheme
5	Rufus River	0.83	1.10	existing scheme
8	Buronga	1.55	3.00	existing scheme
10	Mildura-Merbein	1.88	3.00	existing scheme
11	Mallee Cliffs	2.67	3.00	existing scheme
12	Barr Creek Drainage Diversion Scheme	6.81	6.00	existing scheme
13	Pyramid Creek	NA – commissioned 2006	1.90	existing scheme
NA	Murtho	0	1.90	scheme under construction – SA
NA	Loxton	0	1.80	scheme under construction – SA
NA	Waikerie 2L	0	0.70	scheme under construction – SA
NA	Dareton	0	1.50	possible new scheme – NSW
NA	Redcliffs	0	5.00	possible new scheme – Vic
NA	Pike River	0	2.00	possible new scheme – SA
	TOTAL	**23.33**	**40.70**	

(1) Salt interception schemes; 3 (Noora Disposal Scheme), 7 (Lake Hawthorn Drainage Diversion Scheme) and 9 (Psyche Bend Drainage Diversion Scheme) do not pump groundwater. Generally these schemes intercept irrigation drainage and storm water runoff (pers comm. Phil Pfeiffer MDBC). The Curlwaa scheme (6), a state scheme, is a tubewell system that was installed to provide both agricultural drainage and reduction of salt accessions to the River Murray from the irrigation induced groundwater mound under the Curlwaa irrigation development. Extraction from Curlwaa is estimated at 0.35 GL/year.

The process of intercepting salt via pumping involves creating a cone of depression alongside the river that alters the natural flow of saline water to the river. Sufficient water must be pumped to create the cone of depression and then maintain it. The volume of water that would have contributed to saline groundwater inflows in the river represents only a portion of the total volume of water pumped by the schemes. The ratio of saline groundwater intercepted compared to total volume pumped varies from scheme to scheme and depends on local conditions and scheme design and construction. For example the first Buronga scheme had a ratio of approximately 60 tonnes of salt pumped to prevent 1 tonne of salt entering the river (Murray-Darling Basin Commission, pers. comm.).

The volume of groundwater extracted by the schemes has not been factored into the total water balance for the region which is consistent with not including irrigation recharge in the water balances associated with the low priority regions along the Murray River.

6.3 Surface–groundwater connectivity

The connectivity mapping aims to provide a catchment context for surface–groundwater interaction, constrain the surface water balance and constrain groundwater balances. The main output is a map of the magnitude and direction of groundwater fluxes adjacent to main streams. The approach uses Darcy's Law and hence estimates the hydraulic conductivity and groundwater gradients surrounding the streams. The method is dependent on the availability of appropriate groundwater data and on reported estimates of hydraulic conductivity.

The area of interest was limited to the mid-Murray River from Albury to Wakool Junction where the Murrumbidgee River joins the Murray. This represents the length of the river that passes through the Riverine Plain portion of the region. 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 March 2005, as this was the most recent date with both a large quantity of available bore and river elevation data.

The aquifer thickness is considered to equate to the depth of the Upper Shepparton Formation due to its heterogeneous nature. The saturated thickness of the shallow alluvial aquifer was estimated at 15 m for the river reaches between Wakool Junction and Swan Hill. The saturated thickness of the alluvial aquifer progressively increases from 30 m between Swan Hill and Torrumbarry to around 40 m from here to the end of the Riverine Plains.

The Murray River intersects the Shepparton Formation in most reaches of the Riverine Plains and comprises mainly silty clay with hydraulically interconnected sand beds along the Murray River. The horizontal hydraulic conductivity of the Upper Shepparton Formation is approximately 5 m/day between Wakool Junction and Swan Hill, 10 m/day between Swan Hill and upstream of Torrumbarry and 5 m/day from Torrumbarry to Howlong.

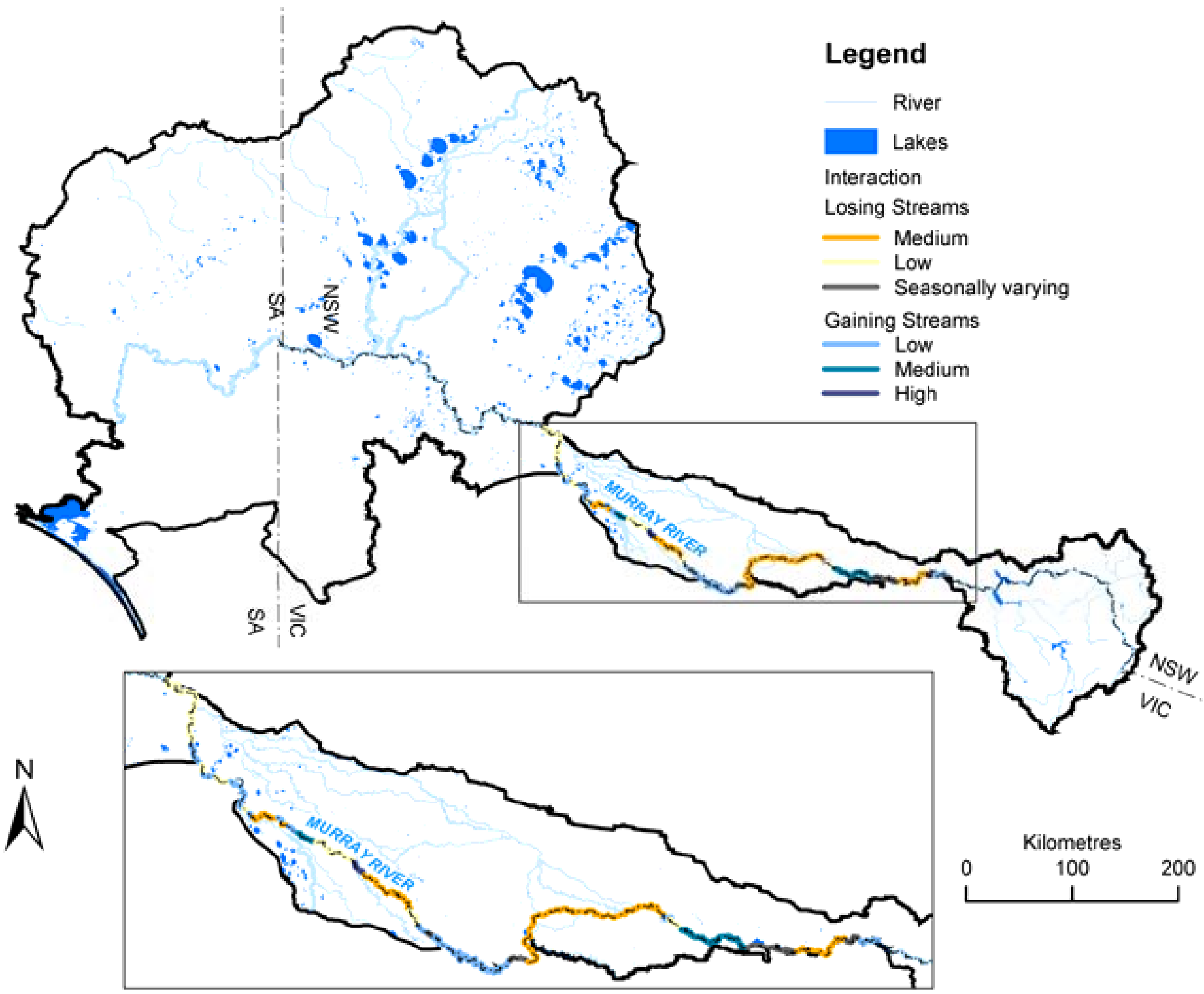

Figure 6-2. Map of surface–groundwater connectivity in the Murray region

Figure 6-2 shows the surface–groundwater connectivity of the Murray region. The Murray River alternates between high flows and low flows but different reaches vary between losing and gaining conditions. Variation from reach to reach is due to a combination of regulated flow conditions and a high degree of irrigation groundwater mound development, particularly downstream of Echuca. The assessment found that the river is:

- typically gaining at low rates as groundwater moves down gradient from bedrock highlands into upper Murray tributaries
- losing on the alluvial plain leading to Lake Mulwala
- approximately hydraulically neutral around the Murray and Ovens river confluence

- under gaining conditions for a significant stretch downstream of Lake Mulwala
- ‘medium losing’ between Tocumwal and upstream of the Goulburn River Junction
- ‘low gaining’ around where the Goulburn and Campaspe rivers meet the Murray River near Echuca
- ‘medium losing’ downstream of Torrumbarry Weir
- highly variable in the section between Barham and Swan Hill reflecting groundwater highs and lows related to irrigation development and river regulation
- between ‘low gaining’ and ‘low losing’ from Swan Hill to Wakool Junction
- hydraulically neutral downstream of Wakool Junction
- likely to be gaining downstream of the analysed area, in the lower Murray River.

Figure 6-3 and Figure 6-4 show the effects of irrigation practices on the relationship between the groundwater and river. There is a large difference between the magnitude and direction of fluxes to and from the river although there is only 4 km between each location. Figure 6-3 shows high gaining conditions near a groundwater mound and Figure 6-4 shows low losing conditions downstream of Bore 501139 as it is located within a groundwater mound caused by surface water irrigation.

Catchment-wide groundwater level falls of 2 to 3 m since the mid-1990s have changed the relationship between groundwater and the Murray River. Figure 6-5 shows approximately hydraulically neutral conditions in the mid 1990s subsequently changing to losing conditions; it indicates substantial falls in groundwater levels since 1997 and implies a reduction in groundwater gains to the river over the same period.

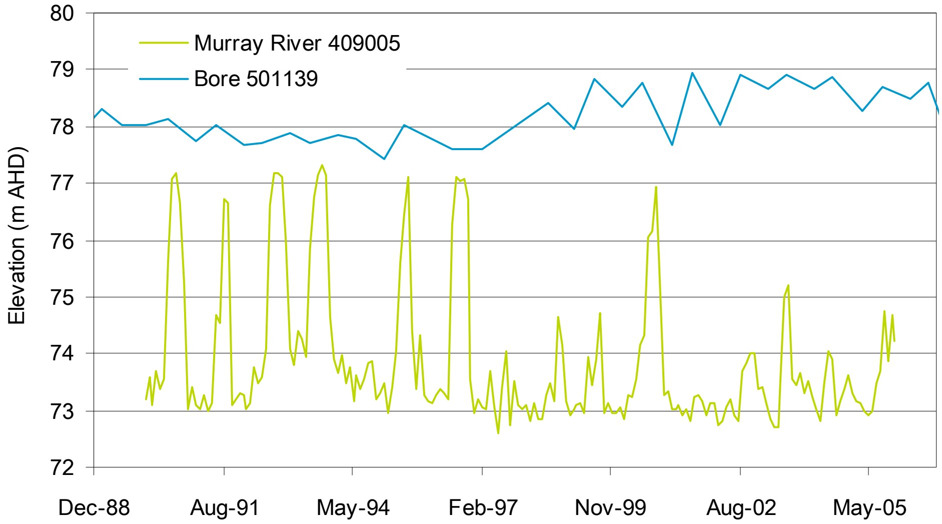

Figure 6-3. Comparison of groundwater and surface water levels at Barham showing raised groundwater levels in the vicinity of a groundwater mound

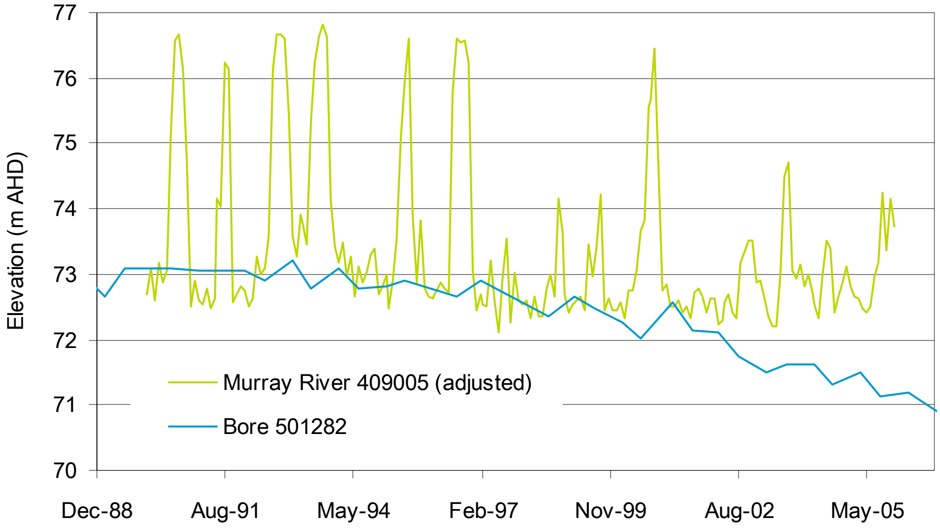

Figure 6-4. Comparison of groundwater and surface water levels downstream of Barham showing decreased groundwater levels away from the groundwater mound

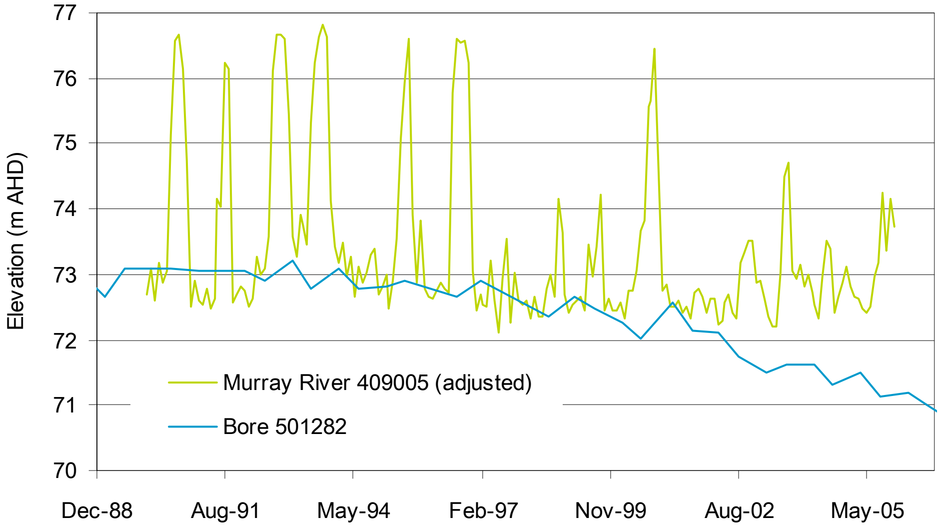

Figure 6-5. Comparison of groundwater and surface water levels at Yarrawonga showing a fall in groundwater levels since 1997 with a probable associated decrease in the volume of groundwater flowing to the river

6.4 Recharge modelling

Rainfall recharge scaling factors (RSFs) are applied in the groundwater modelling and in the simple water balance analyses. Values of diffuse dryland recharge are used to calibrate the groundwater model and to analyse other GMUs within the Murray region. The RSFs are used to multiply the recharge values to provide estimates of dryland rainfall recharge under different climate scenarios. The RSF for Scenario A is 1.0 by definition and close to 1.0 for other scenarios. The impacts of climate change on recharge are reported as percentage changes from Scenario A in Table 6-3. The RSFs are obtained by dividing the percentage change by 100 and adding to 1.0.

The three variants of Scenario C (Cdry, Cmid and Cwet) represent a combination of global climate model (GCM) output and rank mean annual runoff in order to reflect the range of predictions (Chapter 3). Groundwater recharge is not perfectly correlated with mean annual rainfall or runoff and antecedent conditions exert a strong influence. Apart from mean rainfall, diffuse dryland recharge is sensitive to seasonal rainfall, potential evaporation and 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 scenarios reflect mean annual runoff that is more dependent on average and seasonal rainfall.

Recharge also depends on the land use and soils. These can be locally variable and reflect local spatial variation in RSFs. An estimate for a small GMU will be sensitive to these local variations, while in larger areas with a broader range of soils and land uses the estimates will be more robust. RSFs were estimated for all 15 GCMs under Scenario C. In all cases, a one dimensional soil-vegetation-atmosphere water transfer model (WAVES; Zhang and Dawes, 1998) was used for selected points around the MDB for combinations of soils and vegetation. Spatial data on climate, vegetation and soils were then used to interpolate values to regions.

Figure 6-6 shows the percentage change in the modelled mean annual recharge averaged over the Murray 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 percentage change in the mean annual recharge and the percentage change in mean annual rainfall from the corresponding GCMs are tabulated in Table 6-3. The plots show that there is a wide range in results across GCMs and scenarios for the Murray region with just over half the scenarios predicting less recharge and the remainder predicting more recharge. The high global warming scenario predicts both the highest and lowest change in recharge for the Murray.

Only scenarios Cdry, Cmid and Cwet are shown in subsequent reporting. These scenarios are based on the runoff modelling and are indicated in Table 6-3 in bold type. 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 run-off being respectively the second highest, second lowest and the 60th percentile for RSF. The large variability in RSFs is related to the large variability in rainfall produced by the various GCMs. Rainfall and RSFs are correlated, but not perfectly. Some GCMs that indicate reductions in rainfall lead to RSFs greater than 1.0. This is due to the more extreme events being more frequent, in spite of a reduction in mean rainfall.

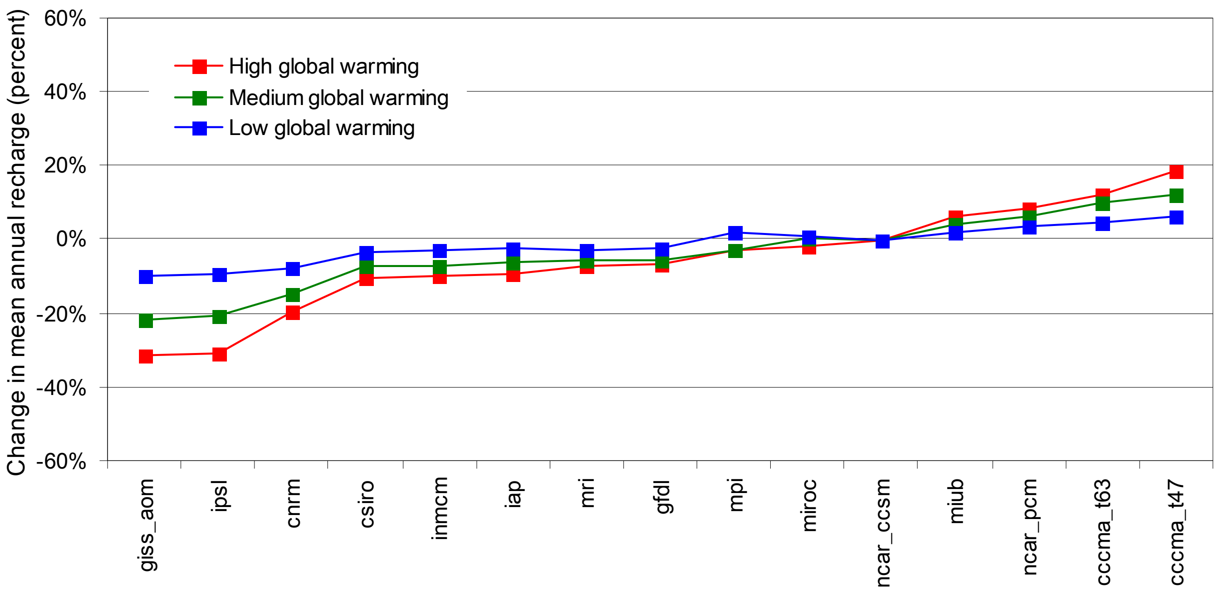

Figure 6-6. Percentage change in mean annual recharge from the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A recharge

Table 6-3. Summary results from the 45 Scenario C simulations. Numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A. Those in bold type have been selected for further modelling.

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Recharge	GCM	Rainfall	Recharge	GCM	Rainfall	Recharge
giss_aom	-21%	-31%	giss_aom	-13%	-22%	giss_aom	-6%	-10%
ipsl	**-19%**	**-31%**	ipsl	-13%	-21%	ipsl	-5%	-9%
cnrm	-13%	-20%	cnrm	-8%	-15%	cnrm	-4%	-8%
csiro	-8%	-10%	csiro	-5%	-7%	csiro	-2%	-3%
inmcm	-6%	-10%	inmcm	-4%	-7%	inmcm	-2%	-3%
iap	-5%	-9%	iap	-3%	-6%	iap	-1%	-2%
mri	-7%	-7%	mri	-4%	-5%	mri	-2%	-3%
gfdl	-12%	-7%	gfdl	-8%	-6%	gfdl	-3%	-2%
mpi	-5%	-3%	mpi	-3%	-3%	mpi	-1%	2%
miroc	6%	-2%	miroc	4%	0%	miroc	2%	1%
ncar_ccsm	2%	0%	**ncar_ccsm**	**1%**	**0%**	ncar_ccsm	1%	0%
miub	4%	6%	miub	3%	4%	miub	1%	2%
ncar_pcm	8%	8%	ncar_pcm	5%	6%	ncar_pcm	2%	4%
cccma_t63	**6%**	**12%**	cccma_t63	4%	10%	cccma_t63	2%	4%
cccma_t47	3%	19%	cccma_t47	2%	12%	cccma_t47	1%	6%

NB: The rainfall for some GCM simulations in Table 6-3 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.

6.5 Groundwater modelling approach

Groundwater extraction in Katunga WSPA GMU and Lower Murray Alluvium GMU was analysed using the Southern Riverine Plains groundwater model that was developed specifically for the project and covers a 292 x 250 km area spanning each side of the Murray River between Yarrawonga and Swan Hill. The model covers major parts of the Loddon River, Campaspe River, Goulburn River, Broken River, Wakool River, Edward River and Billabong Creek catchments.

6.5.1 Model description

The groundwater model covers an area of 34,285 km^2 and utilises a 1 km^2 grid cell resolution. Outcropping bedrock forms the boundary of the active model domain in the south and the northern boundary is defined by Billabong Creek. The groundwater model is divided into five layers based on the hydrogeology of the area: Upper Shepparton Formation, Lower Shepparton Formation, Calivil Formation, Renmark Group and Bedrock (inactivated).

The model combines the existing Lower Murray, Katunga and Campaspe groundwater models to break down the controlling influence of model boundary conditions and provide an enhanced representation of intermediate and regional scale interference patterns.

Only the main stems of major rivers are included in the model. A number of drainage areas are included in the model to help account for tributaries and drainage channels that cannot be explicitly modelled. Drainage cells have only been placed in areas that are prone to shallow water tables and are designed to mimic natural or manmade drainage features that would act to intercept rising watertables. These are particularly common in the irrigated areas of New South Wales.

Dryland rainfall recharge and irrigation recharge are both incorporated into the model. River recharge can also occur where river levels are higher than adjacent groundwater levels. The MODFLOW groundwater evapotranspiration package is used to simulate evapotranspiration from shallow water tables. Groundwater pumping from a total of 2400 extraction bores is simulated. The model was calibrated from the period January 1990 to December 2005.

6.5.2 Scenario implementation

The objective of the numerical modelling was to assess groundwater and surface water impacts under a range of scenarios of groundwater extraction from the Murray region GMUs. The groundwater impacts are characterised by resource condition indicators and the surface water impacts are characterised by river losses to groundwater. Under Scenario A, groundwater extraction was 166 GL/year for the portion of the model contained within the Murray region and 245 GL/year across the entire Southern Riverine Plains groundwater model area. Climate can change dryland recharge, the area of irrigation or river flows. The impact of climate on diffuse dryland recharge was assessed through the application of constant recharge scaling factors (Section 6-4) for each scenario.

Table 6-4 shows the percentage changes in recharge rate for scenarios B and C. Scenario B represents a continuation of the recent climate and Scenario C (scenarios Cdry, Cmid and Cwet) represents the climate predicted for 2030 by the GCMs. Scenario D has the same climate as Scenario C but models changes in groundwater use, commercial plantation forestry and farm dams. River stage (calculated from outputs of the river model) may vary from Scenario C because of water management changes. Under Scenario D, groundwater pumping was increased to a total of 196 GL/year in the Murray section of the model and 300 GL/year across the whole of the model domain. This level of pumping is consistent with the likely future maximum pumping as defined by New South Wales and Victorian governments in the various groundwater plans.

Table 6-4. Change in recharge applied to the model under scenarios B and C

B	Cdry	Cmid	Cwet
-25%	-34%	-3%	+14%

The river and groundwater models are run in a sequence to simulate the effect of climate on surface–groundwater exchange fluxes and both groundwater and surface water balances (Chapter 1). The river model (IQQM) implicitly includes surface–groundwater exchanges within the unattributed gains and losses. The calibration periods for the groundwater and surface water models broadly coincide so changes in the MODFLOW outputs from the calibration period are similar to the changes in groundwater gains and losses included in the river modelled unattributed gains and losses. Extraction rates were assumed to be constant in all cases. Model results include groundwater levels, groundwater balance changes and a number of groundwater indicators (Table 6-5). The environmental groundwater indicator may include: diffuse rainfall and irrigation recharge, river leakage, leakage from overlying aquifers and lateral flow from outside GMU boundaries.

Table 6-5. Definition of groundwater indicators

Groundwater Indicators	
Groundwater security	Percentage of years in which extraction is less than the average recharge over the previous ten-year period. Values less than 100 indicate increasing risk of sustained long-term groundwater depletion and thus a lower security of the groundwater resource.
Environmental groundwater indicator	Ratio of average annual extraction to average annual recharge. 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 percent of the total water use in the region. This indicates the relative importance of groundwater compared with surface water for the region.

6.6 Modelling results

6.6.1 The Southern Riverine Plains groundwater model area

The groundwater balance for the section of the Murray region covered by the Southern Riverine Plains groundwater model is presented in Table 6-6, Figure 6-7 and Figure 6-8. Comparing Scenario A with without-development conditions (Table 6-7) shows that 44 percent of extraction is from surface water sources, 30 percent is derived from reduced groundwater evapotranspiration and 26 percent is due to changes in lateral groundwater flux. The changes in lateral groundwater flux occur across the northern (with the Murrumbidgee region) and southern boundaries. This volume of lateral flow highlights the significant potential for double accounting of water resources.

Table 6-6. Groundwater balance for the modelled part of the Murray region

Groundwater balance	Without-development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	197.8	197.8	171.1	161.5	194.6	212.8	161.5	194.6	212.8
Head dependent boundary	44.6	46.0	48.1	48.9	46.6	45.7	49.0	46.7	45.7
River recharge	145.0	170.5	156.7	151.0	163.7	169.3	151.3	164.4	170.1
Lateral flow	156.1	149.2	146.6	145.6	149.1	151	151.8	154.4	155.8
Total	**543.5**	**563.5**	**522.5**	**507.0**	**554.0**	**578.8**	**513.6**	**560.1**	**584.4**
Outflows									
Groundwater pumping	0.0	166.2	166.1	165.5	166.2	167.1	188.0	192.9	196.1
Head dependent boundaries	119.7	116.1	113.5	112.5	115.3	116.7	112.4	115.2	116.6
Lateral flow	124.8	79.6	72.8	69.8	78.0	81.5	67.7	75.6	79.2
Evapotranspiration	206.9	157.5	137.6	129.9	152.7	163.8	125.5	147.5	157.9
To drains	72.7	32.7	23.9	20.8	31.4	37.2	11.0	18.0	22.3
To rivers	17.8	10.4	7.6	7.7	9.3	11.2	7.7	9.2	11.1
Total	**541.9**	**562.5**	**521.5**	**506.2**	**552.9**	**577.5**	**512.3**	**558.4**	**583.2**
Net river losses to groundwater	127.2	160.1	149.1	143.3	154.4	158.1	143.6	155.2	159
Net losses from surface water	54.5	127.4	125.2	122.5	123.4	120.9	132.6	137.2	136.7

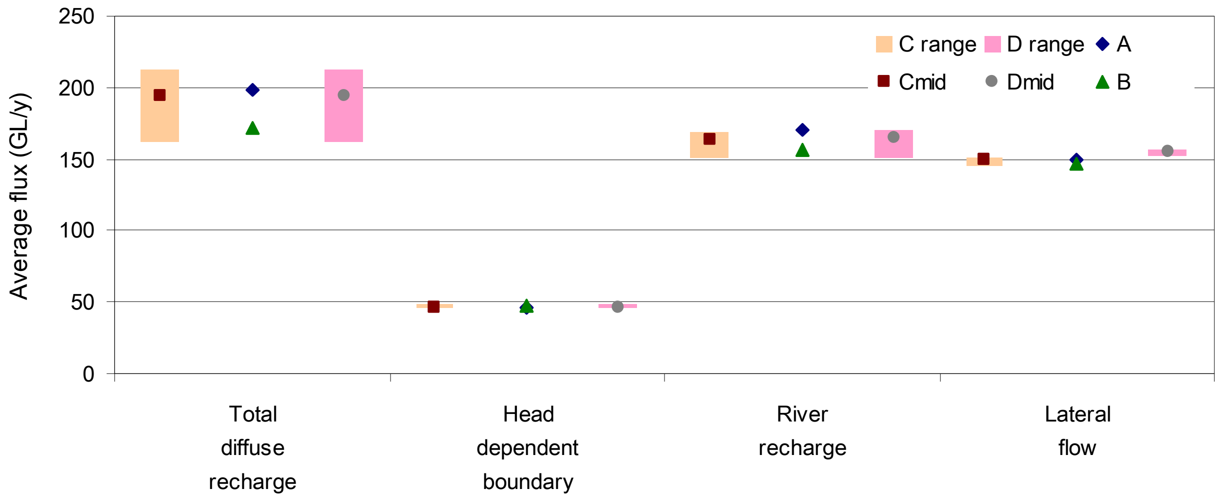

Figure 6-7. Groundwater inflows into the Murray region under scenarios A, B, C and D

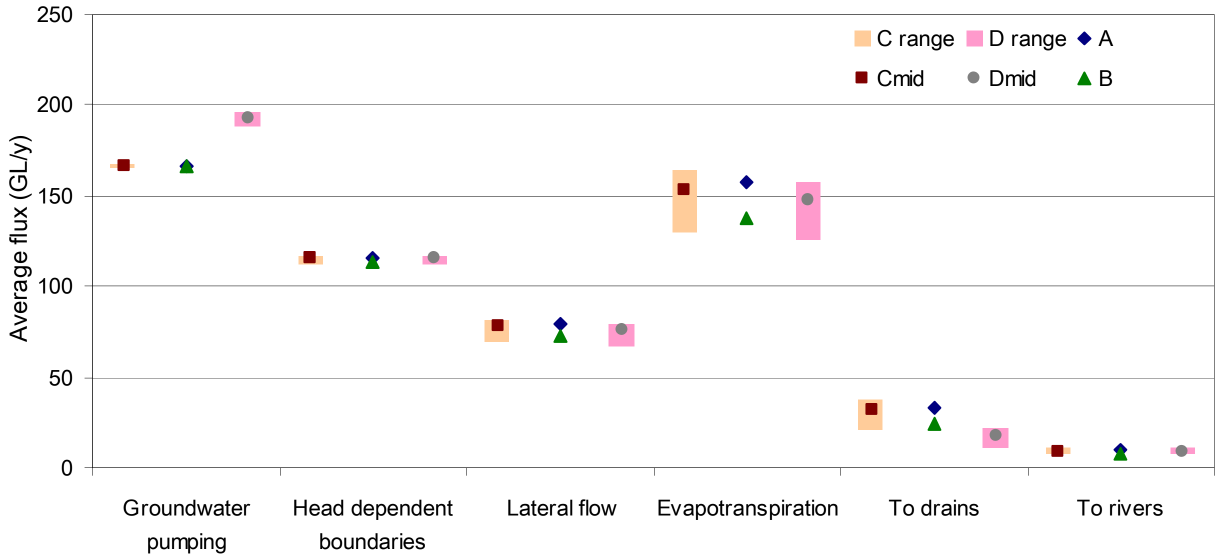

Figure 6-8. Groundwater outflows from the Murray region under scenarios A, B, C and D

Table 6-7. Comparison of the groundwater balance in the Murray region under the pre-development scenario and Scenario A

Groundwater balance	Without-development	A	Difference	Percent of pumping
	GL/y			percent
Inflows				
Groundwater pumping	0.0	166.2	166.2	na
Total diffuse recharge	197.8	197.8	0.0	0%
Net flow in from head dependent boundaries	-75.1	-70.1	5.0	3%
Net flow in from adjacent zone	31.3	69.6	38.3	23%
Outflows				
Groundwater evapotranspiration (negative)	-206.9	-157.5	49.4	30%
Net river loss to groundwater	127.2	160.1	32.9	20%
Discharge from drains	-72.7	-32.7	40.0	24%
Net surface water losses*	**54.5**	**127.4**	**72.9**	**44%**

* Net surface water losses includes both rivers and drains in the model
na – not applicable

6.6.2 Katunga WSPA GMU

The Katunga WSPA GMU lies within the centre of the Southern Riverine Plains groundwater model area and refers solely to the Deep Lead aquifers (a term used in Victoria to describe a combination of the Calivil Formation and Renmark Group aquifers). Three observation bores were selected to indicate the water level changes under the scenarios in both the Calivil Formation and Renmark Group aquifers. Water levels have also been reported for three sites in the Barmah State Forest. Table 6-8 shows the effect of the climate and development scenarios on the mean groundwater levels. Groundwater levels under these scenarios vary from 0.30 m higher to 1.76 m lower than under Scenario A.

Table 6-9 shows the water level for the individual bores and the Barmah State Forest sites. Drawdowns of up to 2 m in the Calivil and Renmark aquifers occur beneath Barmah State Forest and this induces similar drawdowns in the unconfined Upper Shepparton Formation aquifer which may have environmental consequences (Chapter 7).

Table 6-8. Median groundwater levels in the Katunga WSPA GMU under Scenario A and changes from this level under scenarios B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	change from Scenario A (m)						
Layer 3	85.1	-1.0	-1.4	-0.2	0.3	-1.8	-0.5	0.1
Layer 4	84.8	-1.0	-1.4	-0.2	0.3	-1.7	-0.5	0.1
Average	**85.0**	**-1.0**	**-1.4**	**-0.2**	**0.3**	**-1.8**	**-0.5**	**0.1**

Table 6-9. Individual bore groundwater levels in the Katunga WSPA GMU under Scenario A and changes from this level under scenarios B, C and D

Observation bores	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	change from Scenario A (m)						
48282_3	86.7	-1.1	-1.5	-0.2	0.3	-2.0	-0.7	-0.1
51001_3	100.1	-0.9	-1.2	-0.2	0.3	-0.9	-0.0	0.5
97613_3	84.6	-1.1	-1.5	-0.2	0.3	-2.0	-0.6	-0.0
BMSF-1_3	80.7	-1.1	-1.5	-0.2	0.3	-2.0	-0.6	-0.0
BMSF-2_3	79.1	-1.0	-1.4	-0.2	0.3	-1.9	-0.5	0.0
BMSF-3_3	79.6	-1.0	-1.4	-0.2	0.3	-1.9	-0.6	-0.0
51001_4	100.1	-1.0	-1.3	-0.2	0.3	-0.9	-0.1	0.4
97613_4	84.6	-1.1	-1.5	-0.2	0.3	-2.0	-0.6	-0.0
BMSF-1_4	80.7	-1.1	-1.5	-0.2	0.3	-2.0	-0.6	-0.0
BMSF-2_4	79.1	-1.0	-1.4	-0.2	0.3	-1.9	-0.5	0.0
BMSF-3_4	79.6	-1.0	-1.4	-0.2	0.3	-1.9	-0.6	-0.0

Note: BMSF-1, BMSF-2 and BMSF-3 are three sites within Barmah State Forest.

The only recharge mechanism in the modelled Katunga WSPA GMU mass balance is inflow from surrounding aquifers (including the overlying Shepparton WSPA). The only discharge mechanisms are groundwater pumping and outflows across the GMU boundary (Table 6-10, Figure 6-9 and Figure 6-10). Table 6-10 shows that half of the volume pumped is sourced from leakage from the overlying Shepparton Formation and the rest from adjacent aquifers. Pumping from the deep aquifer causes drawdown of the watertable aquifer and hence may impact on stream–aquifer flux, groundwater dependent ecosystems and help to control high watertables.

Table 6-10. Groundwater balance for the Katunga WSPA GMU

Groundwater balance	Without-development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Head dependent boundary	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River recharge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leakage from overlying aquifer	8.0	18.5	18.5	18.5	18.5	18.6	17.0	16.8	16.9
Lateral flow	20.7	35.2	35.2	35.3	35.2	35.2	34.5	34.7	34.7
Total	**28.7**	**53.7**	**53.7**	**53.8**	**53.7**	**53.8**	**51.5**	**51.5**	**51.6**
Outflows									
Groundwater pumping	0.0	22.7	22.7	22.7	22.7	22.7	21.1	21.1	21.1
Head dependent boundaries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leakage to overlying aquifer	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lateral flow	28.4	31.1	31.2	31.3	31.1	31.2	30.6	30.5	30.6
To rivers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**28.7**	**53.8**	**53.9**	**54.0**	**53.8**	**53.9**	**51.7**	**51.6**	**51.7**
Difference (net loss)	**0.0**	**0.1**	**0.2**	**0.2**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**

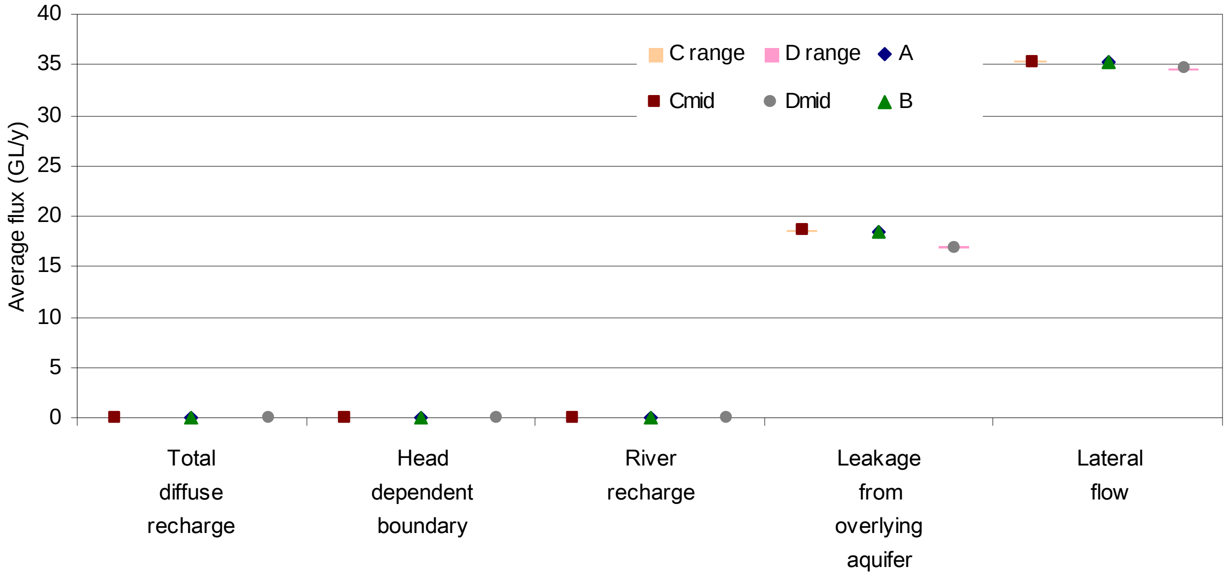

Figure 6-9. Groundwater inflows into the Katunga WSPA GMU under scenarios A, B, C and D

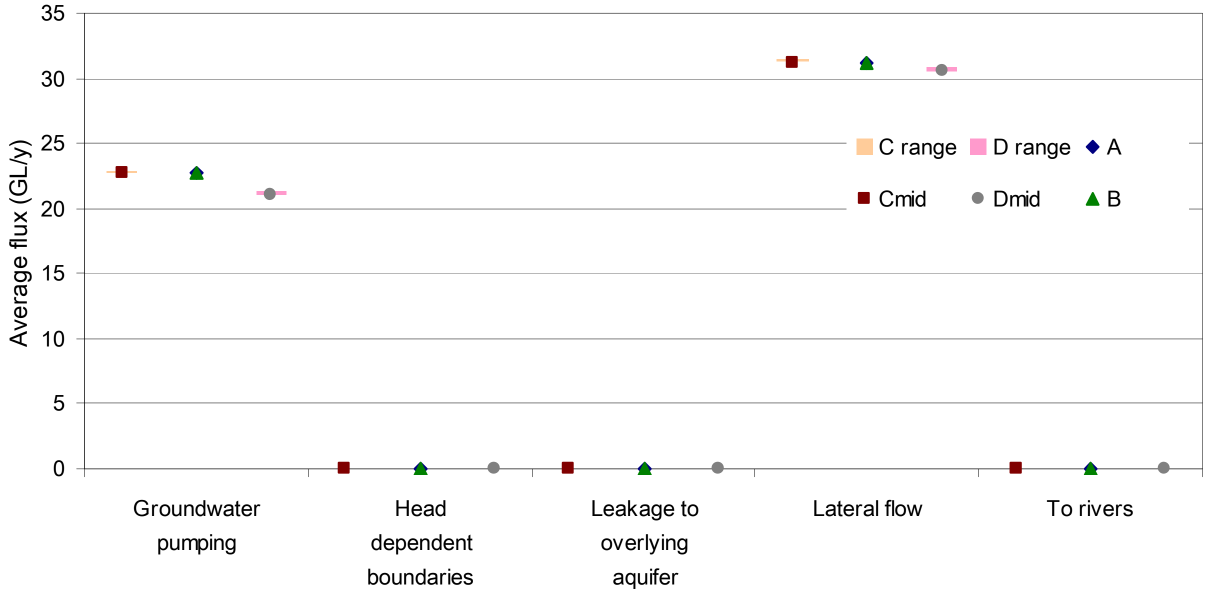

Figure 6-10. Groundwater outflows from the Katunga WSPA GMU under scenarios A, B, C and D

The groundwater indicators for the Katunga WSPA GMU are listed in Table 6-11. Groundwater security is high under all scenarios. The environmental indicator is between 0.40 and 0.41 under all scenarios. Scenario D shows drawdowns in excess of 3 m across the region relative to Scenario A. Drawdowns of up 5.5 m occur in the area of major groundwater extraction.

Table 6-11. Groundwater indicators for the Katunga WSPA GMU under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Security indicator				percent				
	100%	100%	100%	100%	100%	100%	100%	100%
Environmental indicator				ratio				
	0.41	0.41	0.41	0.41	0.41	0.40	0.40	0.40
Drought indicator				m				
Average	**-2.6**	**-3.6**	**-4.0**	**-2.8**	**-2.3**	**-4.3**	**-3.1**	**-2.5**
Observation bore								
48282_3	-2.6	-3.7	-4.1	-2.8	-2.3	-4.5	-3.3	-2.7
51001_3	-4.8	-5.9	-6.0	-5.0	-4.5	-5.4	-4.7	-4.0
97613_3	-2.5	-3.5	-3.9	-2.7	-2.2	-4.4	-3.1	-2.5
BMSF-1_3	-2.1	-3.1	-3.5	-2.3	-1.8	-4.0	-2.7	-2.1
BMSF-2_3	-1.8	-2.7	-3.1	-2.0	-1.5	-3.5	-2.3	-1.8
BMSF-3_3	-1.7	-2.6	-2.9	-1.8	-1.4	-3.4	-2.2	-1.7
51001_4	-4.8	-5.9	-6.0	-5.0	-4.5	-5.4	-4.7	-4.0
97613_4	-2.5	-3.5	-3.9	-2.7	-2.2	-4.4	-3.1	-2.5
BMSF-1_4	-2.1	-3.1	-3.5	-2.3	-1.8	-4.0	-2.7	-2.1
BMSF-2_4	-1.8	-2.7	-3.1	-2.0	-1.5	-3.5	-2.3	-1.8
BMSF-3_4	-1.6	-2.6	-2.9	-1.8	-1.4	-3.4	-2.2	-1.7

6.6.3 Lower Murray Alluvium GMU

The Lower Murray Alluvium GMU includes the Renmark, Calivil and Upper and Lower Shepparton aquifers. Three observation bores were selected to indicate the groundwater level changes under the scenarios in the four main aquifers. Water levels have also been reported for three sites in the Koondrook-Perricoota State Forest.

Table 6-12 shows that groundwater levels vary from 0.2 m higher to 1.1 m lower than under Scenario A. Table 6-13 shows the water level for the individual bores and the Koondrook-Perricoota Forest sites. Drawdowns of up to 1.5 m in the unconfined Upper Shepparton Formation aquifer beneath Koondrook-Perricoota Forest would have some environmental consequences (Chapter 7). Irrigation activity was held constant during each of the climate scenario model runs. This may result in a depth to watertable that does not reflect the actual future condition where irrigation activities would have responded.

Table 6-12. Median groundwater level in the Lower Murray Alluvium GMU under Scenario A and changes from this level under scenarios B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD			change from Scenario A (m)				
Layer 1 (Upper Shepparton)	79.2	-0.8	-1.1	-0.1	0.3	-1.2	-0.2	0.2
Layer 2 (Lower Shepparton)	78.0	-0.7	-1.0	-0.1	0.2	-1.1	-0.2	0.2
Layer 3 (Calivil Formation)	77.4	-0.6	-0.2	-0.1	0.2	-0.9	-0.2	0.1
Layer 4 (Renmark Group)	77.4	-0.4	-0.8	-0.1	0.2	-0.9	-0.2	0.1
Average	**78.0**	**1.7**	**-0.8**	**-0.1**	**0.2**	**-1.0**	**-0.2**	**0.2**

Table 6-13. Individual bore groundwater level in the Lower Murray Alluvium GMU under Scenario A and changes from this level under scenarios B, C and D

Observation bores	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	change from Scenario A (m)						
36350_1	119.2	-1.1	-1.5	-0.1	0.6	-1.5	-0.1	0.6
36585_1	81.7	-1.8	-2.4	-0.3	0.4	-2.7	-0.5	0.3
36718_1	56.2	-0.2	-0.2	-0.1	0.1	-0.2	-0.1	0.1
KPF-3_1	70.5	-0.7	-1.0	-0.1	0.3	-1.1	-0.2	0.2
KPF-4_1	68.5	-0.3	-0.5	-0.1	0.1	-0.5	-0.1	0.1
36350_2	117.5	-0.9	-1.3	-0.1	0.5	-1.3	-0.1	0.5
36585_2	78.1	-1.4	-1.9	-0.2	0.4	-2.2	-0.5	0.2
36718_2	55.7	-0.1	-0.1	-0.0	0.0	-0.1	-0.0	0.0
KPF-3_2	70.3	-0.7	-1.0	-0.1	0.2	-1.1	-0.2	0.2
KPF-4_2	68.5	-0.3	-0.5	-0.1	0.1	-0.5	-0.1	0.1
36350_3	117.7	-0.7	-1.0	-0.1	0.4	-1.0	-0.1	0.4
36585_3	75.1	-1.1	-1.5	-0.2	0.3	-1.9	-0.5	0.1
36718_3	55.2	0.0	-0.0	0.0	0.0	-0.0	0.0	0.0
KPF-3_3	70.3	-0.7	2.3	-0.1	0.2	-1.1	-0.2	0.2
KPF-4_3	68.6	-0.4	-0.5	-0.1	0.1	-0.5	-0.1	0.1
36350_4	117.7	-0.7	-1.0	-0.1	0.4	-1.0	-0.1	0.4
36585_4	75.1	-1.1	-1.5	-0.2	0.3	-1.9	-0.5	0.1
36718_4	55.2	0.0	-0.0	0.0	0.0	-0.0	0.0	0.0
KPF-3_4	70.3	0.0	-1.0	-0.1	0.2	-1.1	-0.3	0.1
KPF-4_4	68.6	0.0	-0.5	-0.1	0.1	-0.5	-0.1	0.1

Note: KPF-3 and KPF-4 are two sites within Koondrook-Perricoota Forest

The Lower Murray Alluvium GMU is the largest in the model area as reflected in the magnitude of the water balance fluxes. The water balance is dominated by fluxes across the GMU boundaries. There is also a large component of discharge across the northern boundary into the Lower Murrumbidgee Alluvium GMU. The water balance for the confined Calivil and Renmark aquifers is presented in Table 6-14. The water balance for the Shepparton aquifers is in Table 6-15. Figure 6-11 and Figure 6-12 summarise the water balance for the entire aquifer sequence. Approximately 80 GL/year is pumped from the deep lead aquifer in New South Wales, about one-third of the Southern Riverine Plains groundwater model area total. Significant leakage from overlying aquifers and flow across model head dependent boundaries is induced. Scenario A shows an overall increase in the net inflow of 39 GL/year compared to without-development conditions.

The net flow out of the region across the model boundaries (which represent the northern and western boundaries of the GMU) under Scenario A is also approximately 32 GL/year less than under without-development conditions. This reduction may have implications for groundwater availability in the Murrumbidgee region though the magnitude of the impact is small when viewed as a proportion of the total discharge in each modelled area. If drawdown occurs in Murrumbidgee region confined aquifers and the boundary condition of the adjoining model changes then the impact may be less than predicted by the model. If this is the case, then the model may be under-predicting downward leakage from the overlying aquifers.

Approximately 25 GL/year is pumped from the Shepparton Formation aquifers. There is also a net increase in flow to underlying confined aquifers of approximately 39 GL/year under Scenario A. This water is mainly sourced from rivers and from a reduction in groundwater evapotranspiration. The net loss of water from the rivers is estimated to be 21 GL/year and the reduction in groundwater evapotranspiration is approximately 20 GL/year. Interaction with the Murrumbidgee region may mean that downward leakage from the Shepparton aquifers to the confined aquifers is under-predicted by the model and hence the impact on the river systems and on groundwater evapotranspiration may also be under-predicted.

Table 6-14. Groundwater balance for the Lower Murray Alluvium GMU – deep lead (Calivil and Renmark aquifers)

Groundwater balance	Without-development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	2.5	2.5	2.1	2.0	2.4	2.7	2.0	2.4	2.7
Head dependent boundary	45.3	58.7	61.6	63.0	59.4	57.9	63.3	59.7	58.1
River recharge	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.3
Leakage from overlying aquifer	74.9	108.8	100.6	96.8	106.6	110.8	97.2	107.0	111.2
Lateral flow	137.7	133.8	131.4	130.5	133.3	134.5	128.1	131.3	132.8
Total	**260.7**	**304.1**	**295.9**	**292.5**	**302.0**	**306.2**	**290.8**	**300.7**	**305.1**
Outflows									
Groundwater pumping	0.0	79.4	79.4	79.4	79.4	79.4	79.5	79.5	79.5
Head dependent boundaries	174.2	155.6	150.9	148.8	154.4	157.0	148.4	154.1	156.7
Leakage to overlying aquifer	44.5	40.0	38.4	37.9	39.6	40.3	37.3	39.1	39.9
Lateral flow	41.5	28.7	26.9	26.1	28.3	29.2	25.3	27.7	28.6
To rivers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**260.2**	**303.7**	**295.6**	**292.2**	**301.7**	**305.9**	**290.5**	**300.4**	**304.7**

Table 6-15. Groundwater balance for the Lower Murray Alluvium GMU – Shepparton Formation aquifers

Groundwater balance	Without-development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	116.8	116.8	98.7	92.2	114.6	126.9	92.2	114.6	126.9
Head dependent boundary	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
River recharge	93.8	109.7	100.7	96.5	105.1	109.4	96.2	105.0	109.3
Leakage from underlying aquifer	44.5	40.0	38.4	37.9	39.6	40.3	37.3	39.1	39.9
Lateral flow	6.4	7.5	7.3	7.2	7.4	7.5	7.0	7.4	7.5
Total	**261.6**	**274.1**	**245.2**	**233.9**	**266.8**	**284.2**	**232.8**	**266.2**	**283.7**
Outflows									
Groundwater pumping	0.0	24.6	24.5	24.2	24.6	25.5	24.2	24.7	25.5
Head dependent boundaries	3.0	2.8	2.3	2.1	2.7	2.9	2.1	2.6	2.9
Leakage to underlying aquifer	74.9	108.8	100.6	96.8	106.6	110.8	97.2	107.0	111.2
Lateral flow	8.5	10.0	9.8	9.4	9.8	9.9	9.5	9.9	10.0
Evapotranspiration	117.3	97.0	85.7	81.0	94.1	100.5	79.8	93.2	99.7
To drains	35.6	16.7	11.9	10.2	16.0	19.3	10.0	15.8	19.1
To rivers	12.7	7.7	5.6	5.5	6.9	8.3	5.6	6.9	8.3
Total	**252.0**	**267.6**	**240.4**	**229.2**	**260.7**	**277.2**	**228.4**	**260.1**	**276.7**

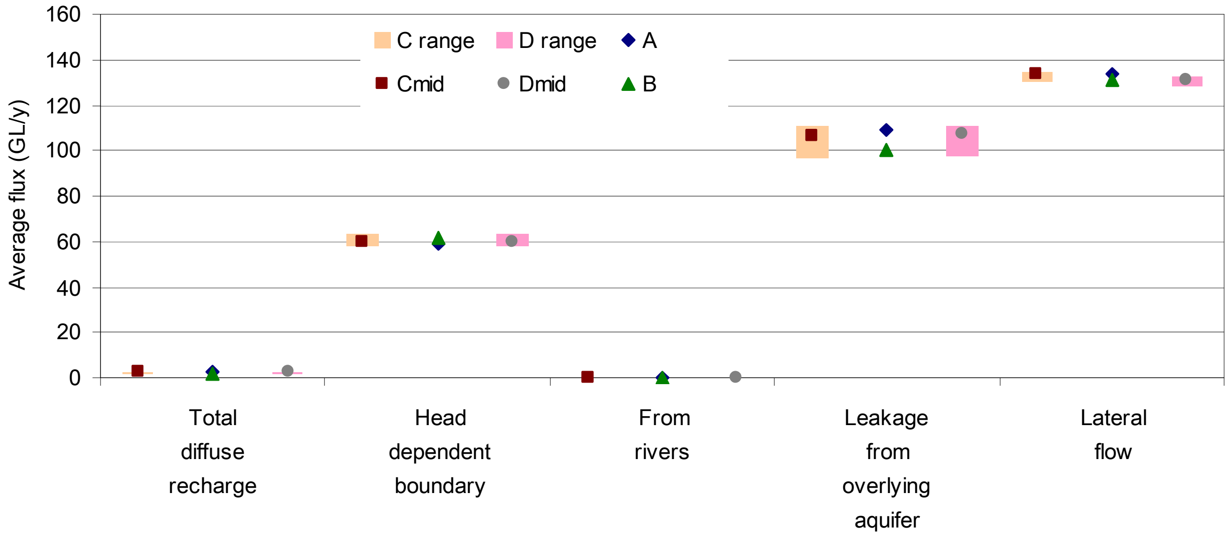

Figure 6-11. Groundwater inflows into the Lower Murray Alluvium GMU – deep lead (Calivil and Renmark aquifers)

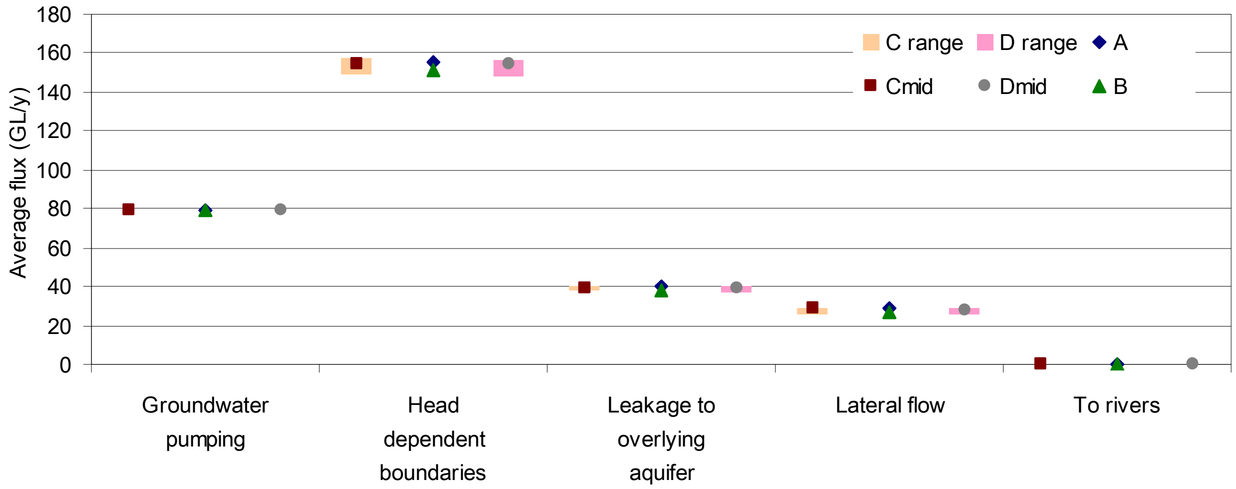

Figure 6-12. Groundwater outflows from the Lower Murray Alluvium GMU – deep lead (Calivil and Renmark aquifers)

The groundwater indicators for the Lower Murray Alluvium GMU are listed in Table 6-16. Groundwater security is high under all scenarios. The environmental indicator for the Calivil and Renmark aquifers is between 0.25 and 0.26. Scenario D shows drawdowns of up to 3 m in the indicator bores in the area of major groundwater extraction.

Table 6-16. Groundwater indicators in the Lower Murray Alluvium GMU under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Security indicator				percent				
Calivil and Renmark	100%	100%	100%	100%	100%	100%	100%	100%
Shepparton	100%	100%	100%	100%	100%	100%	100%	100%
Environmental indicator				ratio				
Calivil and Renmark	0.25	0.25	0.26	0.25	0.24	0.26	0.25	0.25
Shepparton	0.08	0.09	0.09	0.08	0.08	0.09	0.08	0.08
Drought indicator				m				
Average	**-0.8**	**0.88**	**-1.5**	**-0.9**	**-0.6**	**-1.7**	**-`1.0**	**-0.7**
Observation bore								
36350_1	-1.3	-2.1	-2.5	-1.4	-0.8	-2.5	-1.4	-0.8
36585_1	-0.7	-2.3	-2.9	-0.9	-0.3	-3.2	-1.1	-0.4
36718_1	-0.3	-0.5	-0.5	-0.3	-0.3	-0.5	-0.3	-0.3
KPF-3_1	-0.7	-1.4	-1.6	-0.8	-0.5	-1.8	-1.0	-0.6
KPF-4_1	-0.5	-0.8	-0.8	-0.5	-0.4	-0.9	-0.6	-0.4
36350_2	-1.3	-2.0	-2.4	-1.4	-1.0	-2.4	-1.4	-1.0
36585_2	-1.4	-2.7	-3.2	-1.6	-1.1	-3.5	-1.9	-1.3
36718_2	-0.2	-0.3	-0.3	-0.2	-0.2	-0.3	-0.2	-0.2
KPF-3_2	-0.7	-1.3	-1.6	-0.8	-0.5	-1.7	-0.9	-0.6
KPF-4_2	-0.5	-0.8	-0.9	-0.5	-0.4	-0.9	-0.6	-0.4
36350_3	-1.5	-2.1	-2.4	-1.5	-1.1	-2.4	-1.5	-1.1
36585_3	-2.4	-3.5	-3.9	-2.6	-2.2	-4.2	-2.9	-2.4
36718_3	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
KPF-3_3	-0.7	-1.4	1.4	-0.8	-0.5	-1.7	-1.0	-0.6
KPF-4_3	-0.5	-0.8	-0.9	-0.6	-0.4	-0.9	-0.6	-0.4
36350_4	-1.5	-2.1	-2.4	-1.5	-1.1	-2.4	-1.5	-1.1
36585_4	-2.5	-3.5	-3.9	-2.6	-2.2	-4.3	-2.9	-2.4
36718_4	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0	-0.0
KPF-3_4	-0.7	-0.7	-1.6	-0.8	-0.5	-1.8	-1.0	-0.6
KPF-4_4	-0.5	-0.5	-0.9	-0.6	-0.4	-0.9	-0.6	-0.4

6.7 Water balances for unmodelled groundwater management units

Simple water balance analyses were conducted for the lower priority GMUs in the Murray region (Table 6-7) as well as the Upper Murray Alluvium GMU. Two indicators are reported. The first indicator is the ratio of extraction to rainfall recharge (E/R). The E/R ratio was not applied to GMUs where the primary source of water is the deep confined aquifers since rainfall recharge to these systems is negligible. This includes the Murrayville WSPA, Telopea Downs, Kaniva, the South Australia–Victoria Border Zone PWA, the Mallee PWA and the Noora PWA GMUs.

A significant fraction of alluvial aquifer recharge may come from streams either directly from channels or during floods and in these cases extraction may be maintained at E/R ratios greater than 1.0 but streamflow will be impacted. E/R is not used as an indicator for confined aquifers. The second indicator is the average volumetric impact of groundwater extraction on streamflow.

6.7.1 Groundwater extraction

Groundwater extraction in the Murray Uplands is small relative to the large areas of irrigation on the Riverine Plain, however stock and domestic supplies are sourced from these areas and may be locally significant. Early groundwater use in the alluvial sediments of the Murray Uplands was limited to stock and domestic supply and town water supply and irrigators generally utilised surface water. The recent restriction on further allocation of river water for irrigation has increased demand on groundwater. Groundwater is largely sourced from the Murray Group Limestone within the Mallee and Lower Lakes area, except in the Peake, Roby and Sherlock PWA GMU, where the deeper Renmark Formation is more extensively used. Most of the Mallee GMUs have been recharged thousands of years ago or modern recharge is associated with higher salinity. Estimated current and future groundwater extraction from low priority GMUs with significant recharge within the Murray region is shown in Table 6-17. The estimates of current use in areas controlled by New South Wales macro groundwater sharing plans are based on metered data and on an average extraction estimate of 1.5 ML/year for each stock and domestic bore (New South Wales Department of Water and Energy (DWE), pers. comm.).

The New South Wales macro groundwater plan 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 social, economic and environmental values. 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. Long-term extraction limits are based on the calculation of rainfall recharge to each GMU.

Table 6-17. Estimated groundwater extraction for the unmodelled areas of the Murray region

Code	Name	Current extraction (2004/05)	Total entitlements	Future extraction
		GL/y		
N15	Upper Murray Alluvium	(1)30.5	(1)38.6	(1)38.6
N45	Lower Darling Alluvium	(1)2.0	(1)3.7	(1)4.7
N612	Western Murray Porous Rock	(1)4.5	(1)7.6	(1)331.9
N811	Lachlan Fold Belt	(1)5.2	(1)8.6	(1)17.4
N817	Kanmantoo Fold Belt	(1)0.3	(1)0.3	(1)18.0
N818	Adelaide Fold Belt	(1)0.9	(1)1.7	(1)18.3
na	Kiewa unincorporated areas(3)	(2)2.1	(2)2.1	(2)3.5
na	Upper Murray unincorporated areas	(2)2.3	(2)4.1	(2)4.5

(1) Sourced from data supplied by DWE
(2) Source: DSE, 2006
(3) Extraction and entitlement data for the Kiewa unincorporated areas includes data for the Mullindolingong GMA GMU

Groundwater extraction within the low priority areas of the Murray region is forecast to grow in the future. Estimates of the likely maximum extraction were provided for each GMU by DWE for the New South Wales portion of the region and by DSE for the Victorian portion of the region. The 'likely maximum use' within New South Wales is based on the historical development of irrigation, urban and stock and domestic water supply works. The estimated growth rate within a region is based on the rate of historic growth. It is assumed that all new stock and domestic water supply works will be drilled and constructed on separate properties. An average size for each property was calculated. The total additional stock and domestic requirement was then calculated based on assumed usage rates for domestic bores of 2.25 ML/year and for stock bores of 0.0088 ML/ha/year. Estimates of future (year 2030) extraction volumes in Victoria used a methodology that assumed:

- urban use and stock and domestic use will not increase or decrease by the year 2030
- all 'other' use will increase at a rate equal to the mean annual increase in water usage across Australia between 1983/84 and 1996/97 (Land and Water Australia, 2001). This equates to an increase in groundwater usage of 3.65 percent per year for each year from 2004/05 to the year 2030 up to the current entitlement volume.

6.7.2 Estimates of rainfall recharge

Rainfall recharge is the largest component of the water balance and is therefore the focus of this assessment. The following data were provided by DWE for their portion of the catchment. Recharge to the Victorian component was calculated using the forest cover of each area. A different infiltration rate was assigned for forested and unforested areas and recharge was calculated from average annual rainfall records. Estimates of rainfall recharge vary from 1 to 4 percent of average rainfall. Scaled annual recharge for GMUs is shown in Table 6-18. This table does not include several GMUs in the Mallee region for which the resource has been recharged thousands of years ago or modern recharge is associated with high salinity.

Table 6-18. Scaled recharge under scenarios A to C

Code	Name	Recharge	Scaled recharge			
		A	B	Cdry	Cmid	Cwet
		GL/y				
N15	Upper Murray Alluvium	3.9	4.2	3.6	3.8	5.5
N45	Lower Darling Alluvium	18.6	14.9	12.2	17.9	20.6
N612	Western Murray Porous Rock	948.3	793.6	743.0	910.8	1120.6
N811	Lachlan Fold Belt	138.9	107.3	90.5	134.0	158.7
N817	Kanmantoo Fold Belt	60.1	63.9	43.4	61.3	80.6
N818	Adelaide Fold Belt	43.5	25.3	27.0	52.3	56.2
na	Kiewa unincorporated areas	17.8	14.4	12.3	17.3	19.2
na	Upper Murray unincorporated areas	78.0	63.2	53.8	75.7	84.2

na – not applicable

The ratio of current (2004/05) groundwater extraction to recharge (E/R) is shown in Table 6-19. This ratio is used as an indicator of potential stress on the aquifer. Where E/R exceeds 1.0 groundwater is being extracted at a rate greater than the rate of recharge. New South Wales macro groundwater sharing plans allocate 30 to 50 percent of rainfall recharge to environmental purposes (E/R of 0.5–0.7).

Table 6-19. Comparison of groundwater extraction with scaled rainfall recharge

Code	Name	2004/05 Extraction	2030 Extraction	E/R							
				A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
		GL/y		ratio							
N15	Upper Murray Alluvium	30.5	40.5	7.82	7.26	8.47	8.03	5.55	11.25	10.66	7.36
N45	Lower Darling Alluvium	2.0	4.7	0.11	0.13	0.16	0.11	0.10	0.38	0.26	0.23
N612	Western Murray Porous Rock	4.5	331.9	<0.01	0.01	0.01	<0.01	<0.01	0.45	0.36	0.30
N811	Lachlan Fold Belt	5.2	17.4	0.04	0.05	0.06	0.04	0.03	0.19	0.13	0.11
N817	Kanmantoo Fold Belt	0.3	18.0	<0.01	<0.01	<0.01	<0.01	<0.01	0.42	0.29	0.22
N818	Adelaide Fold Belt	0.9	18.3	0.02	0.03	0.03	0.02	0.02	0.68	0.35	0.32
na	Kiewa unincorporated areas*	2.1	3.5	0.12	0.14	0.17	0.12	0.11	0.28	0.20	0.18
na	Upper Murray unincorporated areas	2.3	4.5	0.03	0.04	0.04	0.03	0.03	0.08	0.06	0.05

na – not applicable

* Extraction data for the Kiewa unincorporated areas include extraction from the Mullindolingong GMA GMU.

Under Scenario A the E/R ratio ranges from less than 0.01 to 7.82 for the unmodelled areas of the Murray region. Excluding the Upper Murray Alluvium GMU there would be a maximum increase in E/R of 0.02 under Scenario B and 0.05 under scenarios Cmid and Cdry. Scenario Cwet is the only scenario that leads to a decline in the E/R ratio due to the 2030 climate predicting higher annual rainfall than the historical average. Scenarios Dwet, Dmid and Ddry lead to more significant increases due to increased groundwater use.

For the Upper Murray Alluvium (N15) GMU rainfall recharge is approximately 4 GL/year. According to the macro plan figures a sustainability index of 70 percent should be applied resulting in an LTAEL of about 2.7 GL/year. The current extraction limit is 38.6 GL/year and use in 2004/05 was 30.5 GL. Thus E/R values range between 5.55 and 11.25 under the different scenarios. The results of the Upper Murray groundwater model (Mampitiya, 2006) indicate that the alluvial aquifer could not sustain increased pumping over approximately 20 GL without causing significant storage declines and subsequently increasing leakage from the river.

6.7.3 Impact of extraction from unmodelled groundwater management units on streamflow

For the non-modelled areas the impact of groundwater extraction was estimated using a simple relationship with the volume of extraction and involving a 'connectivity factor'. The main volume of extraction comes from the Upper Murray Alluvium GMU. A connectivity factor of 80 percent was used for this GMU based on that estimated from modelling of similar GMUs in the Murrumbidgee and Ovens regions and to be consistent with existing modelling of this GMU (Mampitiya, 2006). The connectivity factor for other GMUs were chosen to be consistent with previous regional reports in this series. On this basis, estimated impacts of groundwater extraction on streamflow are shown in Table 6-20. The impact of estimated future (2030) groundwater extraction under Scenario D conditions is summarised in Table 6-21. Under Scenario D conditions, Murray River flow would be depleted by approximately 40 GL/year. The time lags associated with the fractured rock areas is expected to be relatively small (<10 years for 50 percent response) compared to the alluvia (10 to 20 years for 50 percent response).

Table 6-20. Potential impact of 2004/05 groundwater extraction on streamflow of unmodelled areas

Code	Name	2004/05 Extraction	Degree of connectivity of productive Aquifer and Murray River	Volume of streamflow potentially depleted
		GL/y		GL/y
N811	Lachlan Fold Belt GMU (NSW)	5.2	0.3	1.6
N45	Upper Murray Alluvium GMU (NSW)	30.5	0.8	24.4
na	Upper Murray unincorporated areas (Vic)	2.3	0.3	0.7
na	Kiewa unincorporated areas (Vic)*	2.1	0.8	1.7
	Total	**40.1**		**28.4**

na – not applicable

*Extraction data for the Kiewa unincorporated areas includes extraction from the Mullindolingong GMA GMU

Table 6-21. Potential impact of increased groundwater extraction on streamflow of unmodelled areas under Scenario D

Code	Name	2030 extraction	Degree of connectivity of productive aquifer and Murray River	Volume of stream flow potentially depleted
		GL/y		GL/y
N811	Lachlan Fold Belt GMU (NSW)	17.4	0.3	5.2
N45	Upper Murray Alluvium GMU (NSW)	38.6	0.8	30.9
na	Upper Murray unincorporated areas (Vic)	4.5	0.3	1.3
na	Kiewa unincorporated areas (Vic)*	3.5	0.8	2.8
	Total	**63.9**		**40.2**

na – not applicable

*Extraction data for the Kiewa unincorporated areas includes extraction from the Mullindolingong GMA GMU

The total impacts of groundwater extraction from both modelled and non-modelled areas on the Murray River are given in Table 6-22. These impacts have been included in the river modelling described in Chapter 4, noting:

- only Upper Murray Alluvium GMU has been included from non-modelled regions, given the small contributions from other GMUs
- only the Murray and main anabranches have been included in the Murray River model, while lower parts of rivers such as the Goulburn, Loddon, Campaspe and Broken Creek, etc have not been included
- drains have not been included.

Table 6-22. Total streamflow impacts of groundwater extraction relative to no development under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/year							
Southern Riverine Plains Model	72.9	70.7	68.0	68.9	66.4	78.1	82.7	82.2
Unmodelled areas	28.4	28.4	28.4	28.4	28.4	40.1	40.1	40.1
Total	**101.3**	**99.1**	**96.4**	**97.3**	**94.8**	**118.2**	**122.8**	**122.3**

6.8 Conjunctive water use indicators

Groundwater can provide a more secure water source during drier periods. Irrigators may elect to change from surface water to groundwater during years of low flow where such exchanges are feasible. 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. Table 6-23 shows these indicators for years of lowest surface water diversions up to a year with average flow.

Groundwater is from 5 to 8 percent of total diversions in the Murray region under Scenario A. This does not change much under Scenario Cmid (5 to 9 percent) and Scenario Cwet (5 to 8 percent), but does under Scenario B (6 to 17 percent) and under Scenario Cdry (7 to 19 percent). The proportion changes to 15 to 24 percent under Scenario Dmid, 18 to 41 percent under Scenario Ddry and 15 to 20 percent under Scenario Dwet. These results show that groundwater forms a minor source of water for the region as a whole under average flow years but is more important in drier years.

Table 6-23. Conjunctive water use indicator: ratio (as a percentage) of groundwater to total water diversion for catchment in the Murray region in one-, three- and five-year periods of lowest surface water diversions of lowest flow and the average year under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Lowest 1-year period	8%	17%	19%	9%	8%	41%	24%	20%
Lowest 3-year period	7%	9%	10%	7%	6%	26%	19%	17%
Lowest 5-year period	6%	8%	9%	7%	6%	24%	18%	17%
Average	5%	6%	7%	5%	5%	18%	15%	15%

6.9 Discussion of key findings

The Murray region has one of the higher levels of groundwater extraction in the MDB. Nonetheless, the amount of groundwater used is small relative to the amount of surface water diversion. In years of lower river flow, it is relatively more important.

Approximately half of this extraction occurs in the GMUs of the Southern Riverine Plains (Katunga WSPA and Lower Murray Alluvium). Modelling suggests that this level of extraction can be sustained. Large fractions of the recharge comes from diffuse recharge (including irrigation areas), river recharge and flow from outside of the region. About 40 percent of groundwater loss occurs through evapotranspiration with a significant part of this from the red gum forests of Barmah-Millewa and Gunbower-Pericoota. There is also a large outflow from the region. The large lateral flows show the degree of interaction between nearly all of the GMUs of the Southern Riverine Plains region. Downward leakage through the Shepparton formation implies that groundwater salinisation could be an issue in some areas. This was not investigated in this project.

Extraction from the upland areas (Upper Murray and Kiewa areas) has increased in recent times. The high degree of connection with streams mean that this will impact on river flow, but impact is relatively small compared to the groundwater extraction from the Riverine Plains. Extraction from the Mallee region will have little impact on streams and is mostly limited by groundwater salinisation processes.

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7 Environment

This chapter presents the environmental assessments undertaken for the Murray region. It has four sub-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

- There are many important environmental assets along the Murray and lower Darling rivers including several Ramsar-listed sites and numerous nationally important sites (many of these are also designated as 'Icon Sites' under Murray-Darling Basin Commission's Living Murray Initiative). Assessment of the environmental implications of changes in water availability is however, largely beyond the terms of reference (Chapter 1) of this project. The exception is reporting against environmental water allocations and quantified environmental flow rules specified in water sharing plans. Environmental assessments form a very small part of the project.
- The Murray, lower Darling and most tributaries are affected by a high level of water resources development.
- Several water plans in the Murray region govern intertwined water resource management arrangements including environmental water provisions. The hydrological modelling assesses these provisions except in South Australia.
- Assessments are reported for the following Icon Sites: Barmah-Millewa Forest; Gunbower-Koondrook-Perricoota Forest; Hattah Lakes; Chowilla Floodplain and Lindsay-Wallpolla Islands; and the Lower Lakes, Coorong and Murray Mouth. Assessments are also reported for the Lower Darling River and associated Darling Anabranch Lakes.

7.1.2 Key messages

- For the major wetlands and floodplain forests along the Murray River, water resource development in the Murray region and in the upstream contributing regions has approximately doubled the average period between significant inundation events (to at least 3.5 years). Flood volumes have also been greatly reduced such that the average annual flood volume is now less than a quarter, and in some cases only a fifth, of the volume under without-development conditions.

- For the Lower Lakes, Coorong and Murray Mouth, water resource development has increased the average period between the flood events required to flush the river mouth and help sustain the lake and estuarine ecosystems from 1.2 years to 2.2 years. Flood volumes have also been greatly reduced such that the average annual flood volume is only a fifth of the volume under without-development conditions.

- For the Darling Anabranch Lakes, water resource development has more than trebled the average period between significant inundation events. Flood volumes have also been greatly reduced such that the average annual flood volume is only a fifth of the volume under without-development conditions.

- In all the above cases, the hydrological changes resulting from water resource development have been major, and are associated with the significant declines that have been observed in these flood-dependent ecosystems.

- A long-term continuation of the climate of the last ten years (1997 to 2006) would cause additional significant hydrological change for the Icon Sites. The average period between assessed beneficial floods would in all cases be close to three times the period under without-development conditions under the historical climate. Flood magnitudes would also decline significantly such that average annual flood volumes would, for all Icon Sites, be 5 percent or less of the without-development volumes. As the recent climate in the Darling Basin has not been significantly different to the historical climate, a long-term continuation of this climate would have no consequences for the Darling River Anabranch Lakes.

- The best estimate 2030 climate, while less severe than a continuation of the recent climate, would still lead to important increases in the average period between beneficial floods for all assessed sites. These increases, combined with reduced flood sizes, would mean that average annual flood volumes would be in the range 8 to12 percent of the without-development volumes (under historical climate, except for the Darling Anabranch Lakes where average annual volumes would be 15 percent of the without-development volumes). These hydrological changes would have very serious consequences for the ecosystem health of all sites.

- The wet extreme 2030 climate would lead to little change in flood frequency for the assessed sites. However, flood events would be somewhat larger – except in the case of Gunbower-Koondrook-Perricoota Forests, where event size would fall slightly. These hydrological changes would not be expected to have additional impacts on the assessed sites.

- The dry extreme 2030 climate would cause hydrologic changes slightly more severe than a long-term continuation of the recent climate. Hence the average period between floods would be three or more times the average period under without-development conditions (under the historical climate) and average annual flood volumes would be only 1 or 2 percent of without-development volumes, except for the Darling Anabranch Lakes where average annual flood volumes would be 10 percent of the without-development volumes.

- Of the future developments considered, the increases in groundwater extraction would have noticeable impacts on the hydrology of some Icon Sites. The groundwater levels under Barmah-Millewa and Gunbower-Koondrook-Perricoota forests would be expected to fall by up to 1.0 m. This is in addition to reductions in groundwater levels of a similar magnitude under these forests due to the current levels of groundwater extraction.

7.1.3 Uncertainty

The main uncertainties involving analysis and reporting include:

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

7.2 Approach

This chapter focuses on rules for the provision of environmental water and the assessment of hydrological indicators (defined by prior studies) for key environmental assets in the region. A broader description of the region, water resources and important environmental assets is in Chapter 2. The Murray-Darling Basin Commission's Living Murray Initiative is aimed at addressing the decline in the health of the Murray River system via a range of actions including water recovery and improved water delivery infrastructure (MDBC, 2006). The Initiative focuses on six 'Icon Sites' described later in this chapter. The Murray region also includes the Menindee Lakes, the Darling River downstream of the Menindee Lakes and the Great Darling Anabranch.

7.2.1 Summary of environmental flow rules

The environmental flow arrangements for the Murray River are complex, despite coordination of the interests of the three state governments by the Murray-Darling Basin Commission. The Murray River has several important environmental assets including many Ramsar sites and six Icon Sites. Overall, environmental flow management of the Icon Sites is coordinated under the Living Murray Environmental Watering Plan (MDBC, 2006) and each site has an environmental management plan. The Environmental Watering Plan guides decisions on the volume, timing and frequency of water to be provided to each Icon Site. This covers water from the Murray and (where relevant) the Murrumbidgee and Goulburn rivers. The environmental assets of the Lower Darling River and Great Darling Anabranch are subject to separate management arrangements and not covered by the Initiative.

New South Wales, Victoria and South Australia have separate, but linked statutory environmental water provisions as outlined below.

New South Wales

The Water Sharing Plan for the New South Wales Murray and Lower Darling Regulated River Water Sources, 2003 (DIPNR, 2004) contains environmental water provisions for the New South Wales Murray including:

- 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 the 2000/01 level of water resource development and the management rules in the water sharing plan
- a number of rules relating to the management of a Barmah-Millewa Environmental Water Allowance which has a maximum 'credit' of 350 GL
- a regulated river (conveyance) access licence with 30,000 shares committed as adaptive environmental water
- a regulated river (high security) access licence with 2027 shares committed as adaptive environmental water
- the ability to commit additional access licences for environmental purposes.

The Water Sharing Plan (DIPNR, 2004) contains environmental water provisions for the Lower Darling including:

- 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 the 2000/01 level of water resource development and the management rules in the water sharing plan
- a number of rules for relating to the management of an Environmental Contingency Allowance which is targeted at reducing blue-green algal bloom problems
- the ability to commit access licences for environmental purposes.

Victoria

The Victorian Murray Environmental Water Reserve of the Victorian Department of Sustainability and Environment has environmental provisions for the Victorian Murray (DSE, 2007) including:

- River Murray Flora and Fauna Reserve Bulk Entitlement of 27.6 GL
- Barmah-Millewa Forest Environmental Water Allocation
- all other water in the Basin not allocated for consumptive use, that is, water in excess of the Murray-Darling Basin Commission's Cap on surface water diversions.

South Australia

Under the Water Allocation Plan for the Murray River (RMCWMB, 2004) the following provisions exist for environmental water:

- a maximum of 200 GL for wetland management purposes where the wetland can be managed at or below the South Australian entitlement flow and pursuant to the Murray-Darling Basin Agreement (MDBC, 2006g). (Note: the Department of Water, Land and Biodiversity Conservation says that the 200 GL allocation for wetland management is part of the system losses and river maintenance component of the South Australia Entitlement Flow. The water available in any year is the volume of savings achieved through a reduction in evaporative losses in managed wetlands. This is generally in the order of 3 to 5 GL.)
- 22.2 GL for environmental land management in the Lower Murray Reclaimed Areas Irrigation Management Zone (for management of saline groundwater effects)
- water above the entitlement flow can be allocated for wetland management, pursuant to the Murray-Darling Basin Agreement.

7.2.2 Environmental assets and indicators

The Murray region contains several large and important wetlands including those along the Lower Darling and Great Darling Anabranch. The Icon Sites along the Murray River and the wetlands of the Great Darling Anabranch are assessed in this report. The Icon Sites are well studied and a substantial level of information is available on their hydrological and ecological characteristics. The wetlands of the Great Darling Anabranch are less well studied.

The Icon Sites are all nationally important (although with slightly different geographic definitions) and are either part or entirely Ramsar-listed. The following descriptions are from Environment Australia (2001) and other cited sources. The relevant asset environmental management plans (MDBC, 2006a–f) and the Living Murray Initiative supporting documents (CRCFE, 2003) were consulted for information on hydrological indicators. The Murray-Darling Basin Commission recommended key hydrological indicators for each Icon Site and for the Darling Anabranch Lakes. The environmental assets (Figure 7-1) and hydrological indicators (Table 7-1) selected for use in the Murray region are described below.

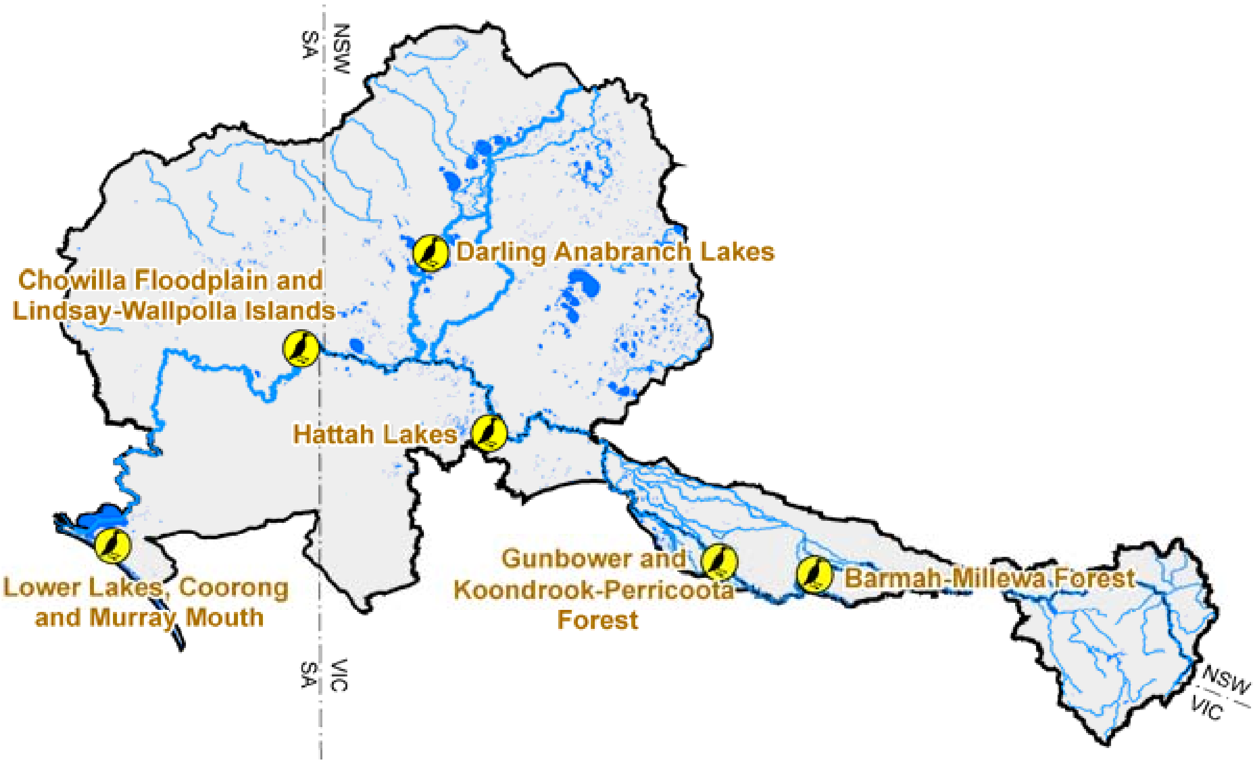

Figure 7-1. Location of environmental assets assessed for the Murray region

Barmah-Millewa Forest

The Barmah-Millewa Forest (MDBC, 2006a) (Figure 7-2) is the largest River Red Gum (*Eucalyptus camaldulensis*) forest and woodland in Australia and covers approximately 66,000 ha of Murray River floodplain. The Barmah Forest (VIC034) covers some 29,500 ha in Victoria and the Millewa Forest (NSW053) some 33,636 ha in New South Wales. Part of the forest is nationally and internationally important (Ramsar-listed) and is protected under international bird agreements. It provides a diverse range of wetland environments and supports large breeding colonies for waterbirds such as Egrets (*Ardea spp*), Ibis (*Threskiornis spp*) and Rufous Heron (*Nycticorax caledonicus*). The forest has diverse plant associations, supports rare and threatened plant species and provides habitat and food sources for native fish (MDBC, 2006a).

The forest is highly valued as a recreational and tourist area, has been used by Indigenous people for a long period and there are many important cultural sites. The Barmah Forest has a combination of land tenures, including state forest, reference area, state park, recreational reserve and private land. The Millewa Forest is state forest and timber reserve.

The Barmah-Millewa Forest Icon Site begins to wet once the channel capacity at the Barmah Choke is exceeded: 10.6 GL/day at Yarrawonga. An interim Living Murray Initiative ecological objective for the Barmah-Millewa Forest is 'healthy vegetation in at least 55 percent of the area of the forest including virtually all of the Giant Rush, Moira Grass, River Red Gum forest, and some River Red Gum woodland' (MDBC, 2006a). This area is flooded at flows between 10.6 to 18.3 GL/day (MDBC, 2006a). The Icon Site environmental management plan (MDBC, 2006a) outlines the duration and seasonal flow requirements and the Murray-Darling Basin Commission recommended that a target duration of 60 days during August to December be used in this assessment.

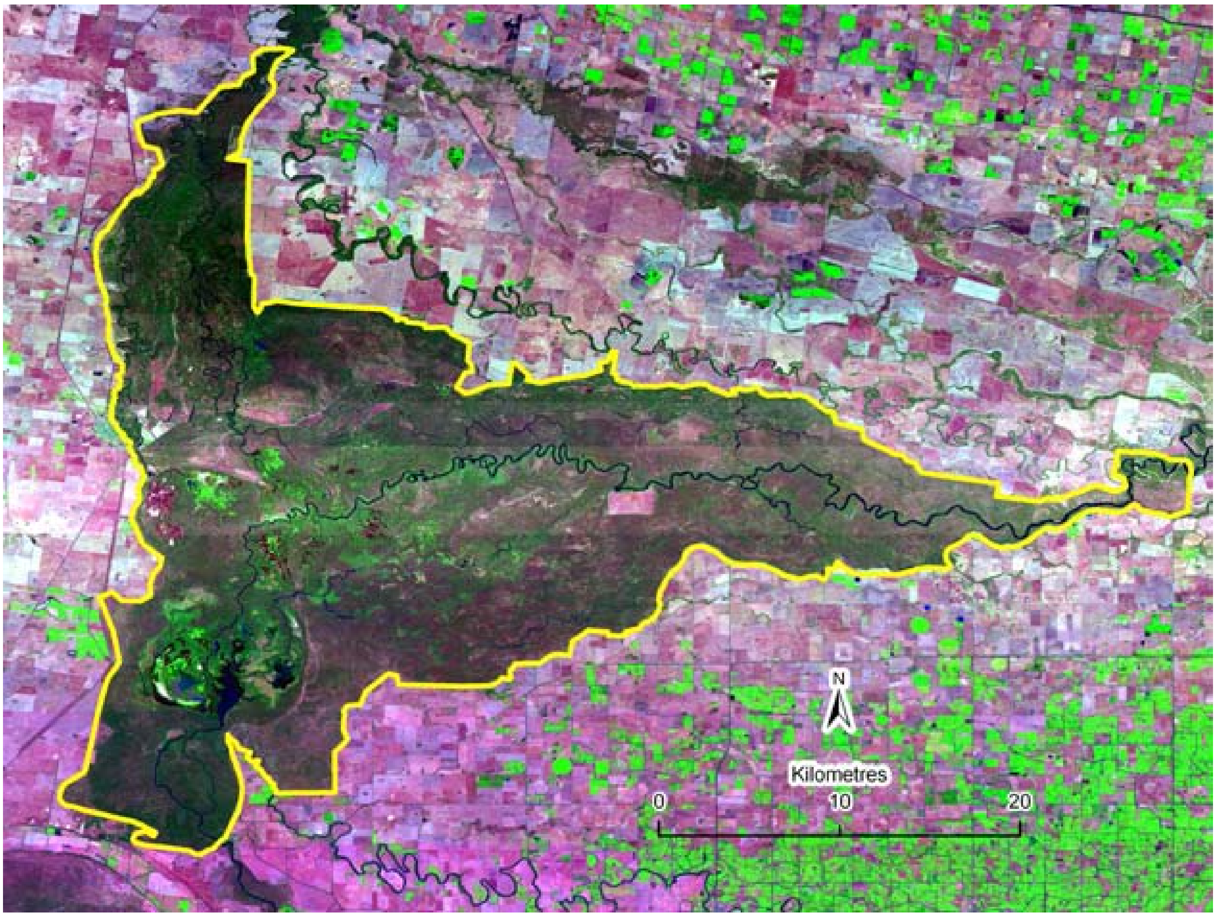

Figure 7-2. Satellite image of Barmah-Millewa Forest

Gunbower-Koondrook-Perricoota Forest

The combined Gunbower-Koondrook-Perricoota Forest (MDBC, 2006b; Figure 7-3) is the second largest River Red Gum forest in Australia and covers 50,000 ha. The Gunbower Forest (VIC040, also known as Gunbower Island) covers some 19,500 ha in Victoria and is nationally and internationally important (Ramsar-listed). The Koondrook-Perricoota Forests (NSW046) in New South Wales covers approximately 30,000 ha and is included in the New South Wales Central Murray State Forests Ramsar site (MDBC, 2006b). The wetland complex is an important breeding area for waterbirds such as the Rufous Heron (*Nycticorax caledonicus*) and the Intermediate Egret (*Ardea intermedia*) and provides habitat for other rare or threatened species (MDBC, 2006b).

The Gunbower Forest is highly valued as a recreational and tourist area. There is evidence from the nearby Kow Swamp that the area has been used by Indigenous people for at least 13,000 years and the forest contains many important cultural sites. Land tenure is primarily state forest and there is some private land. Part of the Koondrook-Perricoota is a wildlife refuge.

The general commence-to-flow level for both the Gunbower and the Koondrook-Perricoota forests is 30 GL/day at Torrumbarry (CRCFE, 2003). The Icon Site environmental management plan (MDBC, 2006b) provides general wetland flow regime requirements for seasonality and duration but not for flow thresholds. The Murray-Darling Basin Commission recommended that an indicator of 30 GL/day at Torrumbarry for 30 days during August to January be used in this assessment.

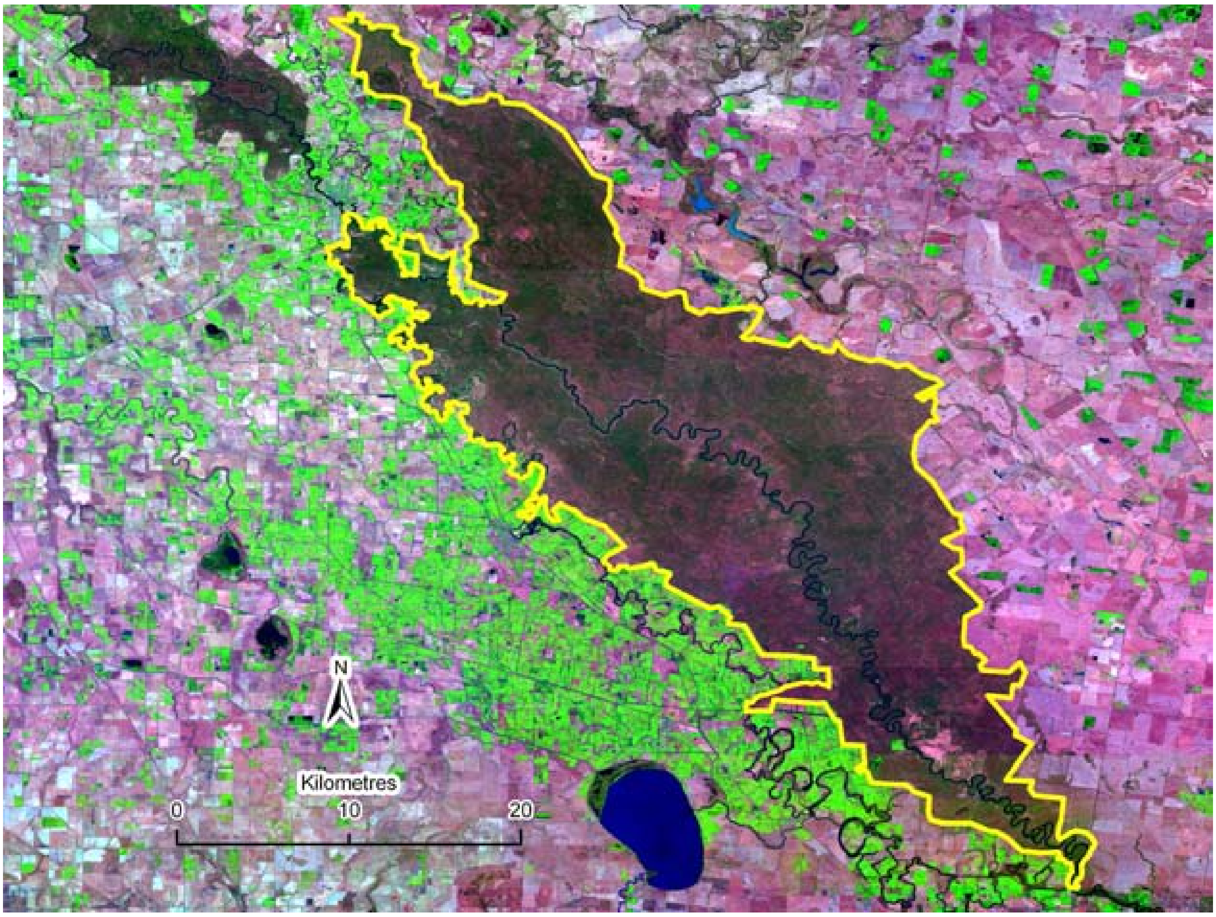

Figure 7-3. Satellite image of Gunbower-Koondrook-Perricoota Forest

Hattah Lakes

The Hattah Lakes (MDBC, 2006c) (Figure 7-4) comprise a series of intermittent and perennial freshwater lakes covering over 1000 ha including the nationally significant Hattah Lakes wetlands (VIC007). The Hattah-Kulkyne Lakes Ramsar site includes 12 of the lakes. The lakes are also part of the Hattah-Kulkyne National Park Biosphere Reserve. Most of the lakes fill from Murray River flows via Chalka Creek. The varied inundation conditions at the lakes support a wide diversity of plants and animals. The lakes can provide feeding and breeding areas for many waterbirds and native fish.

The lakes are heavily used for recreational purposes including camping, fishing, bushwalking, canoeing and nature study. Evidence of Indigenous use of the area is extensive with numerous cultural sites. Land tenure is national park.

The Icon Site environmental management plan (MDBC, 2007c) identifies a flow of 36.7 GL/day at Euston as the commence-to-flow level for the lakes via Chalka Creek. It does not include information on duration and seasonality. The Murray-Darling Basin Commission recommended that an indicator of 36.7 GL/day at Euston for 60 days during August to January should be used in this assessment.

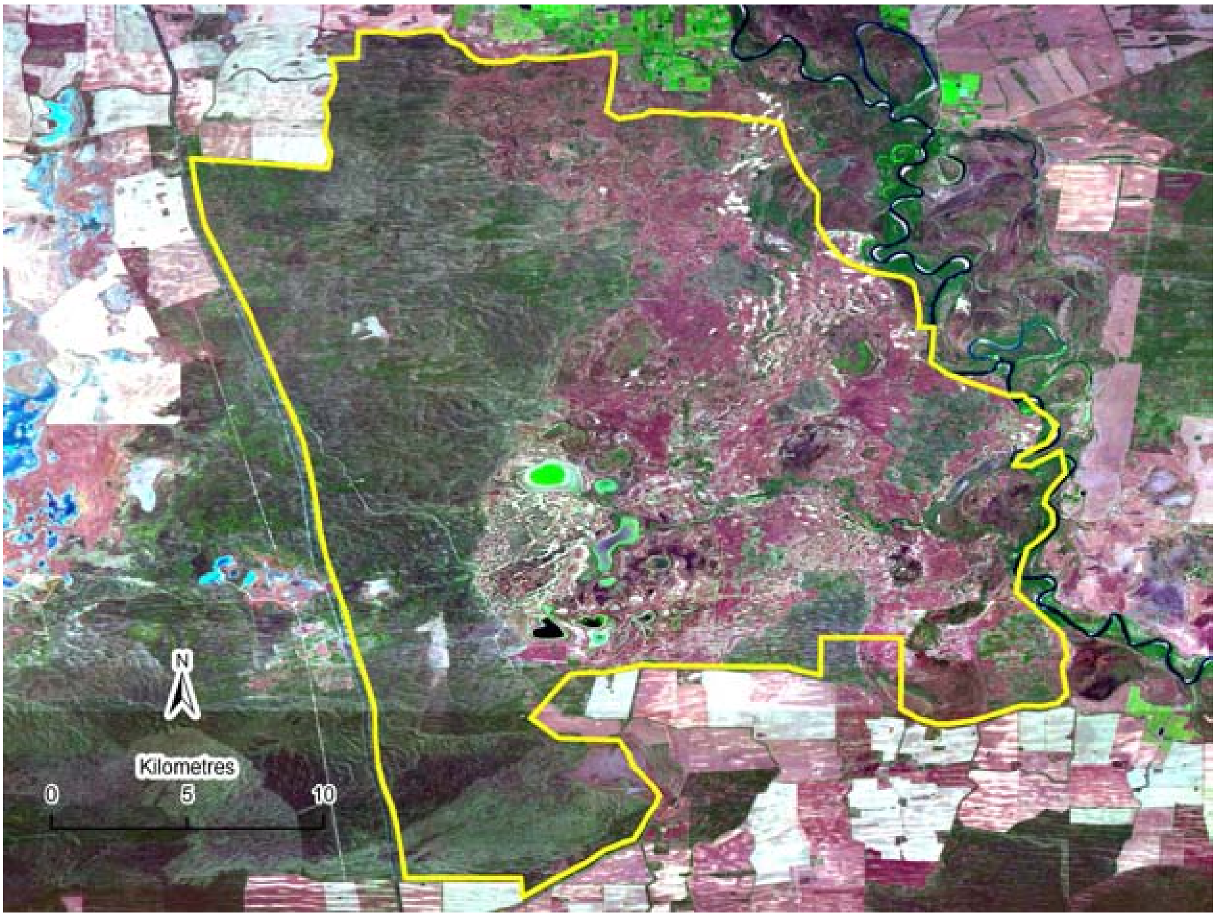

Figure 7-4. Satellite image of Hattah Lakes

Chowilla Floodplain and Lindsay-Wallpolla Islands

The combined Chowilla Floodplain and Lindsay-Wallpolla Islands (MDBC, 2006d) (Figure 7-5) are broad floodplains largely in South Australia and Victoria with a small area that extends into New South Wales. The total area is around 45,000 ha of which about 25,000 ha are in Victoria and about 20,000 ha are in South Australia. Chowilla Floodplain and associated anabranch system is part of the 30,600 ha Ramsar-listed Riverland wetland which is also listed on the national and state directories of important wetlands. The floodplain contains a mix of southern and northern Australian ecosystems and species.

Chowilla Floodplain has 28 plant species of state significance, four animal species of national significance and 23 animal species of state significance. Lindsay and Wallpolla islands have two plant species of national significance and 51 of state significance. They support 27 animal species of national significance and 37 annual species of state significance. Five species of waterbird using the islands are protected under international migratory bird agreements.

There is extensive evidence of occupation by Indigenous people for 12,000 years as many cultural sites remain. The area is also used for a wide range of activities including farming, grazing, recreation, hunting and tourism. Most of the area is crown land. Chowilla Floodplain is a game reserve and part of the Bookmark Biosphere Reserve. Other parts of the floodplain are national park and forest reserve.

The Icon Site environmental management plan (MDBC, 2006d) identifies flows to achieve environmental objectives for this system that range from 5 to 100 GL/day at the South Australian border. There is negligible increase in floodplain area inundated for flows that exceed 140 GL/day (MDBC, 2006d). The Murray-Darling Basin Commission recommended that a flow threshold of 50 GL/day for 90 days at the South Australian border during August to January be used in this assessment.

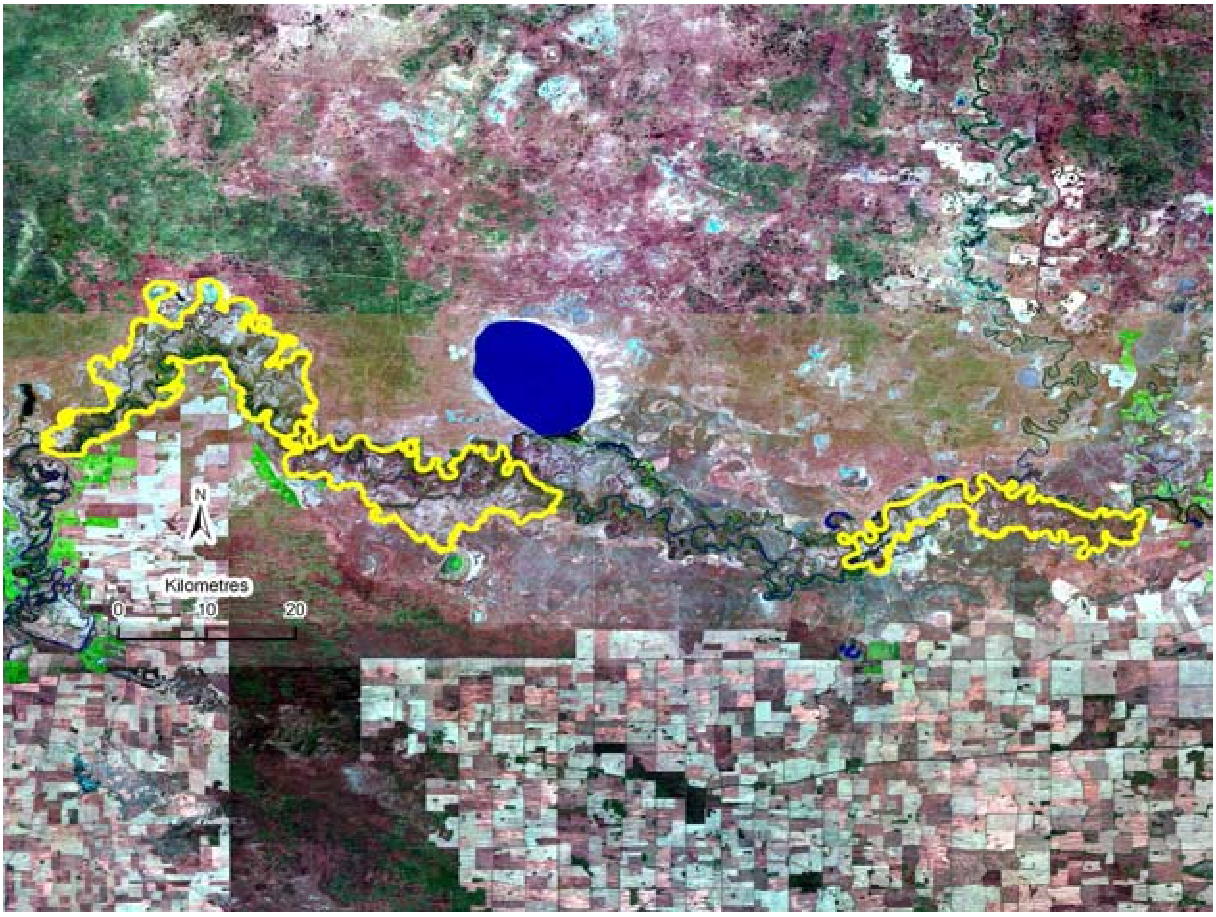

Figure 7-5. Satellite image of Chowilla Floodplain and Lindsay-Wallpolla Islands

Lower Lakes, Coorong and Murray Mouth

The Lower Lakes, Coorong and Murray Mouth (MDBC, 2006e; Figure 7-6) are important for breeding and feeding of many species of waterbirds and native fish. The Lower Lakes (Lakes Albert and Alexandrina) are isolated from the Murray mouth and the Coorong by barrages. The Coorong is about 140 km long and covers 660 km^2. The Coorong includes the Murray estuary (incorporating the Murray mouth and connection with the Southern Ocean), the northern lagoon and the southern lagoon. The area provides habitat for over 85 species of waterbirds and supports over half of the waterbirds found in South Australia. It is ranked amongst the top six waterbird sites in Australia based on species diversity and abundance (MDBC 2006e). Much of the area is wetland and is nationally important. The Coorong and Lakes Alexandrina and Albert are Ramsar-listed.

The Coorong is one of the most important archaeological sites for Indigenous culture in Australia. Over 6000 sites have been found and some date to nearly 6000 years ago. The Coorong became part of an important transport route between Adelaide and Melbourne after European settlement. The area is now very important for a wide range of recreational activities and recreational and commercial fishing. Grazing and farming is also undertaken over large areas of the area margin. Most of the area is crown land and the Coorong lagoons are national park and aquatic reserve.

The River Murray Water Allocation Plan (RCMWMB, 2004) recommends a minimum delivery during spring and early summer of 600 GL (20 GL/day at the barrages) over a consecutive 30-day period to be provided six years out of ten. The Murray-Darling Basin Commission confirmed the 20 GL/day flow (MDBC, 2006e) and recommended that 20 GL/day for 30 days during the period September to February be used in this assessment.

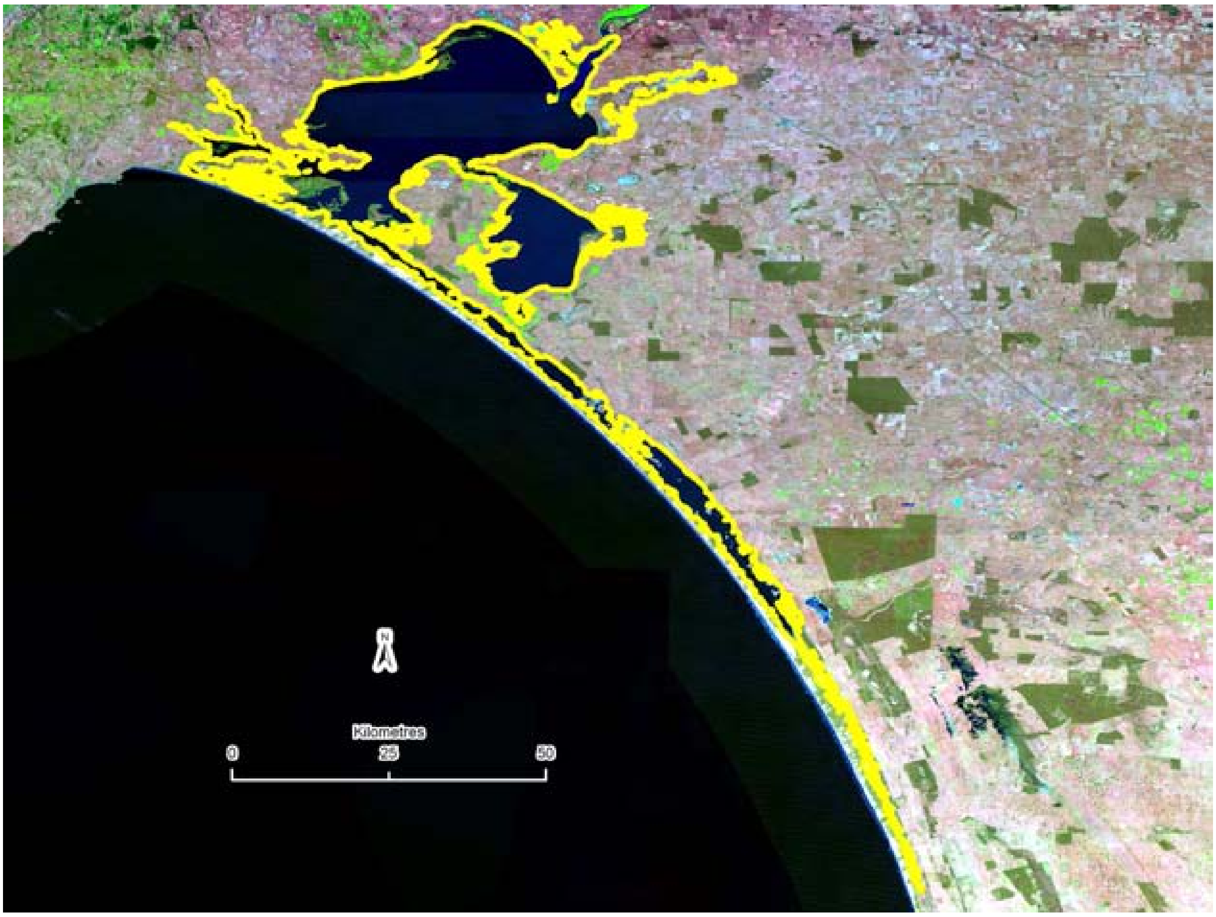

Figure 7-6. Satellite image of Lower Lakes, Coorong and Murray Mouth

Lower Darling River and associated Darling Anabranch Lakes (NSW020)

The following description is from Environment Australia (2001). The Darling Anabranch Lakes are located on the Great Anabranch of the Darling River (Figure 7-7). Comprising some 14 lakes and associated river channel and marginal vegetation, the wetlands cover around 269,000 ha. The Anabranch is a former channel of the Darling River that receives floodwater from the lower Darling River. The upstream lakes receive floodwater and fill prior to the lakes at the downstream end of the Anabranch. The Anabranch also receives a stock and domestic release from Menindee Lakes restricted to the Anabranch channel only.

The vegetation surrounding the lakes is dominated by Black Box *(Eucalyptus largiflorens*), Nitre Goosefoot (*Chenopodium nitraceum*) and Lignum (*Muelhlenbeckia florulenta)*. Several species of native fish are recorded including Golden Perch (*Macquaria ambigua*), Murray Cod (*Maccullochella peelii peelii*) and Bony Bream (*Nematalosa erebi*). The lakes support many species and large numbers of waterbirds.

The lakes have particular importance for occupation by Indigenous people and sites and artefacts exist particularly in the lake lunettes. The land tenure is Western Lands lease with the exception of Nearie Lake which is a nature reserve. Land use is primarily grazing and lake bed cropping is common following floods.

The Great Darling Anabranch has two main inflow points from the Darling River:

- an offtake some 100 km downstream of Menindee. The commence-to-flow level for this off-take is 12 GL/day at Weir 32
- Tandou Creek that has a commence-to-flow level of 20 GL/day at Weir 32 (R. Cooke, NSW Department of Water and Energy, pers. comm.).

Commence-to-flow levels for the Anabranch lakes are confounded by the construction of block banks across the channels into the lakes. These banks were constructed to prevent inflows to the lakes by 'stock and domestic replenishment release' historically provided to Anabranch landholders. The hydrology of the lakes system including how each lake is inundated in flood events is not well understood and no published information was discovered that describes the hydrological relationships with inflows from the Darling River. The Murray-Darling Basin Commission recommended that 12 GL/day for 14 days at Weir 32 during the period August to January be used in this assessment.

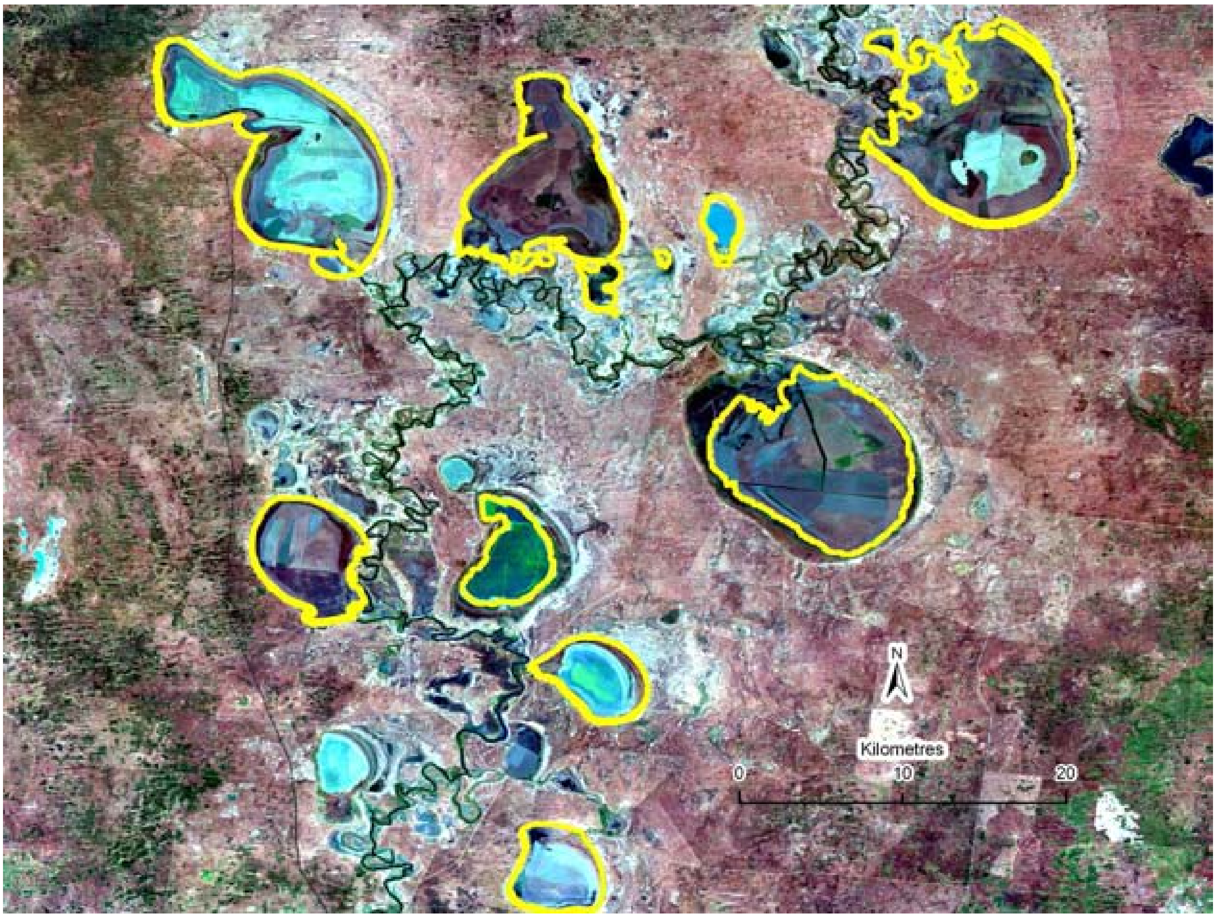

Figure 7-7. Satellite image of Lower Darling River – Darling Anabranch Lakes

Table 7-1. Definition of environmental indicators. Flood volume indicators are the volumes above the threshold specified in the event definition

Flow event description	Flow event definition	Indicators reported
Barmah-Millewa Forest		
Beneficial spring–summer flood	Flows exceeding 18.3 GL/day for 60 days Aug–Dec at Yarrawonga Weir	Average period between floods
		Maximum period between floods
		Average flood volume per year
		Average flood volume per event
Gunbower-Koondrook-Perricoota Forest		
Beneficial spring–summer flood	Flows exceeding 30 GL/day for 30 days Aug–Jan at Torrumbarry Weir	Average period between floods
		Maximum period between floods
		Average flood volume per year
		Average flood volume per event
Hattah Lakes		
Beneficial spring–summer flood	Flows above 36.7 GL/day for 60 days Aug–Jan at Euston Weir	Average period between floods
		Maximum period between floods
		Average flood volume per year
		Average flood volume per event
Chowilla Floodplain and Lindsay-Wallpolla Islands		
Beneficial spring–summer flood	Flows above 50 GL/day for 90 days Aug–Jan at SA border	Average period between floods
		Maximum period between floods
		Average flood volume per year
		Average flood volume per event
Lower Lakes, Coorong and Murray Mouth		
Beneficial spring–summer flood	Flows above 20 GL/day for 30 days Sept–Feb at Barrages	Average period between floods
		Maximum period between floods
		Average flood volume per year
		Average flood volume per event
Lower Darling River and associated Darling Anabranch Lakes		
Beneficial spring–summer flood	Flows above 12 GL/day for 14 days Aug–Jan at Weir 32	Average period between floods
		Maximum period between floods
		Average flood volume per year
		Average flood volume per event

7.3 Results

The projected changes in the environmental indicators are listed by scenario in Table 7-2. These were assessed using the outputs from the river model for the Murray region (Chapter 4) at the specified locations. The South Australian environmental water provisions are not included in the hydrological modelling.

Additional volumes of environmental water (beyond what is currently represented in the river model) will be made available under the Living Murray Initiative. The indicators (and the scenario impacts) represent a commencement point for the Initiative assessments and the provision of water to the Living Murray Icon Sites could be quite different in the future with the implementation of new water management infrastructure and additional environmental water.

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

	P	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Barmah-Millewa Forest	years		percent change from Scenario A						
Average period between floods	1.8	3.5	30%	40%	13%	-1%	42%	13%	0%
Maximum period between floods	4.7	10.9	211%	219%	95%	0%	254%	95%	0%
	GL								
Average flood volume per year	1217	291	-81%	-93%	-49%	10%	-94%	-52%	6%
Average flood volume per event	1947	905	-75%	-91%	-43%	9%	-91%	-45%	6%
Gunbower-Koondrook-Perricoota Forest	years								
Average period between floods	1.7	3.8	30%	35%	15%	1%	35%	17%	1%
Maximum period between floods	4.8	11.8	219%	228%	77%	0%	228%	77%	0%
	GL								
Average flood volume per year	680	118	-90%	-96%	-52%	-6%	-96%	-54%	-8%
Average flood volume per event	1016	401	-87%	-94%	-45%	-6%	-95%	-46%	-8%
Hattah Lakes	years								
Average period between floods	1.6	3.7	35%	38%	12%	-7%	38%	14%	-4%
Maximum period between floods	4.6	11.7	223%	231%	9%[1]	-18%	231%	82%[1]	-17%
	GL								
Average flood volume per year	2379	403	-88%	-93%	-52%	23%	-93%	-55%	17%
Average flood volume per event	3373	1326	-84%	-91%	-46%	15%	-91%	-48%	12%
Chowilla Floodplain & Lindsay-Wallpolla Islands	years								
Average period between floods	2.4	9.3	502%	502%	101%	-30%	502%	101%	-25%
Maximum period between floods	5.7	28.7	113%	113%	21%	-26%	113%	21%	_-26%
	GL								
Average flood volume per year	2431	947	-71%	-83%	-42%	37%	-84%	-44%	33%
Average flood volume per event	2226	836	-74%	-85%	-45%	27%	-86%	-47%	22%
Lower Lakes, Coorong & Murray Mouth	years								
Average period between floods	1.2	2.2	37%	51%	10%	-5%	53%	12%	-6%
Maximum period between floods	1.7	5.8	121%	185%	35%	0%	185%	35%	0%
	GL								
Average flood volume per year	4389	885	-77%	-89%	-44%	27%	-89%	-46%	25%
Average flood volume per event	4820	1740	-69%	-83%	-38%	21%	-84%	-40%	17%
Lower Darling River & associated Darling Anabranch Lakes	years								
Average period between floods	2.7	8.3	1%	7%	4%	-4%	7%	4%	-4%
Maximum period between floods	9.2	22.7	0%	26%	26%	-17%	26%	26%	-17%
	GL								
Average flood volume per year	211	44	-2%	-51%	-28%	73%	-53%	-30%	69%
Average flood volume per event	513	326	-1%	-48%	-25%	66%	-49%	-28%	62%

[1] The marked difference between the Cmid and Dmid values for Hattah Lakes is a result of small changes in event duration and/or magnitude being sufficient to cross the flow threshold or duration criteria used to define flood events. These values should be treated with caution.

7.4 Discussion of key findings

The hydrological changes associated with water resource development and those anticipated due to future climate change are discussed below for each of the environmental assets. In all cases, the hydrologic changes resulting from water resource development have been major and are associated with the significant declines that have been observed in these flood-dependent ecosystems.

7.4.1 Barmah-Millewa Forest

Water resource development has nearly doubled the average period between beneficial flooding of Barmah-Millewa Forest and more than doubled the maximum period between events. The volume of flood events has more than halved so that the flooding volume per year is less than one-quarter of the value for without-development conditions. MDBC (2006a) states that water resources development has manifested in reducing the flood return frequency and inundation duration to the major vegetation communities and associated fauna in the forest.

Under Scenario B the average period between floods increase by 30 percent (to nearly 5 years) and the maximum period between floods would more than treble to be 34 years. Under the recent climate, flood volumes per event would be reduced by 75 percent to be only 12 percent of the without-development event volumes. The flooding volume per year would be reduced by more than 80 percent to be only 5 percent of the without-development event volumes. Reductions in groundwater levels under the Barmah State Forest of around 1.0 m would be expected (Chapter 6). These hydrological changes would have serious consequences for the vegetation and faunal communities of the forest.

Under Scenario Cmid the changes in flood frequency and volume would be less extreme than under a long-term continuation of the recent climate. The average period between floods would increase by 13 percent (to be nearly four years) and the maximum period would increase by 95 percent (to be 21 years). Similarly, the average annual flood volume would be nearly halved to be only 12 percent of the without-development average annual flood volume for the historical climate. Reductions in groundwater levels under the Barmah State Forest of around 1.0 m would be expected. These hydrological changes would be expected to cause further degradation of the vegetation and faunal communities of the forest.

Under the extreme 2030 climates the frequency and volumes of flooding are very different to the under Scenario Cmid. Under Scenario Cwet the periods between floods would not change greatly. Flood volumes would increase by a relatively small amount. However, under Scenario Cdry the average period between floods would increase more than under Scenario B conditions, to be close to five years. Flood volumes under Scenario Cdry conditions would reduce by more than 90 percent, such that the average annual flood volume would be only 2 percent of the without-development value under the historical climate. Reductions in groundwater levels under the Barmah State Forest of around 1.4 m would be expected. These hydrological changes would place severe stress on the vegetation communities of Barmah-Millewa Forest.

The aspects of future development considered under Scenario D would have relatively minor impacts on the flooding regime of the Barmah-Millewa Forest Icon Site. The main change associated with Scenario D would be further drops in groundwater levels (up to 2.0 m; Chapter 6) due to increased groundwater extraction.

7.4.2 Gunbower-Koondrook-Perricoota Forest

The flood events assessed for the Gunbower-Koondrook-Perricoota forests have a similar without-development frequency to the floods assessed for Barmah-Millewa Forest, and floods assessed for both locations have suffered the same changes in frequency as a result of water resource development. Thus the assessed floods for the Gunbower-Koondrook-Perricoota forests occur only half as often as under without-development conditions. Not surprisingly, flood volumes here have also been reduced in a similar proportion to further upstream, such that average annual flood volumes are now only 17 percent of what they were under without-development conditions under the historical climate. MDBC (2006b) identifies reductions in a range of flooding events for the forests of between 55 to 77 percent due to water resources development and states that ‘hydrological changes has altered faunal habitat and contributed to lower recruitment rates due the loss of the natural breeding and nesting signals for native fish, birds, aquatic plants and insects’.

Under Scenario B, the average period between floods would increase by 30 percent to be around 5 years while the maximum period between floods would increase greatly to be around 38 years. Annual flood volumes would reduce by 90 percent to be only 2 percent of the without-development flood volume under the historical climate. Reductions in groundwater levels under the Koondrook-Perricoota Forests of 0.3 m to 0.7 m would be expected (Chapter 6).

Under Scenario Cmid the average period between floods would increase by 15 percent to be two and a half times the average period under without-development conditions for the historical climate. The maximum period between floods would increase by 77 percent to be more than four times longer than under without-development conditions under the historical climate. The average annual flood volume would be reduced by 52 percent to be only 8 percent of the average annual volume under without-development conditions under the historical climate. These hydrological changes would have serious consequences for the vegetation and fauna communities of the forest.

Under the extreme 2030 climates the frequency and volumes of flooding are very different to under Scenario Cmid. Under Scenario Cwet the periods between floods would be unaffected and flood volumes would only decrease slightly. However, under Scenario Cdry, and as for Barmah-Millewa Forest, the average period between floods would be increased more than under Scenario B conditions to be more than five years. Flood volumes under Cdry conditions would reduce by well over 90 percent to be a mere 1 percent of the without-development flood volumes under the historical climate. Reductions in groundwater levels under Koondrook-Perricoota Forest of 0.5 m to more than 2.0 m would be expected (Chapter 6). These hydrological changes would have serious consequences for the vegetation and fauna communities of the forest.

The aspects of future development considered under Scenario D would have only minor impacts on the flooding regime of the Gunbower-Koondrook-Perricoota Forest Icon Site. The main change associated with Scenario D would be a further drop in groundwater levels (over 1.0 m; Chapter 6) due to increased groundwater extraction.

7.4.3 Hattah Lakes

The flood events assessed for the Hattah Lakes have a similar without-development frequency to the floods assessed for the Red Gum Forests upstream and these three locations have experienced roughly the same changes in frequency as a result of water resource development. For Hattah Lakes, this includes the impacts of structural works on Chalka Creek.

The assessed floods for the Hattah Lakes occur less than half as often as under without-development conditions. The average annual flood volumes to the Hattah Lakes have also been reduced in a similar proportion to further upstream, with flood volumes now only 17 percent of what they would be under without-development conditions under the historical climate. MDBC (2006c) identifies a 57 percent reduction in the frequency and 65 percent reduction in the duration of some flooding events due to water resources development and the works on Chalka Creek.

Under Scenario B the average period between floods would be increased by 35 percent to close to five years and the maximum period between floods would more than triple to around 38 years. Average annual flood volumes would reduce by 88 percent to be only 2 percent of the without-development flood volume under Scenario A.

Under Scenario Cmid the average period between floods would increase by 38 percent to be two and a half times the average period of without-development conditions under Scenario A. The average annual flood volume would be halved to be 8 percent of the volume under without-development conditions under Scenario A. These additional hydrological changes would be expected to have adverse consequences for the fauna and vegetation communities that these lakes support.

Under the extreme 2030 climates the frequency and volumes of flooding are very different to under Scenario Cmid. Under Scenario Cwet the periods between floods and the flood volumes would be largely unaffected. However, under Scenario Cdry the average period between floods would increase somewhat more than under Scenario B conditions to be a little over 27 years. Average annual flood volumes under Scenario Cdry would reduce by over 90 percent to be a mere 1 percent of the without-development flood volumes under Scenario A. Under this hydrological regime the lakes would receive very little water and would be dry most of the time.

The aspects of future development considered under Scenario D would have only minor additional impacts on the flooding regime of the Hattah Lakes.

7.4.4 Chowilla Floodplain and Lindsay-Wallpolla Islands

The flood events assessed for the Chowilla Floodplain have slightly reduced pre-development frequencies to the floods assessed for the Red Gum Forests further upstream, most likely due to the increased duration (90 days) of the Chowilla events. At Chowilla, the average period between these assessed floods has nearly quadrupled as a result of water resource development, and the maximum period between floods is close to five times the without-development value. The flood volumes to the Chowilla floodplain have also been reduced in a similar proportion to further upstream, with average annual flood volumes now only 39 percent of what they would be under without-development conditions under Scenario A. MDBC (2006d) identifies that under pre-development conditions floods of 80 GL/day occurred once every two years on average but occur about once every eight years under current development conditions. This has resulted in losses of native fauna, reduced exchange of organic carbon and nutrients between the river and floodplain and reduced diversity of waterbirds and terrestrial native fauna (MDBC, 2006d).

Under Scenario B the average period between floods would increase greatly to be nearly 56 years; the maximum period between floods would also increase greatly to be more than 61 years. Average annual flood volumes would reduce by nearly over 70 percent to be only 11 percent of the without-development flood volume under Scenario A.

Under Scenario Cmid the average period between floods would nearly double and the average annual flood volume would be reduced by more than 40 percent to be 23 percent of the volume under without-development conditions under Scenario A. These hydrological changes would be expected to have adverse consequences for the vegetation communities of Chowilla Floodplain and Lindsay-Wallpolla islands.

Under the extreme 2030 climates the frequency and volumes of flooding are very different to under Scenario Cmid. Under Scenario Cwet the flooding regime would be wetter than current development conditions under the historical climate. However, under Scenario Cdry and as for the floodplain forests upstream, the average period between floods would be quite similar to Scenario B conditions. The average annual flood volume under Scenario Cdry would reduce by nearly 80 percent to be only 6 percent of the without-development flood volumes under the historical climate. Under this hydrological regime these floodplain systems would receive very little water and major degradation of the vegetation communities would result.

The aspects of future development considered under Scenario D would have only minor additional impacts on the flooding regime of Chowilla Floodplain and Lindsay and Wallpolla islands.

7.4.5 Lower Lakes, Coorong and Murray Mouth

Water resource development has increased the average period between the assessed beneficial floods from 1.2 to 2.2 years and the maximum period between events has increased from less than two to nearly six years. Equally the average event volume of has been reduced by nearly 70 percent and the average annual volume by around 80 percent. MDBC (2006e) assessed the average annual flow at the barrages to be 27 percent of that under without-development conditions (Chapter 4 shows mean annual flow at the barrages is 39 percent of that under without-development conditions). These changes in flow have resulted in an 80 percent reduction in the area of the Murray estuary, a severe salinity gradient change across the barrages and degraded inter-tidal habitats (MDBC, 2006e).

Under Scenario B the average period between floods would increase to be three years; the maximum period between floods would increase to be nearly 13 years. The average annual flood volume would reduce by 77 percent to be only 5 percent of the without-development flood volume under Scenario A.

Under Scenario Cmid the average period between floods would increase slightly to be double the without-development value under the historical climate. The average annual flood volume would reduce by 38 percent to be 11 percent of the volume under without-development conditions under Scenario A. These hydrological changes would be expected to have adverse consequences for the aquatic communities of the Lower Lakes and the Coorong.

Under the extreme 2030 climates the frequency and volumes of flooding are very different to under Scenario Cmid. Under Scenario Cwet the flood frequency would be similar to current development conditions under Scenario A, the average annual flood volume would increase by 27 percent. However, under Scenario Cdry the average period between floods would increase to be over three years. The average annual flood volume under Scenario Cdry would reduce by 89 percent to be only 2 percent of the without-development flood volumes under Scenario A. Under this hydrological regime the Lower Lakes and Coorong would be expected to change dramatically in ecological character, with the Coorong likely to become a permanently hyper-saline environment supporting a greatly reduced diversity of fauna.

The aspects of future development considered under Scenario D would have no significant additional impacts on the flooding regime of the Lower Lakes, Coorong and Murray Mouth.

7.4.6 Lower Darling River and associated Darling Anabranch Lakes

Water resource development has more than trebled the average period between flooding of the Lower Darling river and the Darling Anabranch Lakes to be over eight years, and has more than doubled the maximum period between floods which is now nearly 23 years. The volume of these flood events has been reduced by 39 percent such that the average annual flood volume is now only 21 percent of the volume under without-development conditions. These changes are likely to have had serious consequences for the ecology of the Anabranch and associated lakes.

Under Scenario B neither the flood frequency nor volumes would be affected reflecting that fact that the recent climate in the Darling Basin has not been significantly different to Scenario A.

Under Scenario Cmid the average period between floods would increase slightly and the average annual flood volume would reduce by 28 percent to be 15 percent of the volume under without-development conditions under Scenario A. These hydrological changes would be expected to have some adverse ecological consequences for the Anabranch and associated lakes.

Under the extreme 2030 climates the frequency and volumes of flooding are very different to under Scenario Cmid. Under Scenario Cwet the flood frequency would increase to be closer to current development conditions under Scenario A and the average annual flood volume would also increase significantly. However, under Scenario Cdry the average period between floods would increase to be close to nine years. The average annual flood volume under Scenario Cdry would reduce by half, such that flood event volumes would be 10 percent of the without-development flood volumes under Scenario A. These latter hydrological changes would be expected to have major ecological consequences for the Anabranch and associated lakes.

The aspects of future development considered under Scenario D would have no significant additional impacts on the flooding regime of the Darling Anabranch and associated lakes.

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					
4012011	5623	1008	1160	215	21%	25%	-18%	-40%	-4%	-13%	4%	6%
4012041	1091	1142	1179	240	21%	5%	-18%	-32%	-4%	-10%	2%	1%
4012111	72	1135	1146	411	36%	1%	-19%	-32%	-4%	-10%	2%	1%
4012240	3614	1091	1094	311	29%	23%	-19%	-37%	-4%	-10%	2%	1%
4015600	247	1639	1018	702	43%	4%	-14%	-27%	-4%	-11%	4%	7%
4015610	492	1097	1137	283	26%	3%	-16%	-31%	-4%	-11%	3%	3%
4015650	212	1436	1061	929	65%	4%	-13%	-15%	-4%	-4%	6%	10%
4015710	53	1353	1062	452	33%	0%	-14%	-29%	-4%	-12%	6%	12%
4022052	1710	1171	1183	263	22%	9%	-18%	-44%	-4%	-14%	2%	1%
4042101	825	431	1296	16	4%	0%	-19%	-46%	-4%	-11%	6%	15%
4042105	1181	423	1306	18	4%	0%	-19%	-44%	-4%	-8%	6%	15%
4072160	431	359	1312	9	2%	0%	-20%	-47%	-4%	-7%	6%	15%
4090161	3996	866	1237	102	12%	8%	-19%	-42%	-4%	-13%	5%	12%
4090423	258	704	1260	44	6%	0%	-19%	-43%	-4%	-12%	6%	18%
4090582	2061	410	1328	16	4%	1%	-20%	-44%	-4%	-8%	7%	16%
4142001	13539	390	1324	13	3%	4%	-20%	-43%	-4%	-8%	6%	15%
4142003	1664	350	1315	8	2%	0%	-20%	-46%	-4%	-7%	6%	15%
4265273	3652	445	1215	19	4%	1%	-17%	-36%	-6%	-15%	4%	8%
4265326	21312	276	1399	3	1%	1%	-21%	-40%	-3%	0%	7%	21%
4265327	51437	229	1464	3	1%	3%	-18%	-33%	-3%	0%	10%	36%
4265328	49829	232	1387	3	1%	3%	-19%	-39%	-2%	4%	9%	27%
4265329	44423	308	1312	4	1%	4%	-20%	-41%	-3%	0%	5%	13%
	207723	**340**	**1362**	**24**	**7%**	**100%**	**-19%**	**-37%**	**-3%**	**-10%**	**6%**	**7%**

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 from Scenario A		
4012011	215	16154	415	0.1	-41%	-15%	4%
4012041	240	1172	1	0.0	-33%	-11%	0%
4012111	411	0	0	0.0	-32%	-10%	1%
4012240	311	6437	9	0.0	-37%	-11%	0%
4015600	702	0	42	0.2	-27%	-11%	6%
4015610	283	100	83	0.2	-31%	-11%	3%
4015650	929	0	35	0.2	-15%	-4%	10%
4015710	452	0	9	0.2	-29%	-12%	12%
4022052	263	1284	383	0.2	-45%	-14%	0%
4042101	16	0	71	0.1	-46%	-11%	15%
4042105	18	0	152	0.1	-44%	-9%	15%
4072160	9	0	0	0.0	-47%	-7%	15%
4090161	102	5302	875	0.2	-44%	-14%	10%
4090423	44	0	17	0.1	-43%	-12%	18%
4090582	16	0	1294	0.6	-45%	-11%	13%
4142001	13	0	7543	0.6	-45%	-11%	12%
4142003	8	0	6	0.0	-46%	-7%	15%
4265273	19	0	0	0.0	-36%	-15%	8%
4265326	3	0	0	0.0	-40%	-1%	21%
4265327	3	0	0	0.0	-33%	0%	36%
4265328	3	2551	0	0.0	-39%	4%	27%
4265329	4	0	0	0.0	-41%	1%	13%
	24	**33000**	**10934**	**0.1**	**-38%**	**-11%**	**6%**

Appendix B River modelling reach mass balances

Upstream of Albury

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	-33.3	63%	6%	37%	66%	12%	41%	66%
Inflows								
Releases from Snowy Scheme	1164	-22%	4%	-5%	-18%	4%	-5%	-18%
Directly gauged	4098	-25%	4%	-12%	-39%	2%	-14%	-40%
Indirectly gauged	0							
Groundwater Inflows	0							
Sub-total	5263	-24%	4%	-11%	-34%	3%	-12%	-35%
Diversions								
NSW diversions	0.1	-21%	1%	-8%	-33%	0%	-9%	-34%
Vic diversions	14.6	-4%	0%	-1%	-15%	0%	-1%	-16%
Sub-total	14.7	-4%	0%	-1%	-15%	0%	-1%	-16%
Outflows								
End-of-system outflow								
Albury flow	5205	-24%	4%	-11%	-34%	3%	-12%	-35%
Losses								
Net evaporation	77	-16%	4%	10%	1%	3%	9%	0%
River groundwater loss	0							
Sub-total	5281	-24%	4%	-10%	-34%	3%	-11%	-35%
Unattributed fluxes								
Total	-0.01	-343%	23%	-69%	59%	-125%	124%	-85%
Mass balance error (%)	0%							

Albury to Yarrawonga

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	-0.7	-17%	0%	-5%	-22%	2%	-6%	-23%
Inflows								
Upstream Model inputs								
Mainstem flow at Albury	5205	-24%	4%	-11%	-34%	3%	-12%	-35%
Ovens at Peechelba	1752	-27%	2%	-13%	-46%	1%	-14%	-46%
Sub-total	6956	-25%	3%	-11%	-37%	2%	-12%	-38%
Subcatchments								
Directly gauged	0							
Indirectly gauged	0							
Groundwater Inflows	0.6	-100%	99%	-40%	-100%	64%	-52%	-100%
Sub-total	6957	-25%	3%	-11%	-37%	2%	-12%	-38%
Diversions								
NSW diversions	1194.5	-24%	1%	-8%	-34%	0%	-9%	-35%
Vic diversions	468.3	-7%	0%	-2%	-20%	0%	-2%	-21%
Sub-total	1662.8	-19%	1%	-7%	-30%	0%	-7%	-31%
Outflows								
End-of-system outflow								
Yarrawonga flow	5115.3	-29%	5%	-14%	-42%	4%	-15%	-42%
Other escaped flows	225.0	-9%	-4%	1%	-17%	-2%	0%	-19%
Losses								
Net evaporation	-46.1	-167%	29%	-95%	-211%	21%	-100%	-212%
River groundwater loss	0							
Sub-total	5294.1	-27%	4%	-13%	-39%	3%	-14%	-40%
Unattributed fluxes								
Total	0.6	-96%	94%	-38%	-97%	61%	-50%	-97%
Mass balance error (%)	0%							

Yarrawonga to Torrumbarry

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	-0.4	-24%	-5%	-22%	-18%	8%	-23%	-18%
Inflows								
Upstream Model inputs								
Mainstem flow at Yarrawonga	5115	-29%	5%	-14%	-42%	4%	-15%	-42%
Goulburn-Broken-Campaspe inflow	1909	-57%	-5%	-22%	-60%	-6%	-22%	-61%
Sub-total	7025	-36%	2%	-16%	-47%	1%	-17%	-47%
Subcatchments								
Directly gauged	0							
Indirectly gauged	23.1	-11%	-1%	0%	-31%	-1%	0%	-33%
Groundwater Inflows	0							
Sub-total	7048	-36%	2%	-16%	-47%	1%	-17%	-47%
Diversions								
NSW diversions	73	-21%	0%	-8%	-34%	-1%	-8%	-35%
Vic diversions	922	-9%	0%	-2%	-21%	0%	-2%	-22%
Sub-total	995	-9%	0%	-2%	-22%	0%	-2%	-23%
Outflows								
End-of-system outflow								
Torrumbarry flow	4213	-37%	0%	-15%	-45%	-1%	-16%	-46%
Other escaped flows	1520	-47%	9%	-26%	-62%	7%	-27%	-63%
Losses								
Net evaporation	309	-54%	0%	-26%	-69%	-1%	-28%	-70%
River groundwater loss	10.5	-54%	-7%	-26%	-75%	2%	-16%	-68%
Sub-total	6053	-41%	2%	-18%	-51%	1%	-19%	-51%
Unattributed fluxes								
Total	-0.001	414%	166%	469%	-408%	186%	188%	-205%
Mass balance error (%)	0%							

Edward-Gulpa to Stevens Weir

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	-0.1	-38%	5%	-28%	-27%	13%	-29%	-27%
Inflows								
Upstream Model inputs								
Mainstem flow to Edward System	1520	-47%	9%	-26%	-62%	7%	-27%	-63%
	190	-9%	-4%	1%	-16%	-3%	0%	-19%
Sub-total	1710	-43%	7%	-23%	-57%	6%	-24%	-58%
Subcatchments								
Directly gauged	0							
Indirectly gauged	0							
Groundwater Inflows	0							
Sub-total	1710	-43%	7%	-23%	-57%	6%	-24%	-58%
Diversions								
NSW diversions	346	-22%	0%	-7%	-31%	-1%	-8%	-32%
Vic diversions	0							
Sub-total	346	-22%	0%	-7%	-31%	-1%	-8%	-32%
Outflows								
End-of-system outflow								
Stevens Weir flow	1248	-52%	10%	-29%	-69%	8%	-30%	-69%
Other escaped flows	118	0%	0%	0%	0%	0%	0%	0%
Losses								
Net evaporation	-2.5	412%	-51%	160%	600%	-28%	173%	617%
River groundwater loss	0.9	-18%	1%	-9%	-34%	0%	-9%	-35%
Sub-total	1364	-48%	9%	-27%	-64%	8%	-28%	-65%
Unattributed fluxes								
Total	0.0004	-75117%	100%	-25%	-32897%	5%	-53%	-30272%
Mass balance error (%)	0.0%							

Stevens Weir to Kyalite

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	0.0	-159%	49%	-135%	124%	33%	-116%	127%
Inflows								
Upstream Model inputs								
Mainstem Stevens Weir flow	1248	-52%	10%	-29%	-69%	8%	-30%	-69%
Billabong Creek inflow	329	-35%	13%	-11%	-34%	11%	-12%	-35%
Sub-total	1577	-49%	11%	-25%	-61%	9%	-27%	-62%
Subcatchments								
Directly gauged	0							
Indirectly gauged	995	-72%	-2%	-34%	-79%	-3%	-35%	-79%
Groundwater Inflows	0							
Sub-total	2571	-58%	6%	-29%	-68%	4%	-30%	-69%
Diversions								
NSW Diversions	70	-10%	0%	-3%	-18%	-1%	-3%	-19%
Vic Diversions	0							
Sub-total	70	-10%	0%	-3%	-18%	-1%	-3%	-19%
Outflows								
End-of-system outflow								
Kyalite flow	2160	-57%	6%	-29%	-67%	4%	-30%	-67%
Other escaped flows	0							
Losses								
Net evaporation	339	-73%	8%	-31%	-87%	6%	-34%	-88%
River groundwater loss	2	-66%	-6%	-41%	-77%	-7%	-41%	-75%
Sub-total	2501	-59%	6%	-29%	-69%	4%	-31%	-70%
Unattributed fluxes								
Total	0.0005	61516%	-105%	-99%	26799%	-14%	-154%	24631%
Mass balance error (%)	0.0%							

Torrumbarry to Wakool Junction

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	-0.1	-28%	3%	-33%	32%	6%	-30%	31%
Inflows								
Upstream model inputs								
Mainstem Torrumbarry flow	4213	-37%	0%	-15%	-45%	-1%	-16%	-46%
Kyalite inflow	2160	-57%	6%	-29%	-67%	4%	-30%	-67%
Sub-total	6374	-44%	2%	-20%	-52%	1%	-21%	-53%
Subcatchments								
Directly gauged	0							
Indirectly gauged	377	-26%	6%	-8%	-44%	6%	-9%	-45%
Groundwater Inflows	0							
Sub-total	6751	-43%	2%	-19%	-52%	1%	-20%	-53%
Diversions								
NSW diversions	97	-21%	0%	-8%	-34%	-1%	-8%	-35%
Vic diversions	60	-7%	1%	-1%	-17%	0%	-1%	-17%
Sub-total	156	-16%	0%	-5%	-27%	0%	-6%	-28%
Outflows								
End-of-system outflow								
Wakool Junction flow	5639	-40%	3%	-18%	-50%	2%	-19%	-50%
Other escaped flows	877	-82%	-2%	-39%	-89%	-4%	-40%	-90%
Losses								
Net evaporation	67	148%	19%	90%	174%	23%	92%	174%
River groundwater loss	12	-62%	-5%	-23%	-77%	-5%	-23%	-77%
Sub-total	6594	-44%	2%	-20%	-53%	1%	-20%	-53%
Unattributed fluxes								
Total	-0.001	554%	-151%	14%	-155%	-37%	-68%	-91%
Mass balance error (%)	0.0%							

Wakool Junction to Wentworth

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date				01/07/1895				
Model end date				30/06/2006				
			percent change from Scenario A					
Storage volume								
Change over period	-0.1	-63%	17%	-52%	21%	9%	-47%	20%
Inflows								
Upstream model inputs								
Mainstem Wakool Junction flow	5639	-40%	3%	-18%	-50%	2%	-19%	-50%
Murrumbidgee Balranald flow	1152	-54%	23%	-19%	-47%	21%	-21%	-49%
Darling Burtundy flow	852	1%	47%	-11%	-37%	43%	-14%	-39%
Sub-total	7643	-37%	11%	-17%	-48%	9%	-19%	-49%
Subcatchments								
Directly gauged	0							
Indirectly gauged	0							
Groundwater Inflows	0							
Sub-total	7643	-37%	11%	-17%	-48%	9%	-19%	-49%
Diversions								
NSW diversions	85	-15%	1%	-4%	-19%	0%	-5%	-19%
Vic diversions	329	-6%	0%	-1%	-15%	0%	-1%	-16%
Sub-total	414	-8%	0%	-1%	-16%	0%	-2%	-17%
Outflows								
End-of-system outflow								
Wentworth flow	7083	-40%	12%	-19%	-51%	10%	-20%	-52%
Other escaped flows	0							
Losses								
Net evaporation	146	-2%	3%	4%	10%	3%	4%	10%
River groundwater loss	0							
Sub-total	7229	-39%	11%	-18%	-50%	10%	-20%	-50%
Unattributed fluxes								
Total	-0.001	453%	-50%	2%	-69%	17%	8%	-87%
Mass balance error (%)	0.0%							

Menindee to Murray

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date				01/07/1895				
Model end date				30/06/2006				
				percent change from Scenario A				
Storage volume								
Change over period	0.0							
Inflows								
Upstream Model inputs								
Mainstem Weir 32 flow	1317	1%	55%	-11%	-39%	51%	-14%	-41%
Cawndilla outlet release	108	-5%	31%	-9%	-36%	28%	-11%	-37%
Sub-total	1425	0%	53%	-11%	-39%	49%	-14%	-41%
Subcatchments								
Directly gauged	0							
Indirectly gauged	0							
Groundwater Inflows	0							
Sub-total	1425	0%	53%	-11%	-39%	49%	-14%	-41%
Diversions								
NSW diversions	65	-3%	26%	-9%	-37%	24%	-11%	-38%
Vic diversions	0							
Sub-total	65	-3%	26%	-9%	-37%	24%	-11%	-38%
Outflows								
End-of-system outflow								
Darling Burtundy flow	852	1%	47%	-11%	-37%	43%	-14%	-39%
Anabranch outflows	184	-2%	110%	-14%	-50%	103%	-17%	-52%
Losses								
Net evaporation	324	0%	42%	-11%	-39%	39%	-14%	-40%
River groundwater loss	0							
Sub-total	1361	0%	54%	-11%	-39%	50%	-14%	-41%
Unattributed fluxes								
Total	-0.01	2%	-72%	-103%	103%	-86%	-63%	195%
Mass balance error (%)	0.0%							

Wentworth to Rufus River

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/07/1895							
Model end date	30/06/2006							
		percent change from Scenario A						
Storage volume								
Change over period	0.0	-44%	34%	-45%	101%	5%	-36%	105%
Inflows								
Upstream Model inputs								
Mainstem Wentworth flow	7083	-40%	12%	-19%	-51%	10%	-20%	-52%
Anabranch outflows	184	-2%	110%	-14%	-50%	103%	-17%	-52%
Sub-total	7267	-39%	14%	-19%	-51%	12%	-20%	-52%
Subcatchments								
Directly gauged	0							
Indirectly gauged	0							
Groundwater Inflows	0							
Sub-total	7267	-39%	14%	-19%	-51%	12%	-20%	-52%
Diversions								
NSW diversions	15	-23%	2%	-8%	-32%	1%	-8%	-33%
Vic diversions	91	-4%	0%	0%	-9%	0%	0%	-9%
Sub-total	106	-7%	0%	-1%	-12%	0%	-2%	-13%
Outflows								
End-of-system outflow								
Flow to South Australia	6679	-40%	15%	-19%	-54%	13%	-21%	-55%
Other escaped flows	0							
Losses								
Net evaporation	482	-26%	10%	-11%	-21%	9%	-11%	-21%
River groundwater loss	0							
Sub-total	7161	-39%	14%	-19%	-51%	13%	-20%	-52%
Unattributed fluxes								
Total	-0.002	933%	-29%	299%	-95%	-17%	191%	72%
Mass balance error (%)	0.00%							

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.

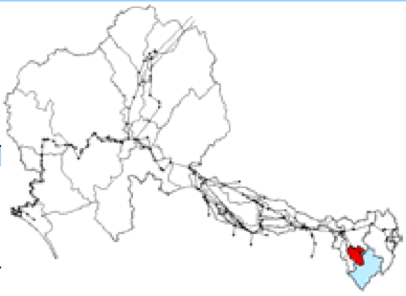
Table	Description
Change-uncertainty ratios	Information on the significance of the projected changes under different scenarios, considering the performance of the river model in explaining observed flow patterns at the end of the reach. In this table, the projected change is compared to the river model 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	401204 Mitta Mitta @ Tallandoon	Reach 1
Upstream gauge	401211 Mitta Mitta @ Colemans	

Reach length (km)	43
Area (km^2)	1091
Outflow/inflow ratio	1.37
Net gaining reach	

Land use	ha	%
Dryland	109,086	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006



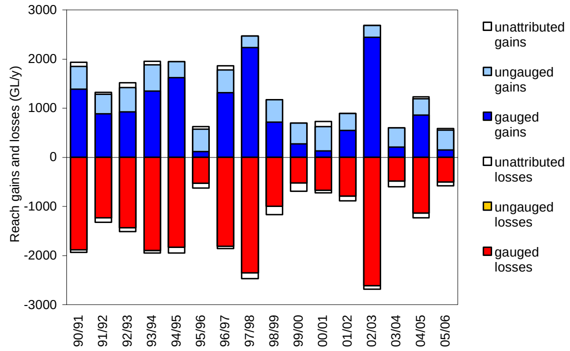
This is a strongly gaining reach. Flows are dominated by runoff immediately following rain.

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

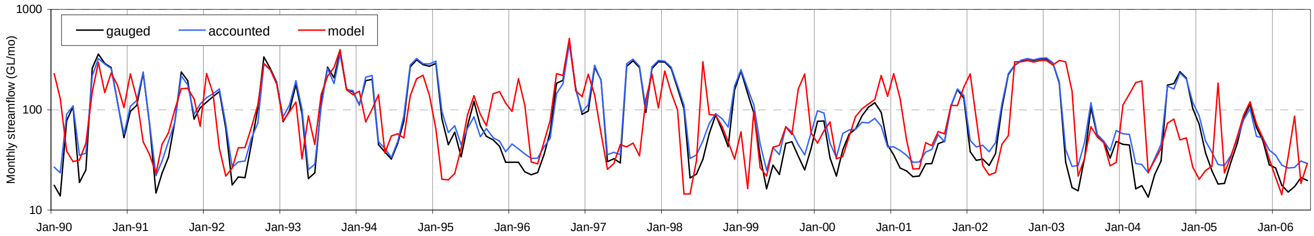
Baseline model performance is poor. Accounting explains observed flows extremely well.

The projected changes are generally greater than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.68	0.93	0.81
Attributed	0.97	0.93	0.95
Fraction of variance			
Gauged	0.93	1.00	0.96
Attributed	0.99	1.00	0.99



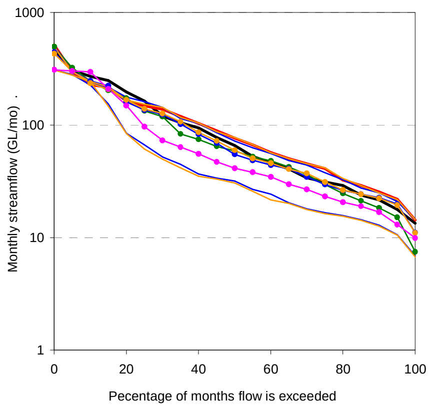
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.07	-0.10	-0.01	-0.05	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.36	-0.36	-0.01	-0.02	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.94**	**-0.93**	-0.06	-0.09	Adjusted 5.5%



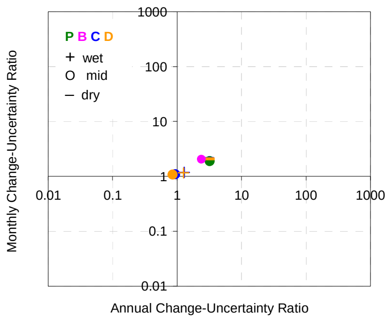
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	936	946	-10
Tributary inflows	0	0	0
Local inflows	0	403	-403
Unattributed gains and noise	-	38	-38
Losses	GL/y	GL/y	GL/y
Main stem outflows	1285	1294	-10
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	93	-93
	-349	0	-349

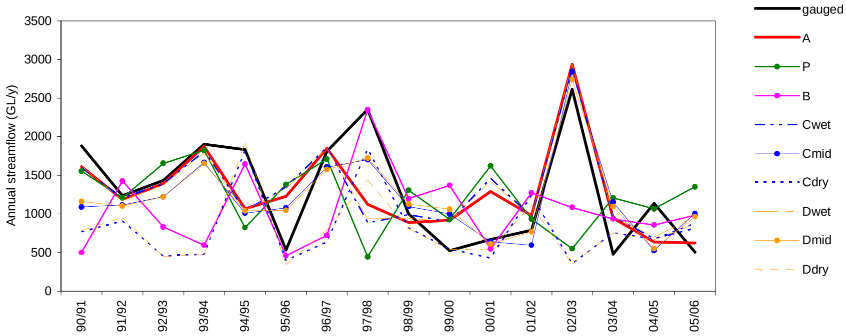
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.29	0.98
Log-normalised	0.17	0.93
Ranked	0.08	0.98
Low flows only	<0	<0
High flows only	<0	0.86
Annual		
Normal	0.48	0.98
Log-normalised	0.39	0.96
Ranked	0.32	0.94

Definitions:
- low flows (flows<10% percentile) : 21.6 GL/mo
- high flows (flows>90% percentile) : 270.1 GL/mo



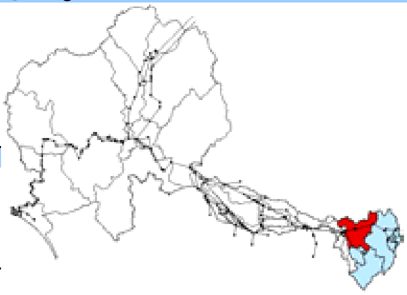
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.2	2.4	1.3	0.9	3.1	1.3	0.9	3.1
Monthly streamflow	1.9	2.1	1.2	1.1	2.1	1.2	1.1	2.1





Downstream gauge	409016 Murray @ D/S Hume Dam (Heywoods)	Reach 2
Upstream gauge	401201 Murray @ Jingellic	

Reach length (km)	167
Area (km^2)	3996
Outflow/inflow ratio	1.61
Net gaining reach	



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

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

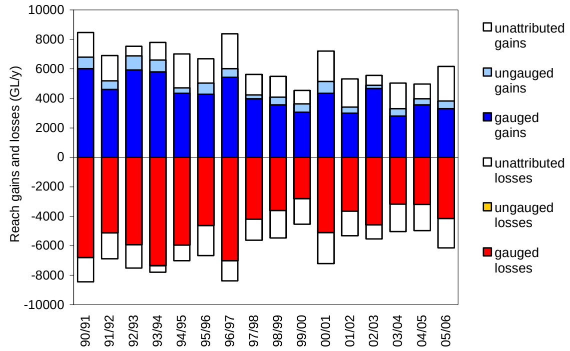
This reach is not modelled. Accounting also explains observed flows extremely well.

There are no projected changes from modelling.

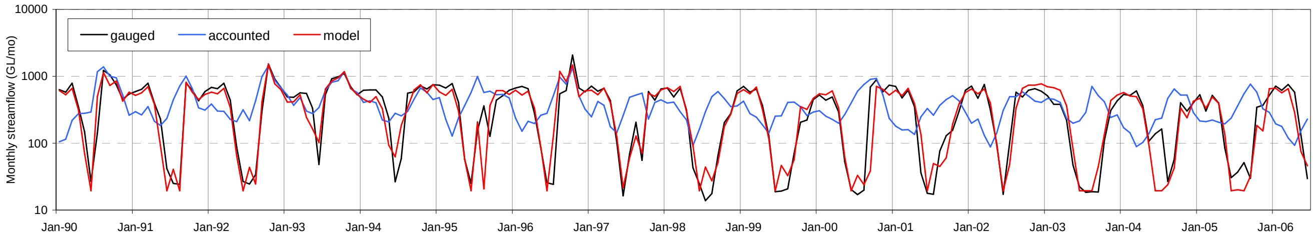
Land use	ha	%
Dryland	379,564	95
Irrigable area	-	-
Open water*	-	-
River and wetlands	20,030	5
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.67	0.75	0.71
Attributed	0.76	0.75	0.76
Fraction of variance			
Gauged	0.59	0.40	0.49
Attributed	0.55	0.40	0.47



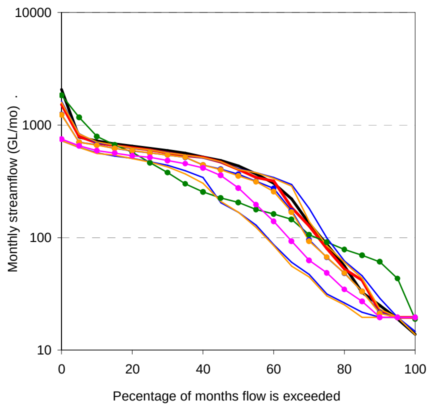
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.35	-0.57	-0.47	-0.53	
Tributary inflows	-0.02	-0.00	-0.06	-0.02	
Main gauge outflows	-0.69	-0.72	-0.61	-0.72	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.27	-0.37	-0.47	-0.46	Adjusted 9.1%



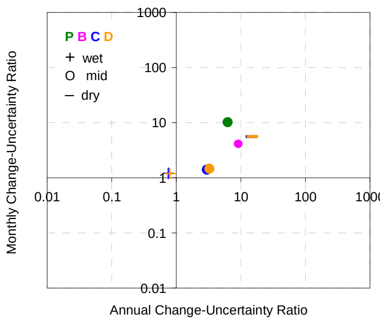
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	2900	2992	-92
Tributary inflows	0	1294	-1294
Local inflows	0	565	-565
Unattributed gains and noise	-	1563	-1563
Losses	GL/y	GL/y	GL/y
Main stem outflows	4629	4832	-203
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	3	-3
Unspecified losses	0	-	0
Unattributed losses and noise	-	1579	-1579
	-1729	0	-1729

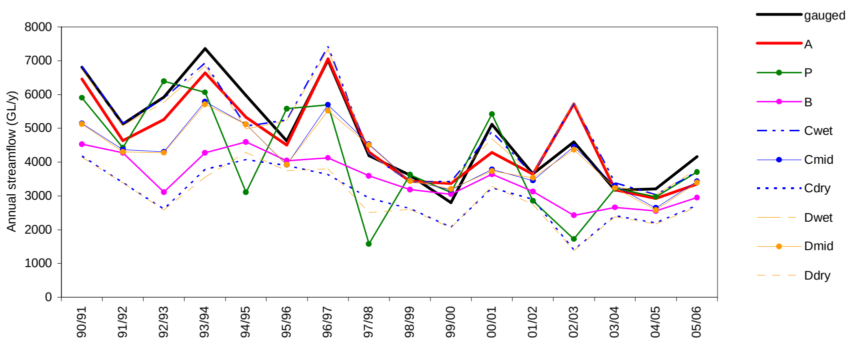
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.83	<0
Log-normalised	0.82	<0
Ranked	0.79	<0
Low flows only	<0	<0
High flows only	0.69	<0
Annual		
Normal	0.85	0.81
Log-normalised	0.83	0.80
Ranked	0.81	0.76

Definitions:
- low flows (flows<10% percentile) : 24.9 GL/mo
- high flows (flows>90% percentile) : 721.4 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.3	9.1	0.8	3.0	14.6	0.8	3.2	15.0
Monthly streamflow	10.2	4.1	1.2	1.4	5.6	1.2	1.5	5.6



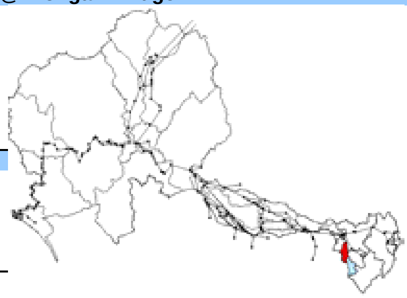


Downstream gauge	402222 Kiewa @ Kiewa Main Station	Reach 3
Upstream gauge	402203 Kiewa @ Mongan Bridge	

Reach length (km)	45
Area (km^2)	565
Outflow/inflow ratio	1.17
Net gaining reach	

Land use	ha	%
Dryland	56,531	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006



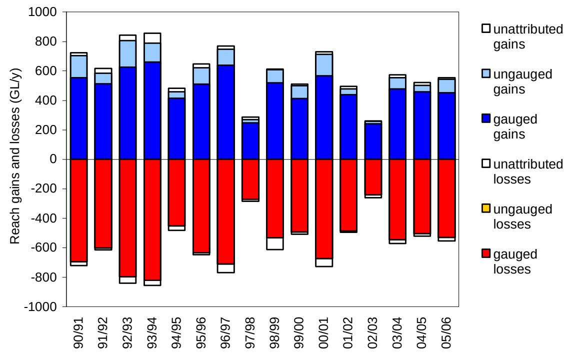
This is a strongly gaining reach. Flows are dominated by infows from upstream.

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

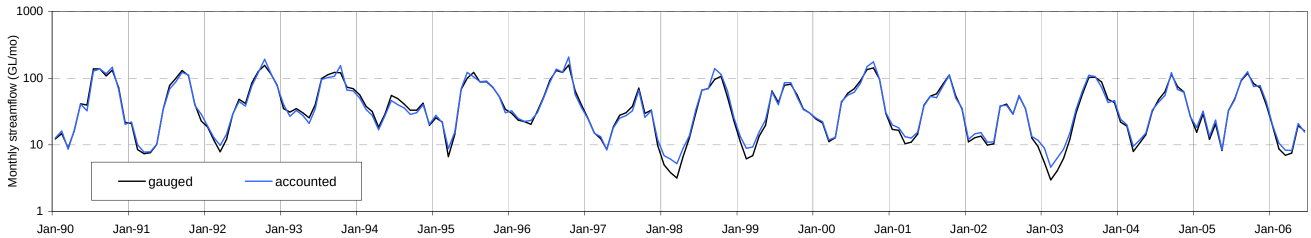
This reach is not modelled. Accounting also explains observed flows extremely well.

There are no projected changes from modelling.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.81	0.95	0.88
Attributed	0.96	0.95	0.96
Fraction of variance			
Gauged	0.94	0.97	0.96
Attributed	0.99	0.97	0.98



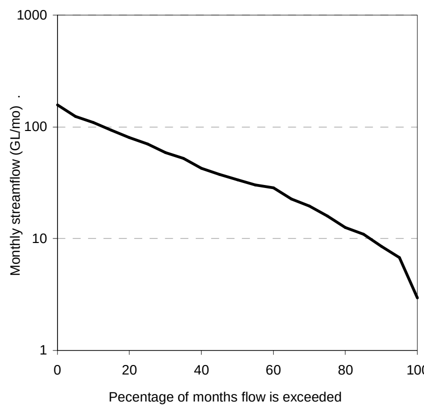
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.61	-0.78	-0.25	-0.28	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.76	-0.84	-0.12	-0.34	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.70	-0.83	-0.14	-0.35	Adjusted 6.8%



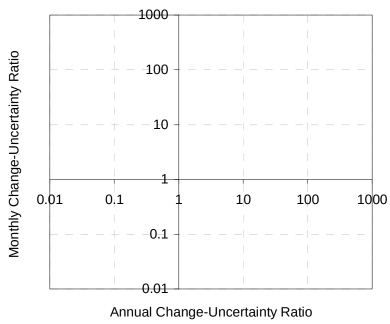
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	482	-482
Tributary inflows	0	0	0
Local inflows	0	88	-88
Unattributed gains and noise	-	22	-22
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	562	-562
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	30	-30
	0	0	0

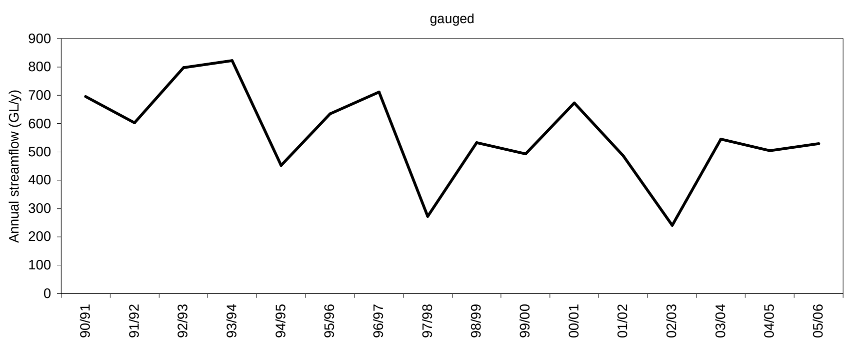
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.96
Log-normalised	-	-
Ranked	<0	0.99
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	<0	0.97
Log-normalised	-	-
Ranked	<0	0.97

Definitions:
- low flows (flows<10% percentile) : 8.5 GL/mo
- high flows (flows>90% percentile) : 109.4 GL/mo



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



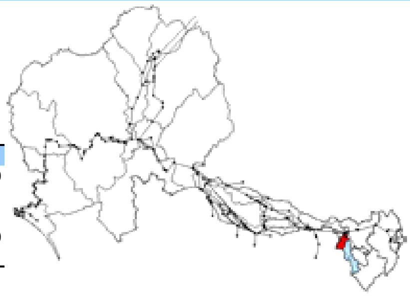


Downstream gauge	402205 Kiewa @ Bandiana	Reach 4
Upstream gauge	402222 Kiewa @ Kiewa Main Station	

Reach length (km)	16
Area (km^2)	563
Outflow/inflow ratio	1.18
Net gaining reach	

Land use	ha	%
Dryland	56,096	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	180	0
Open water*	-	-

* averages for 1990–2006



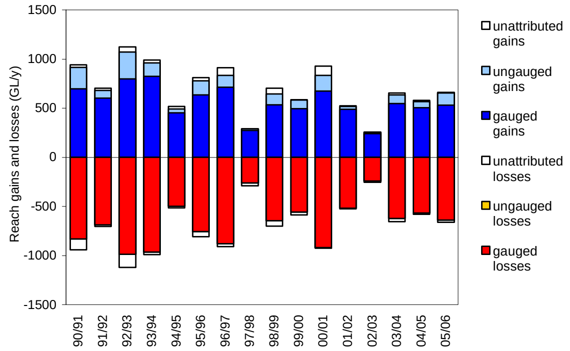
This is a gaining reach. Flows are dominated by inflows from upstream.

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

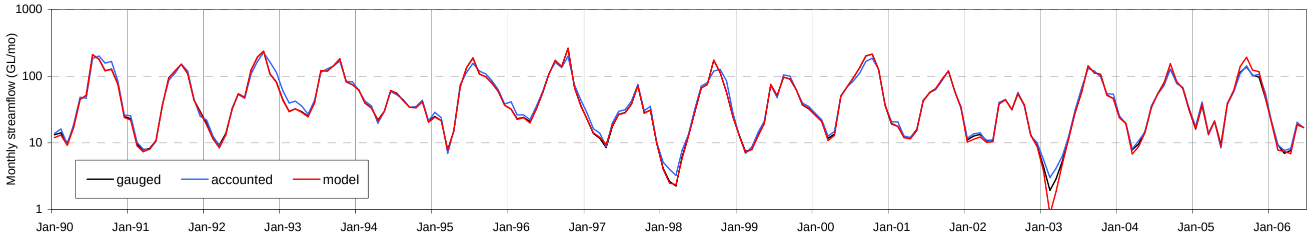
Baseline model performance is excellent. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.80	0.95	0.88
Attributed	0.96	0.95	0.95
Fraction of variance			
Gauged	0.89	0.98	0.94
Attributed	0.98	0.98	0.98



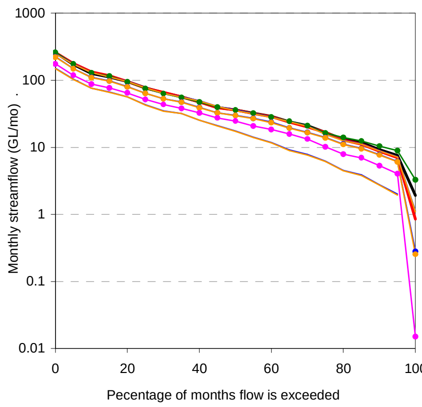
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.73	-0.76	-0.05	-0.21	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.87	-0.80	-0.03	-0.26	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.78	-0.80	-0.11	-0.25	Adjusted 107.5%



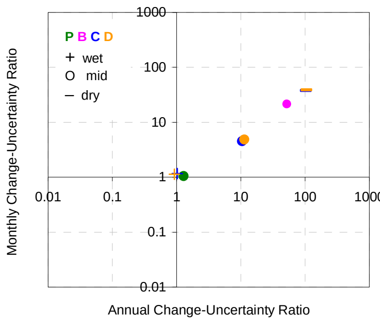
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	562	-562
Tributary inflows	0	0	0
Local inflows	0	107	-107
Unattributed gains and noise	-	29	-29
Losses	GL/y	GL/y	GL/y
Main stem outflows	668	661	7
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	37	-37
	-668	0	-668

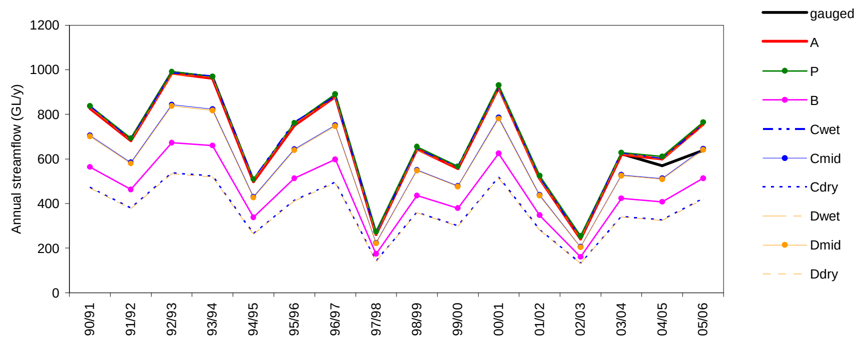
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.99	0.95
Log-normalised	0.99	0.98
Ranked	1.00	0.99
Low flows only	0.93	0.87
High flows only	0.88	0.51
Annual		
Normal	0.98	0.97
Log-normalised	0.99	0.98
Ranked	0.96	0.96

Definitions:
- low flows (flows<10% percentile) : 9.3 GL/mo
- high flows (flows>90% percentile) : 126.0 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.3	52.0	1.0	10.5	102.7	0.9	11.4	104.9
Monthly streamflow	1.1	21.5	1.2	4.5	38.0	1.1	4.9	38.8



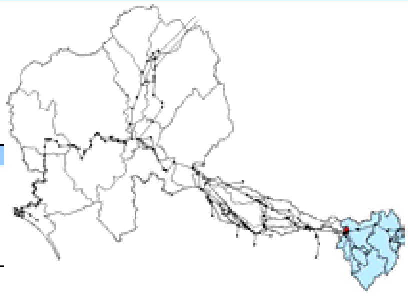


Downstream gauge	409017 Murray @ Doctor's Point	Reach 5
Upstream gauge	409016 Murray @ D/S Hume Dam (Heywoods)	

Reach length (km)	18
Area (km²)	164
Outflow/inflow ratio	1.12
Net gaining reach	

Land use	ha	%
Dryland	15,371	94
Irrigable area	-	-
Open water*	-	-
River and wetlands	980	6
Open water*	-	-

* averages for 1990–2006



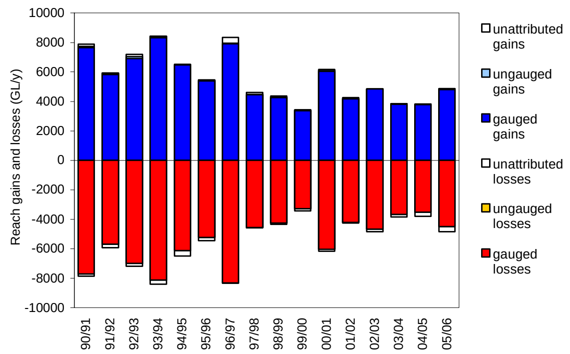
This is a gaining reach. Flows are dominated by inflows from upstream.

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

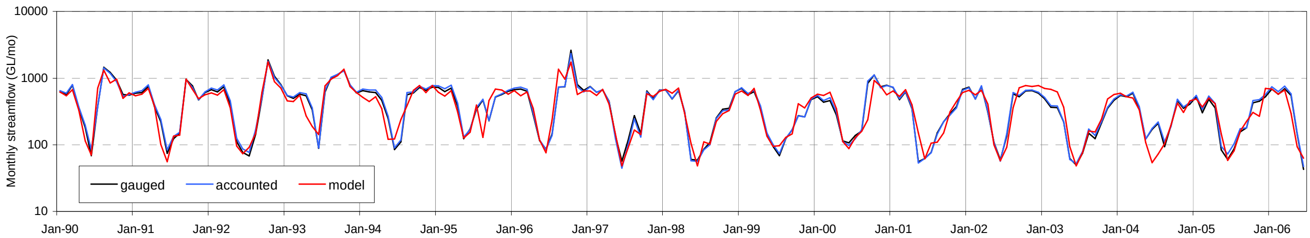
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

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



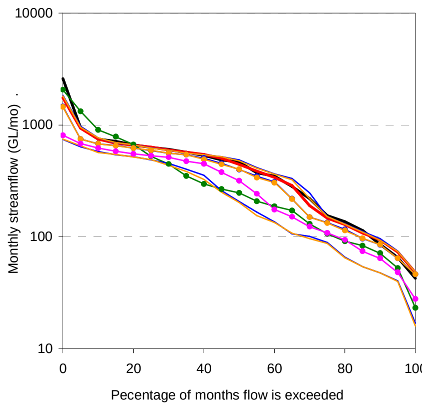
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.47	-0.06	-0.33	-0.41	
Tributary inflows	**-0.51**	-0.48	-0.36	-0.46	
Main gauge outflows	**-0.60**	-0.17	-0.19	-0.31	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.36	-0.38	-0.31	-0.35	Adjusted 538.9%



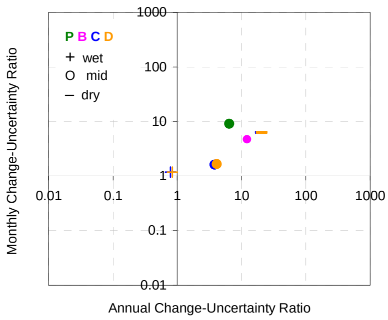
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	4629	4832	-203
Tributary inflows	0	661	-661
Local inflows	0	53	-53
Unattributed gains and noise	-	69	-69
Losses	GL/y	GL/y	GL/y
Main stem outflows	5297	5434	-137
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	1	-1
Unspecified losses	0	-	0
Unattributed losses and noise	-	180	-180
	-668	0	-668

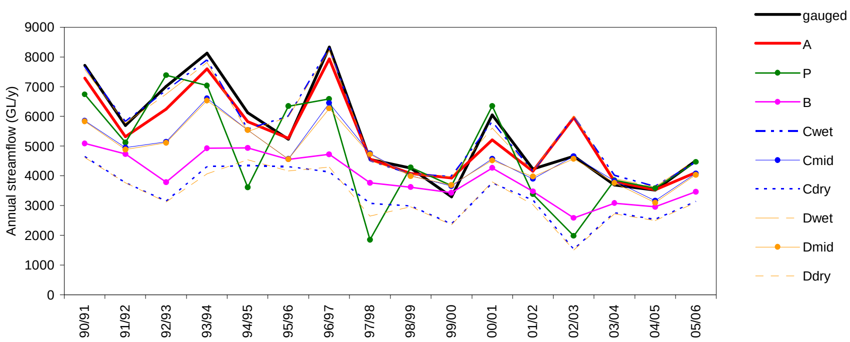
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.84	0.99
Log-normalised	0.87	0.99
Ranked	0.81	0.99
Low flows only	<0	0.73
High flows only	0.63	0.98
Annual		
Normal	0.89	0.98
Log-normalised	0.88	0.98
Ranked	0.89	0.98

Definitions:
- low flows (flows<10% percentile) : 85.8 GL/mo
- high flows (flows>90% percentile) : 745.9 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.4	12.2	0.8	3.8	19.9	0.8	4.1	20.5
Monthly streamflow	9.1	4.7	1.2	1.6	6.3	1.2	1.7	6.3



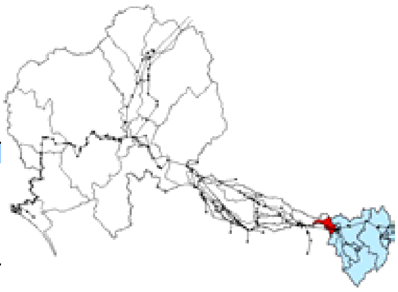


Downstream gauge	409002 Murray @ Corowa	Reach 6
Upstream gauge	409017 Murray @ Doctor's Point	

Reach length (km)	154
Area (km^2)	835
Outflow/inflow ratio	1.03
Net gaining reach	

Land use	ha	%
Dryland	79,947	96
Irrigable area	-	-
Open water*	-	-
River and wetlands	3,540	4
Open water*	-	-

* averages for 1990–2006



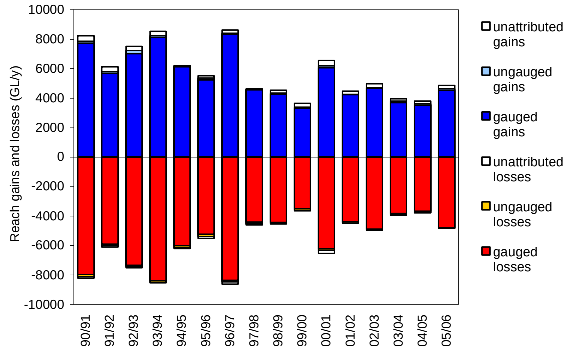
This is niether a gaining nor a losing reach. Flows are dominated by inflows from upstream.

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

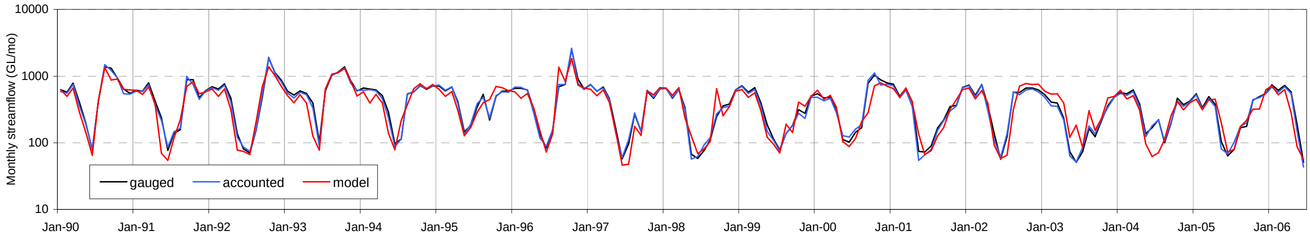
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

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



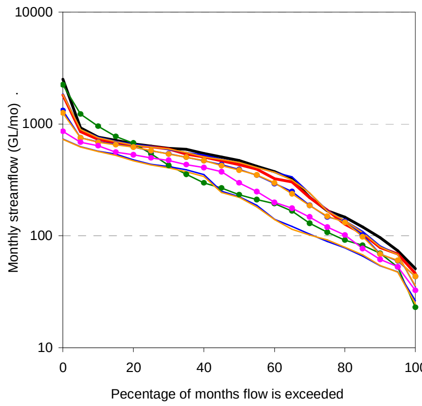
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.14	-0.10	-0.48	-0.33	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.22	-0.16	-0.42	-0.27	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.04	-0.06	-0.19	-0.02	Adjusted 159.5%



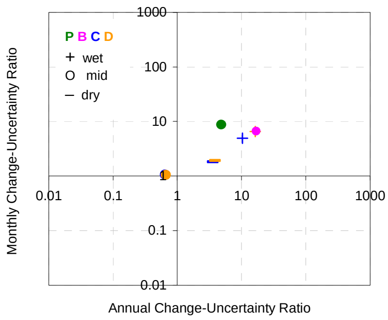
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5297	5434	-137
Tributary inflows	0	0	0
Local inflows	0	95	-95
Unattributed gains and noise	-	230	-230
Losses	GL/y	GL/y	GL/y
Main stem outflows	5218	5588	-370
Distributary outflows	0	0	0
Net diversions	0	85	-85
River flux to groundwater	0	-	0
River and floodplain losses	0	9	-9
Unspecified losses	0	-	0
Unattributed losses and noise	-	77	-77
	79	0	79

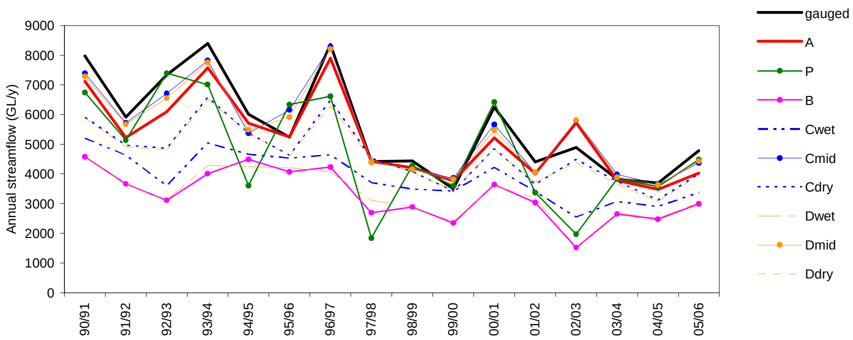
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.84	0.99
Log-normalised	0.84	0.99
Ranked	0.82	0.99
Low flows only	<0	0.30
High flows only	0.61	0.97
Annual		
Normal	0.85	0.99
Log-normalised	0.85	0.98
Ranked	0.86	0.98

Definitions:
- low flows (flows<10% percentile) : 96.2 GL/mo
- high flows (flows>90% percentile) : 763.8 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.8	10.4	0.6	3.6	16.4	0.7	3.8	16.9
Monthly streamflow	8.8	4.9	1.1	1.8	6.5	1.0	1.9	6.6



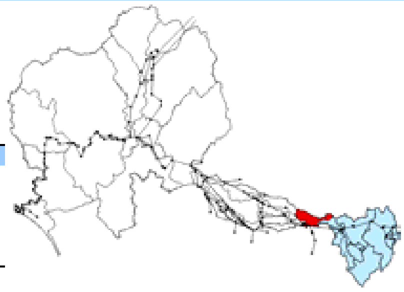


Downstream gauge	**409025 Murray @ Yarrawonga Weir**	**Reach 7**
Upstream gauge	**409002 Murray @ Corowa**	

Reach length (km)	109
Area (km^2)	1595
Outflow/inflow ratio	0.92
Net losing reach	

Land use	ha	%
Dryland	146,755	92
Irrigable area	-	-
Open water*	-	-
River and wetlands	12,770	8
Open water*	-	-

* averages for 1990–2006



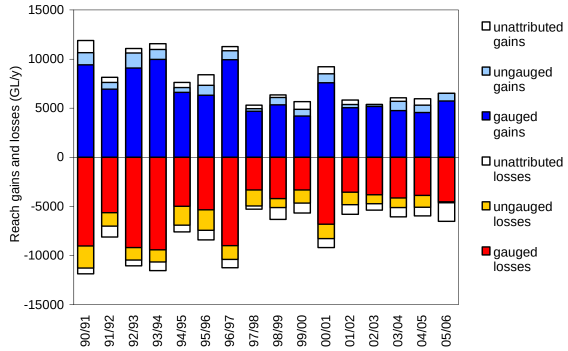
This is a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. Estimated local runoff explains some of the ungauged gains but a large adjustment was required. There are large recorded diversions and ungauged losses.

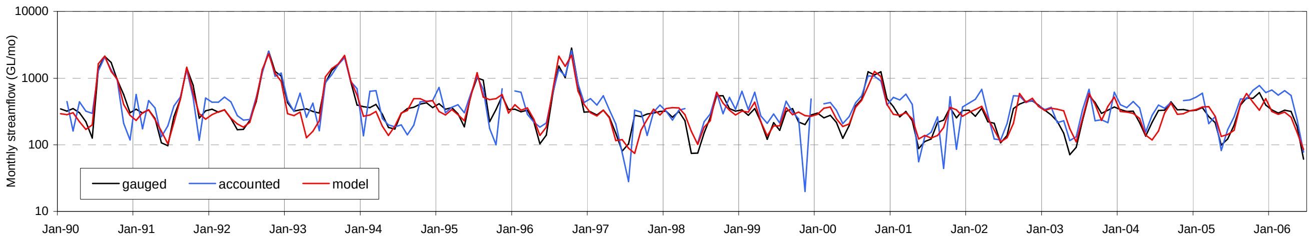
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are generally much greater than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.83	0.72	0.78
Attributed	0.93	0.89	0.91
Fraction of variance			
Gauged	0.91	0.91	0.91
Attributed	0.95	0.96	0.96



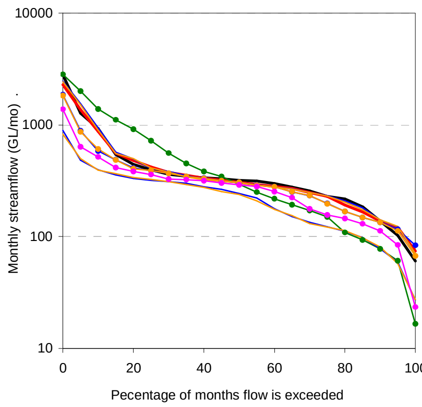
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.22	-0.07	-0.40	**-0.62**	
Tributary inflows	**-0.83**	**-0.66**	**-0.51**	**-0.59**	
Main gauge outflows	**-0.70**	-0.44	-0.21	-0.10	
Distributary outflows	-	-	-	-	
Recorded diversions	-0.39	**-0.53**	**-0.89**	**-0.90**	
Estimated local runoff	**-0.81**	**-0.63**	**-0.54**	**-0.66**	Adjusted 208.1%



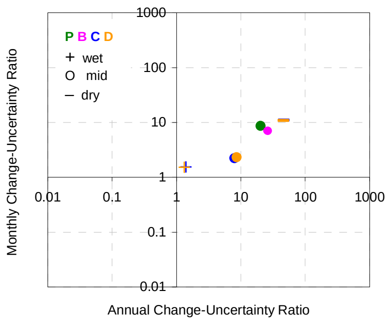
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5218	5588	-370
Tributary inflows	0	991	-991
Local inflows	0	781	-781
Unattributed gains and noise	-	519	-519
Losses	GL/y	GL/y	GL/y
Main stem outflows	5100	5137	-37
Distributary outflows	0	0	0
Net diversions	0	1803	-1803
River flux to groundwater	0	-	0
River and floodplain losses	0	37	-37
Unspecified losses	0	-	0
Unattributed losses and noise	-	901	-901
	118	0	118

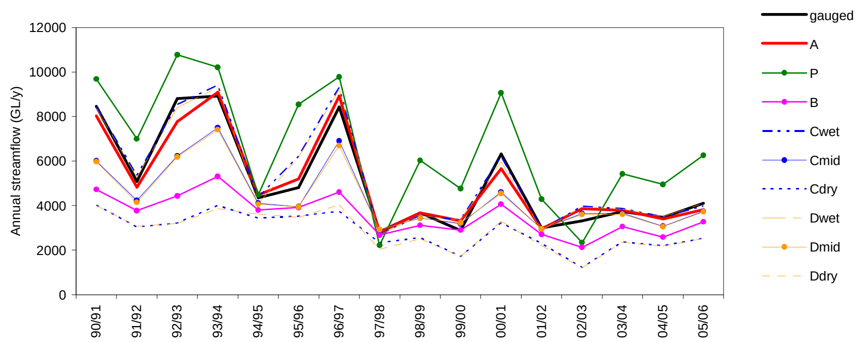
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.91	0.86
Log-normalised	0.84	-
Ranked	0.71	0.56
Low flows only	<0	<0
High flows only	0.67	0.90
Annual		
Normal	0.96	0.91
Log-normalised	0.96	0.88
Ranked	0.91	0.93

Definitions:
- low flows (flows<10% percentile) : 137.9 GL/mo
- high flows (flows>90% percentile) : 927.5 GL/mo



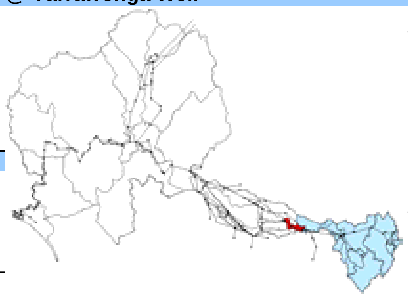
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	20.2	26.2	1.4	8.0	46.1	1.3	8.6	45.8
Monthly streamflow	8.6	7.0	1.5	2.2	11.0	1.5	2.3	10.9





Downstream gauge	409202 Murray @ Tocumwal	Reach 8
Upstream gauge	409025 Murray @ Yarrawonga Weir	

Reach length (km)	101
Area (km^2)	554
Outflow/inflow ratio	0.99
Net losing reach	



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

Most of the inflows are gauged. There are some recorded diversions and ungauged losses are small.

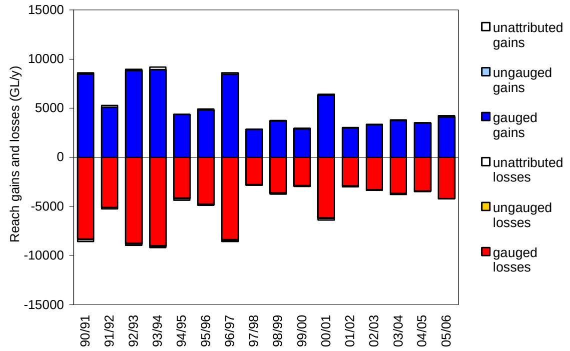
Baseline model performance is very good Accounting also explains observed flows extremely well.

The projected changes are generally greater than river model uncertainty.

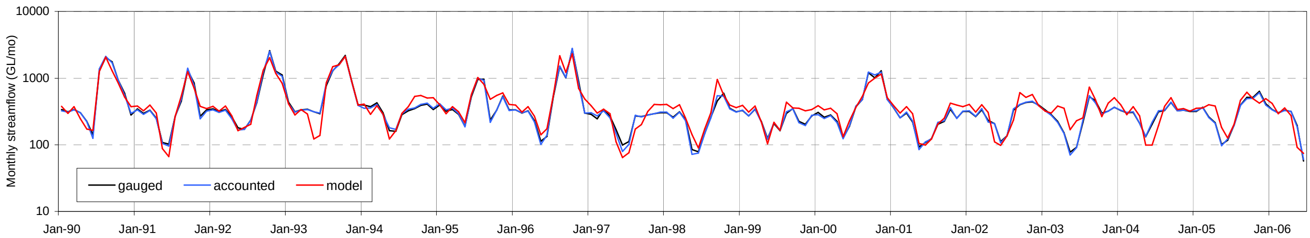
Land use	ha	%
Dryland	49,648	90
Irrigable area	-	-
Open water*	-	-
River and wetlands	5,780	10
Open water*	-	-

* averages for 1990–2006

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



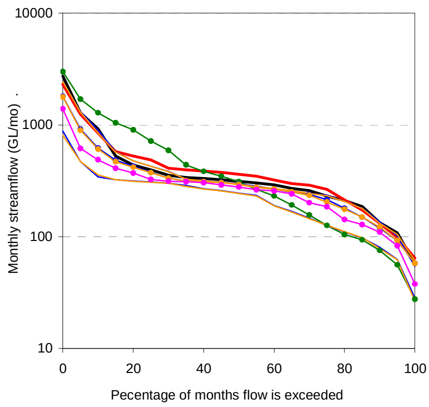
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.41	-0.08	-0.45	-0.40	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.45	-0.13	-0.40	-0.33	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.24	-0.20	-0.41	-0.05	Adjusted -100.0%



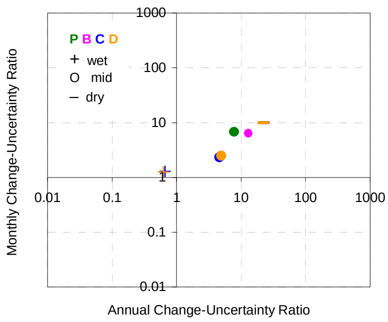
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5100	5137	-37
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	95	-95
Losses	GL/y	GL/y	GL/y
Main stem outflows	5374	5081	293
Distributary outflows	0	0	0
Net diversions	0	35	-35
River flux to groundwater	0	-	0
River and floodplain losses	0	27	-27
Unspecified losses	0	-	0
Unattributed losses and noise	-	89	-89
	-274	0	-274

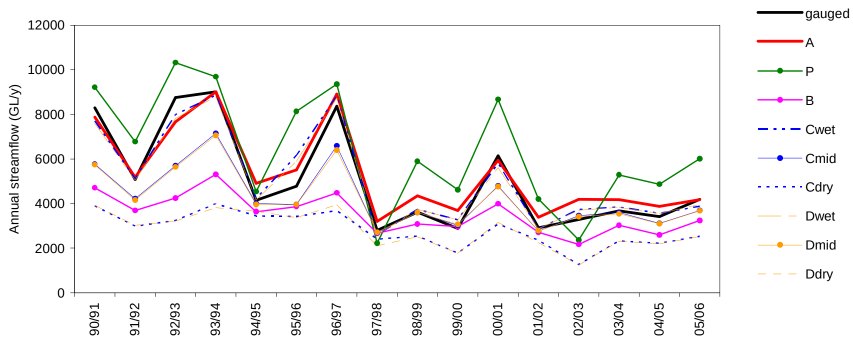
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.91	1.00
Log-normalised	0.83	0.99
Ranked	0.77	0.99
Low flows only	<0	0.86
High flows only	0.73	0.99
Annual		
Normal	0.93	1.00
Log-normalised	0.89	1.00
Ranked	0.89	0.99

Definitions:
- low flows (flows<10% percentile) : 133.7 GL/mo
- high flows (flows>90% percentile) : 924.9 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	7.8	12.9	0.7	4.6	22.2	0.6	4.9	22.1
Monthly streamflow	6.8	6.4	1.3	2.4	9.9	1.3	2.5	10.0



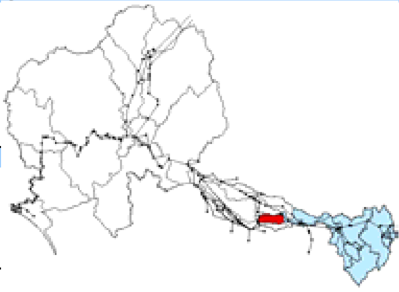


Downstream gauge	409006 Murray @ Picnic Point	Reach 9a
Upstream gauge	409202 Murray @ Tocumwal	

Reach length (km)	106
Area (km^2)	1116
Outflow/inflow ratio	0.47
Net losing reach	

Land use	ha	%
Dryland	75,690	68
Irrigable area	-	-
Open water*	-	-
River and wetlands	35,860	32
Open water*	-	-

* averages for 1990–2006



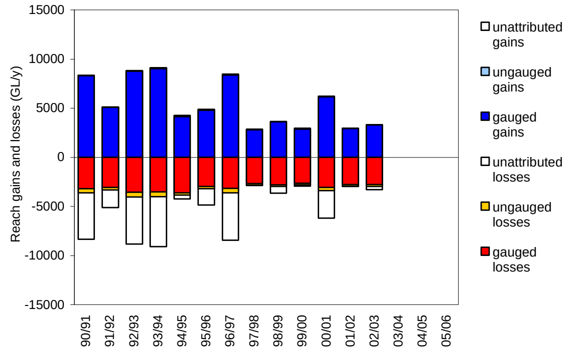
This is a strongly losing reach, losing high flows to teh Edwards-Wakool system. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are no recorded diversions and ungauged losses are small.

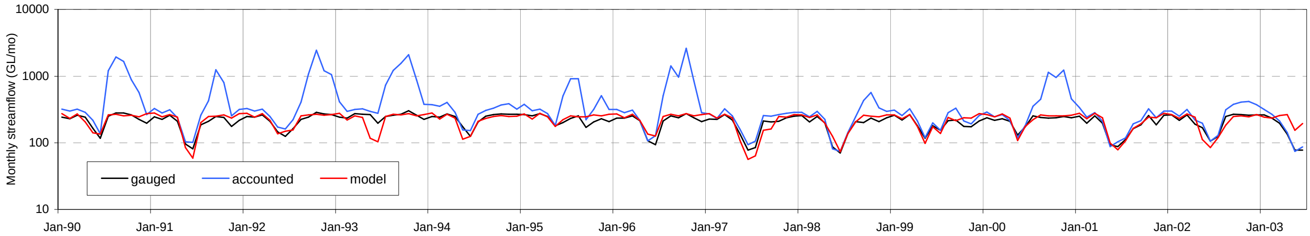
Baseline model performance is reasonable. Accounting does not explain observed flows well.

The projected changes are similar to or greater than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.99	0.56	0.78
Attributed	0.99	0.62	0.80
Fraction of variance			
Gauged	1.00	0.15	0.57
Attributed	1.00	0.24	0.62



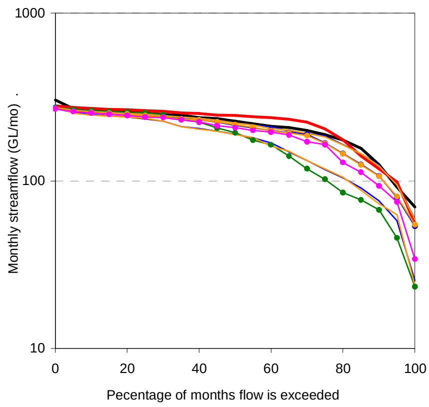
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.14	-0.31	**-0.99**	**-0.81**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.11	-0.15	-0.37	-0.43	
Distributary outflows	-0.10	-0.16	-0.49	**-0.53**	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.11	-0.11	**-0.56**	-0.43	Adjusted -0.6%



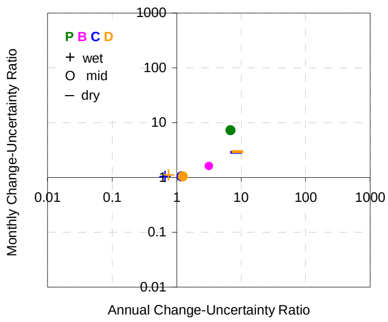
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5673	5386	287
Tributary inflows	0	0	0
Local inflows	0	13	-13
Unattributed gains and noise	-	51	-51
Losses	GL/y	GL/y	GL/y
Main stem outflows	2659	2550	109
Distributary outflows	0	516	-516
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	286	-286
Unspecified losses	0	-	0
Unattributed losses and noise	-	2097	-2097
	3014	0	3014

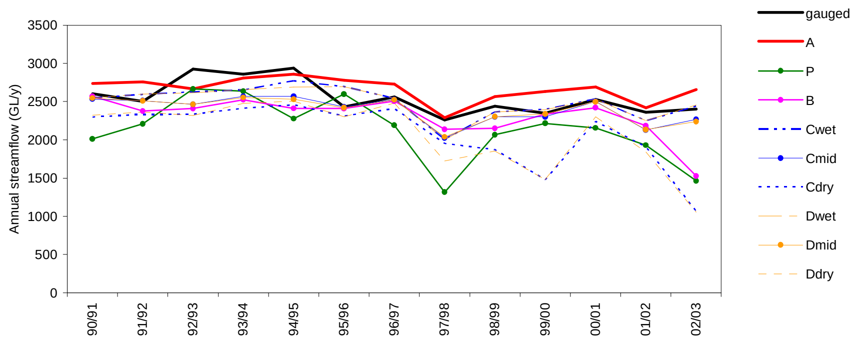
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.59	<0
Log-normalised	0.63	<0
Ranked	0.38	0.61
Low flows only	<0	0.15
High flows only	<0	<0
Annual		
Normal	0.17	<0
Log-normalised	0.16	<0
Ranked	0.45	0.65

Definitions:
- low flows (flows<10% percentile) : 124.8 GL/mo
- high flows (flows>90% percentile) : 265.1 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.8	3.2	0.7	1.2	8.4	0.7	1.3	8.7
Monthly streamflow	7.3	1.6	1.0	1.0	2.9	1.1	1.0	3.0



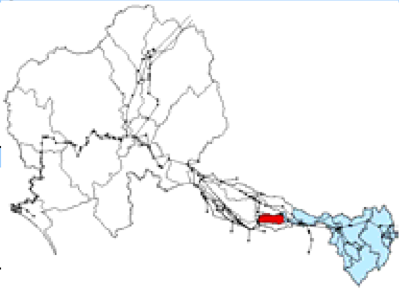


Downstream gauge	409008 Edward @ Offtake	Reach 9b
Upstream gauge	409202 Murray @ Tocumwal	

Reach length (km)	106
Area (km^2)	1116
Outflow/inflow ratio	0.10
Net losing reach	

Land use	ha	%
Dryland	75,690	68
Irrigable area	-	-
Open water*	-	-
River and wetlands	35,860	32
Open water*	-	-

* averages for 1990–2006



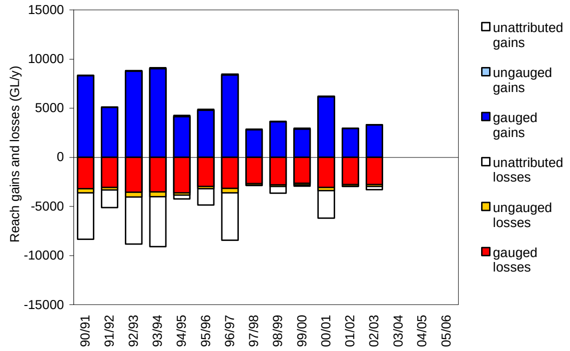
This is a strongly losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are no recorded diversions and ungauged losses are small.

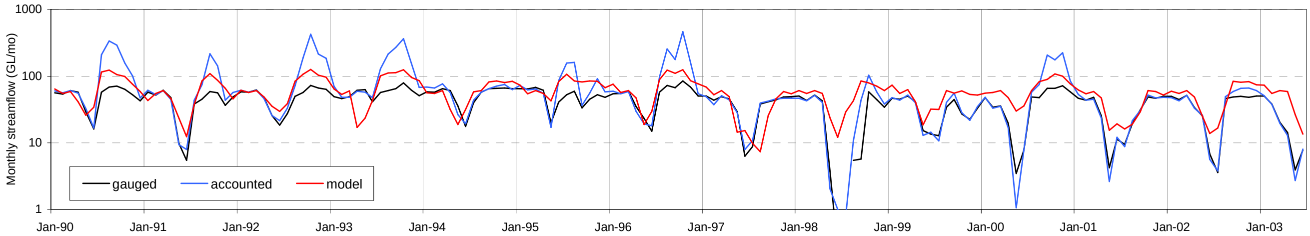
Baseline model performance is very poor. Accounting also explains observed flows poorly.

The projected changes are generally less than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.99	0.56	0.78
Attributed	0.99	0.62	0.80
Fraction of variance			
Gauged	1.00	0.15	0.57
Attributed	1.00	0.24	0.62



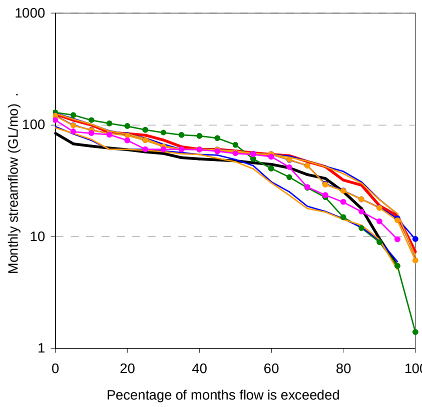
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.14	-0.31	**-0.99**	**-0.81**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.10	-0.16	-0.49	**-0.53**	
Distributary outflows	-0.11	-0.15	-0.37	-0.43	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.11	-0.11	**-0.56**	-0.43	



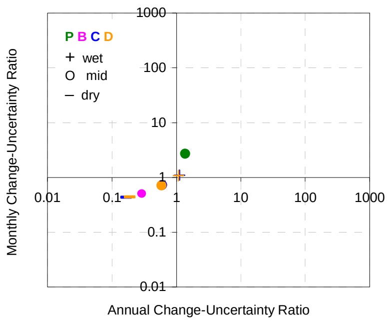
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5673	5386	287
Tributary inflows	0	0	0
Local inflows	0	13	-13
Unattributed gains and noise	-	51	-51
Losses	GL/y	GL/y	GL/y
Main stem outflows	719	516	203
Distributary outflows	0	2550	-2550
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	286	-286
Unspecified losses	0	-	0
Unattributed losses and noise	-	2098	-2098
	4954	0	4954

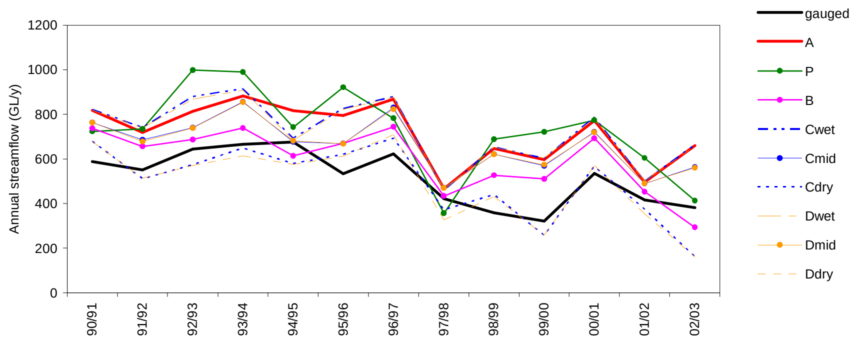
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	<0
Log-normalised	-	-
Ranked	0.47	0.85
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	<0	<0
Log-normalised	<0	<0
Ranked	0.66	0.58

Definitions:
- low flows (flows<10% percentile) : 9.6 GL/mo
- high flows (flows>90% percentile) : 64.7 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.4	0.3	1.1	0.6	0.2	1.1	0.6	0.2
Monthly streamflow	2.7	0.5	1.1	0.7	0.4	1.1	0.7	0.4



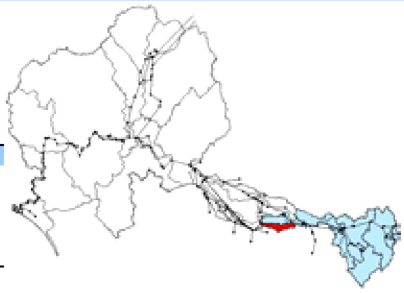


Downstream gauge	**409215 Murray @ Barmah**	**Reach 10**
Upstream gauge	**409006 Murray @ Picnic Point**	

Reach length (km)	28
Area (km^2)	825
Outflow/inflow ratio	1.30
Net gaining reach	

Land use	ha	%
Dryland	81,305	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	1,230	1
Open water*	-	-

* averages for 1990–2006



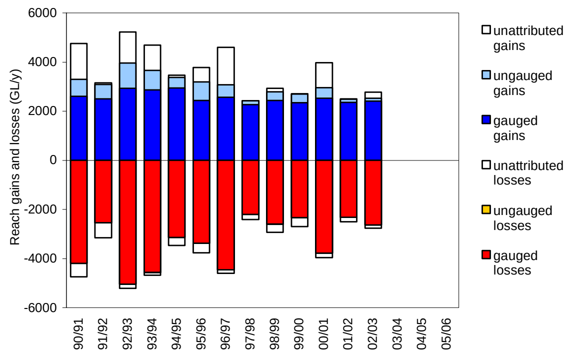
This is a gaining reach. Flows are dominated by inflows from upstream.

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

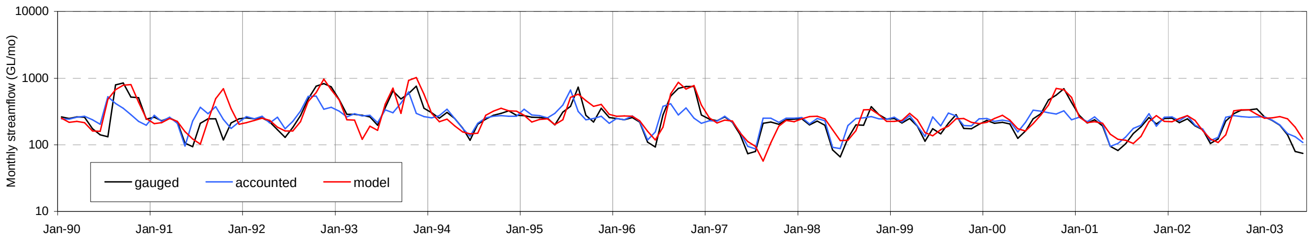
Baseline model performance is reasonable. Accounting explains observed flows modestly.

The projected changes are similar to river model uncertainty, except for the Cmid and Dmod scenarios where projected changes are less than model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.71	0.92	0.81
Attributed	0.84	0.92	0.88
Fraction of variance			
Gauged	0.28	0.92	0.60
Attributed	0.51	0.92	0.71



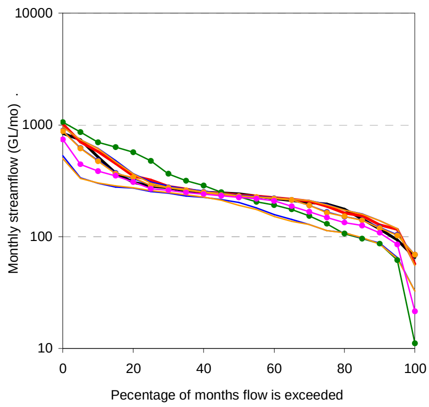
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.35	-0.34	-0.06	-0.00	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.95**	**-0.76**	-0.18	-0.36	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.37	-0.38	-0.10	-0.19	Adjusted 555.3%



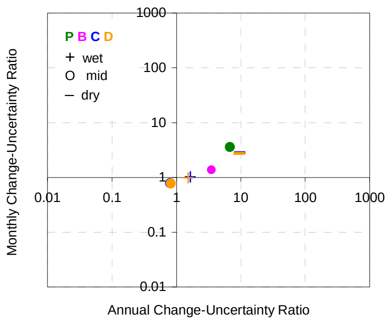
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	2659	2550	109
Tributary inflows	0	0	0
Local inflows	0	487	-487
Unattributed gains and noise	-	572	-572
Losses	GL/y	GL/y	GL/y
Main stem outflows	3530	3322	208
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	2	-2
Unspecified losses	0	-	0
Unattributed losses and noise	-	285	-285
	-871	0	-871

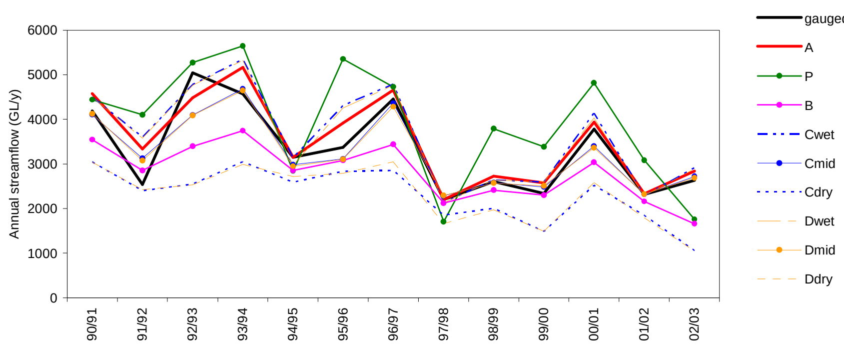
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.67	0.35
Log-normalised	0.60	0.59
Ranked	0.52	0.59
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	0.83	0.48
Log-normalised	0.85	0.56
Ranked	0.87	0.63

Definitions:
- low flows (flows<10% percentile) : 117.2 GL/mo
- high flows (flows>90% percentile) : 514.6 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.7	3.5	1.6	0.8	9.6	1.5	0.8	9.5
Monthly streamflow	3.6	1.4	1.0	0.8	2.8	1.0	0.8	2.8



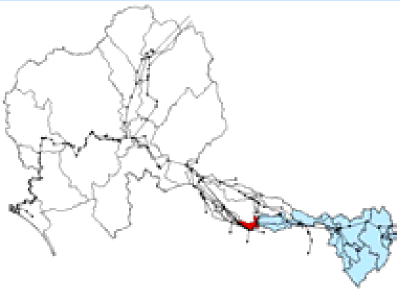


Downstream gauge	409207 Murray @ Torrumbarry Weir	Reach 11
Upstream gauge	409215 Murray @ Barmah	

Reach length (km)	204
Area (km^2)	686
Outflow/inflow ratio	1.14
Net gaining reach	

Land use	ha	%
Dryland	49,879	73
Irrigable area	-	-
Open water*	-	-
River and wetlands	18,700	27
Open water*	-	-

* averages for 1990–2006



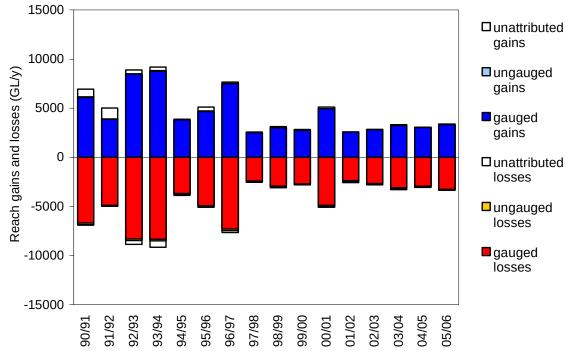
This is a gaining reach. Flows are dominated by inflows from upstream.

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

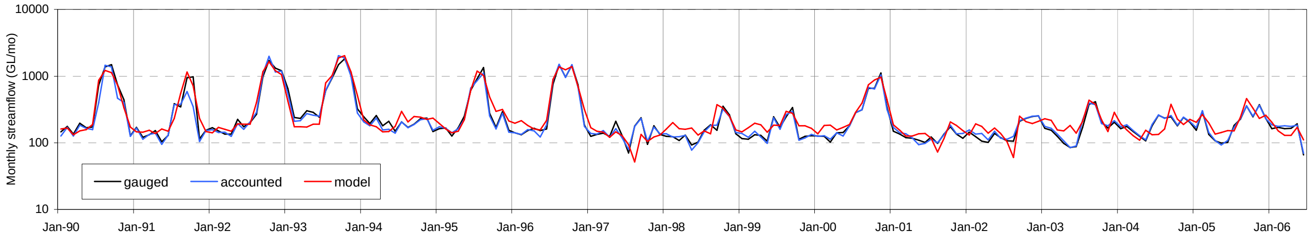
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

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



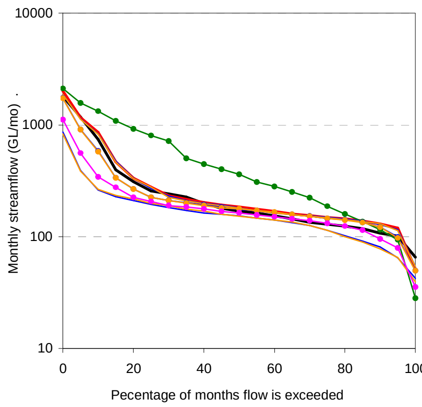
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.07	-0.05	-0.28	-0.20	
Tributary inflows	-0.22	-0.37	**-0.70**	-0.06	
Main gauge outflows	-0.38	-0.40	-0.45	-0.10	
Distributary outflows	-	-	-	-	
Recorded diversions	-0.04	-0.16	-0.11	-0.20	
Estimated local runoff	-0.10	-0.24	-0.43	-0.14	Adjusted -63.5%



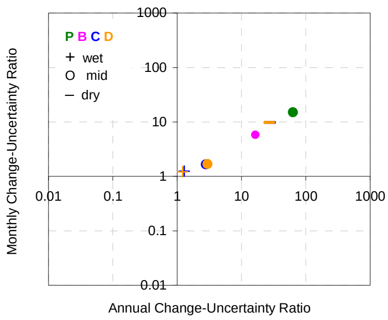
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	3384	3188	196
Tributary inflows	0	1265	-1265
Local inflows	0	24	-24
Unattributed gains and noise	-	226	-226
Losses	GL/y	GL/y	GL/y
Main stem outflows	3832	3633	200
Distributary outflows	0	0	0
Net diversions	0	864	-864
River flux to groundwater	0	-	0
River and floodplain losses	0	72	-72
Unspecified losses	0	-	0
Unattributed losses and noise	-	134	-134
	-448	0	-448

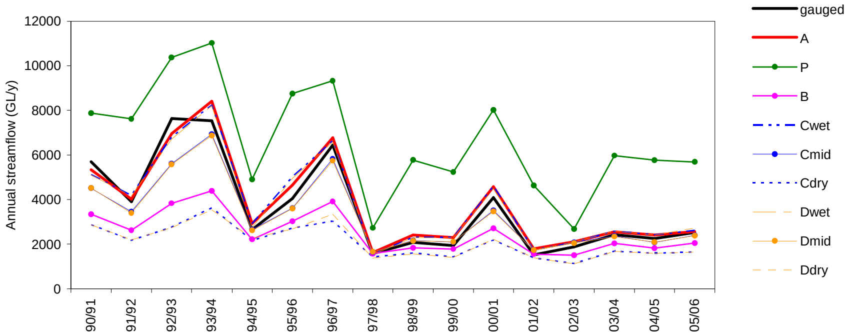
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	0.94
Log-normalised	0.83	0.97
Ranked	0.52	0.96
Low flows only	<0	0.16
High flows only	0.55	0.41
Annual		
Normal	0.96	0.97
Log-normalised	0.96	0.97
Ranked	0.98	0.98

Definitions:
- low flows (flows<10% percentile) : 107.0 GL/mo
- high flows (flows>90% percentile) : 740.2 GL/mo



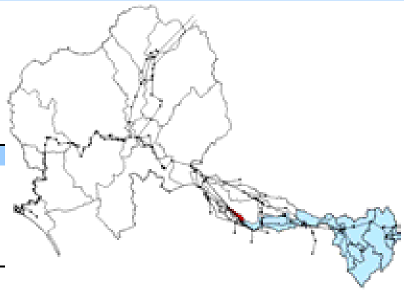
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	62.9	16.4	1.3	2.8	27.5	1.2	3.0	27.0
Monthly streamflow	15.0	5.8	1.2	1.7	9.7	1.2	1.7	9.7





Downstream gauge	409005 Murray @ Barham	Reach 12
Upstream gauge	409207 Murray @ Torrumbarry Weir	

Reach length (km)	66
Area (km^2)	316
Outflow/inflow ratio	0.87
Net losing reach	



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

most of the inflows are gauged. There are few recorded diversions and ungauged losses are small.

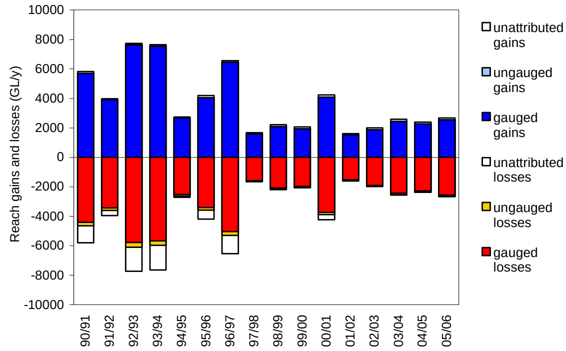
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are greater than river model uncertainty, except in the Cwet, Dwet and Dmid scenarios where projected changes are less than river model uncertainty.

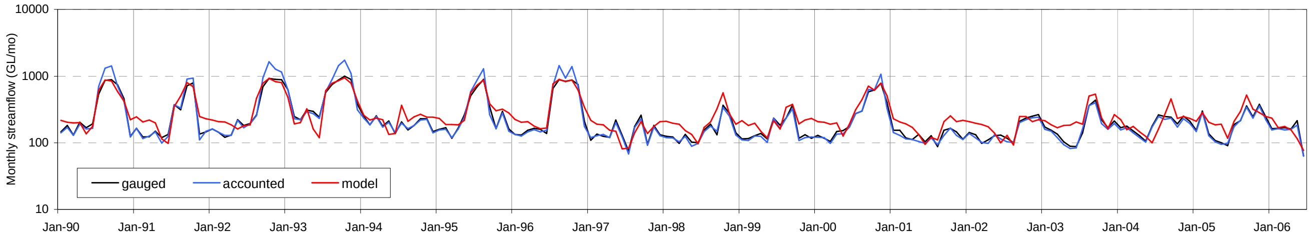
Land use	ha	%
Dryland	7,109	23
Irrigable area	-	-
Open water*	-	-
River and wetlands	24,460	77
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.97	0.84	0.90
Attributed	0.97	0.88	0.93
Fraction of variance			
Gauged	1.00	0.84	0.92
Attributed	1.00	0.87	0.93



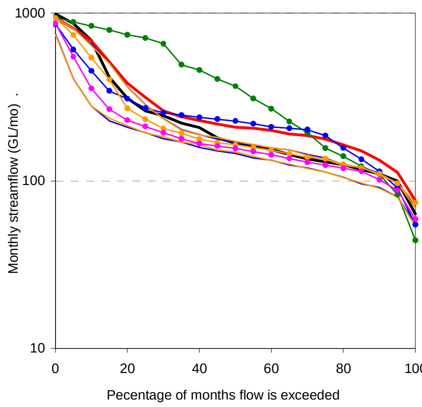
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.11	-0.04	**-0.93**	-0.43	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.03	-0.06	**-0.81**	-0.35	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.09	-0.00	**-0.68**	-0.36	Adjusted 0.0%



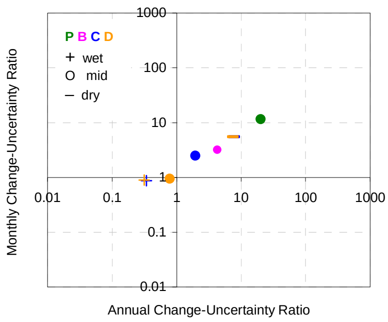
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	3832	3633	200
Tributary inflows	0	0	0
Local inflows	0	2	-2
Unattributed gains and noise	-	114	-114
Losses	GL/y	GL/y	GL/y
Main stem outflows	3539	3150	389
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	153	-153
Unspecified losses	0	-	0
Unattributed losses and noise	-	447	-447
	294	0	294

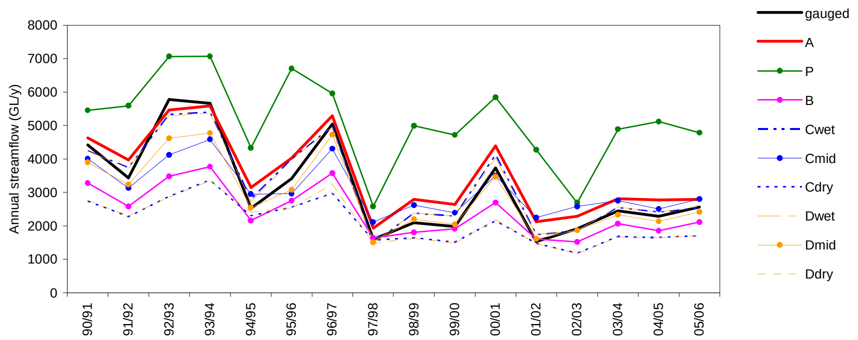
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.89	0.66
Log-normalised	0.72	0.95
Ranked	0.49	0.98
Low flows only	<0	0.66
High flows only	0.33	<0
Annual		
Normal	0.88	0.75
Log-normalised	0.81	0.91
Ranked	0.96	0.99

Definitions:
- low flows (flows<10% percentile) : 109.7 GL/mo
- high flows (flows>90% percentile) : 686.6 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	20.1	4.3	0.3	1.9	7.8	0.3	0.8	7.5
Monthly streamflow	11.6	3.2	0.9	2.5	5.5	0.9	0.9	5.5



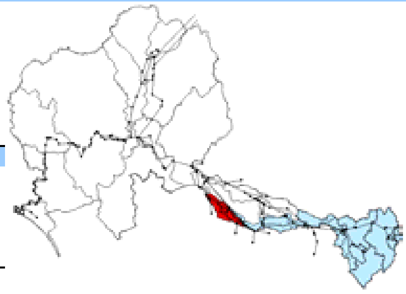


Downstream gauge	409204 Murray @ Swan Hill	Reach 13
Upstream gauge	409005 Murray @ Barham	

Reach length (km)	231
Area (km^2)	2180
Outflow/inflow ratio	0.93
Net losing reach	

Land use	ha	%
Dryland	193,600	89
Irrigable area	-	-
Open water*	-	-
River and wetlands	24,430	11
Open water*	-	-

* averages for 1990–2006



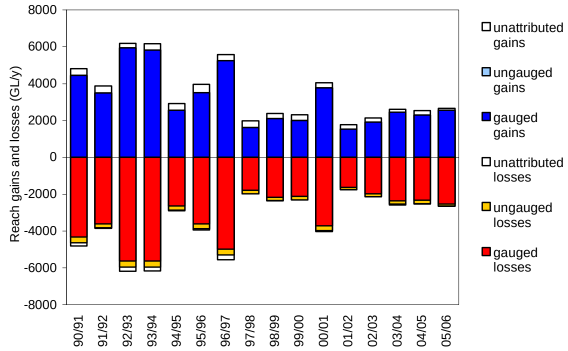
This is a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are some recorded diversions and ungauged losses are small.

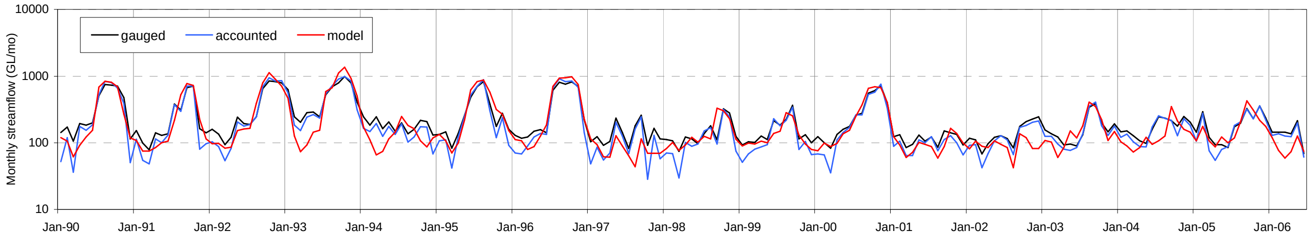
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty for the P, B and Cdry and Ddry scenarios, and less than river model uncertainty for the remaning scenarios.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.92	0.92	0.92
Attributed	0.92	0.98	0.95
Fraction of variance			
Gauged	0.99	0.99	0.99
Attributed	0.99	0.99	0.99



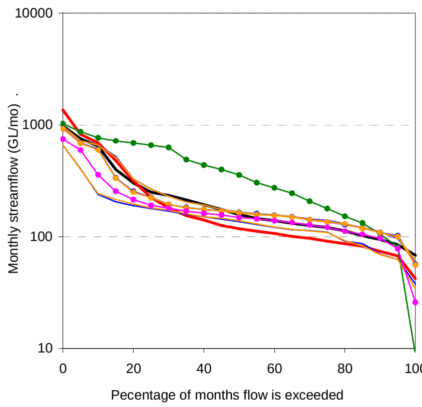
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.33	-0.38	**-0.85**	**-0.64**	
Tributary inflows	-0.25	-0.06	**-0.83**	-0.46	
Main gauge outflows	-0.30	-0.35	**-0.83**	**-0.63**	
Distributary outflows	-	-	-	-	
Recorded diversions	**-0.64**	**-0.72**	-0.32	-0.48	
Estimated local runoff	-0.29	-0.39	**-0.57**	**-0.54**	Adjusted -100.0%



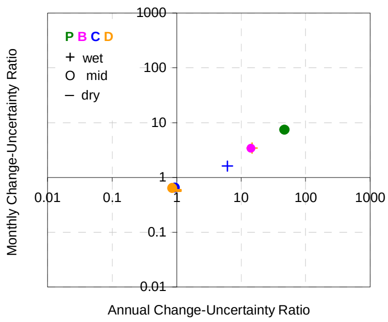
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	3539	3150	389
Tributary inflows	0	52	-52
Local inflows	0	0	0
Unattributed gains and noise	-	289	-289
Losses	GL/y	GL/y	GL/y
Main stem outflows	2828	2938	-110
Distributary outflows	0	0	0
Net diversions	0	360	-360
River flux to groundwater	0	-	0
River and floodplain losses	0	118	-118
Unspecified losses	0	-	0
Unattributed losses and noise	-	73	-73
	711	0	711

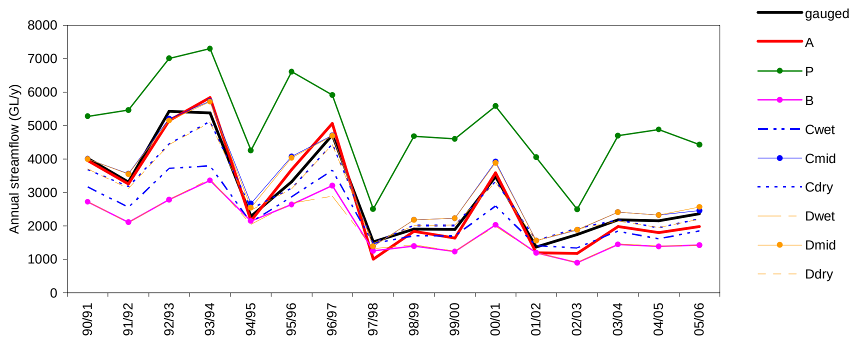
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.82	0.97
Log-normalised	0.61	0.80
Ranked	0.54	0.93
Low flows only	<0	<0
High flows only	<0	0.43
Annual		
Normal	0.94	0.97
Log-normalised	0.84	0.91
Ranked	0.95	0.99

Definitions:
- low flows (flows<10% percentile) : 94.1 GL/mo
- high flows (flows>90% percentile) : 647.5 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	47.0	6.1	0.9	0.9	14.7	0.9	1.0	14.2
Monthly streamflow	7.4	1.6	0.7	0.6	3.4	0.6	0.6	3.4



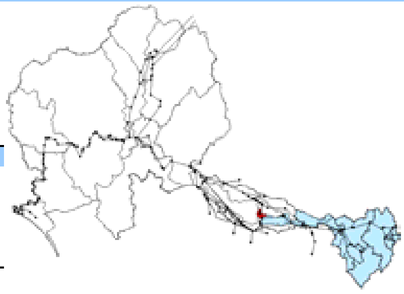


Downstream gauge	409047 Edward @ Toonalook	Reach 14
Upstream gauge	409008 Edward @ Offtake	

Reach length (km)	16
Area (km^2)	250
Outflow/inflow ratio	1.97
Net gaining reach	

Land use	ha	%
Dryland	5,196	21
Irrigable area	-	-
Open water*	-	-
River and wetlands	19,810	79
Open water*	-	-

* averages for 1990–2006



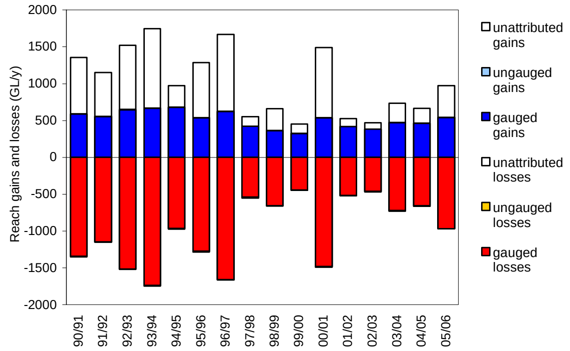
This is a strongly gaining reach. Flows are dominated by inflows from upstream.

Few of the inflows are gauged. There are some recorded diversions and ungauged losses are small.

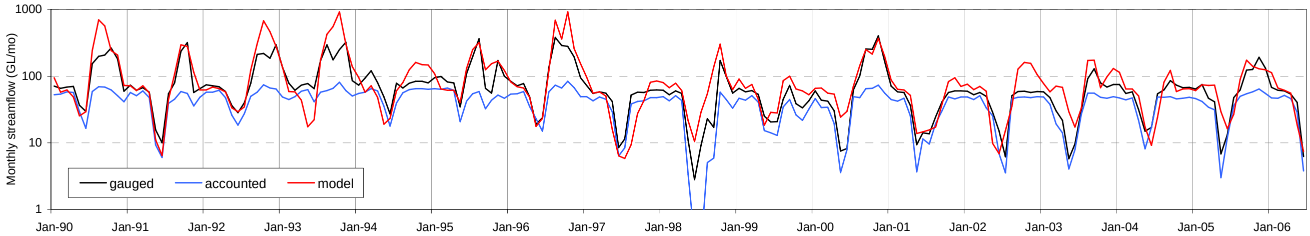
Baseline model performance is poor Accounting also explains observed flows poorly.

The projected changes are mostly similar to or less than than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.50	0.99	0.75
Attributed	0.51	1.00	0.75
Fraction of variance			
Gauged	0.28	1.00	0.64
Attributed	0.28	1.00	0.64



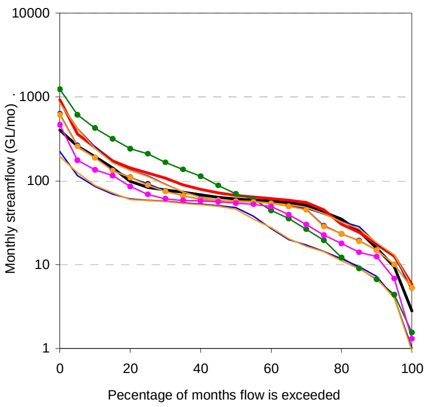
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.51	-0.66	-0.07	-0.08	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.98	-0.88	-0.06	-0.10	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.53	-0.38	-0.04	-0.05	



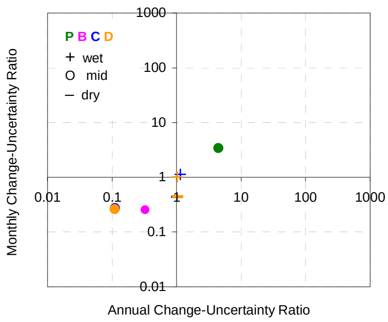
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	705	511	194
Tributary inflows	0	0	0
Local inflows	0	2	-2
Unattributed gains and noise	-	499	-499
Losses	GL/y	GL/y	GL/y
Main stem outflows	1376	1005	370
Distributary outflows	0	0	0
Net diversions	0	7	-7
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	0	0
	-670	0	-670

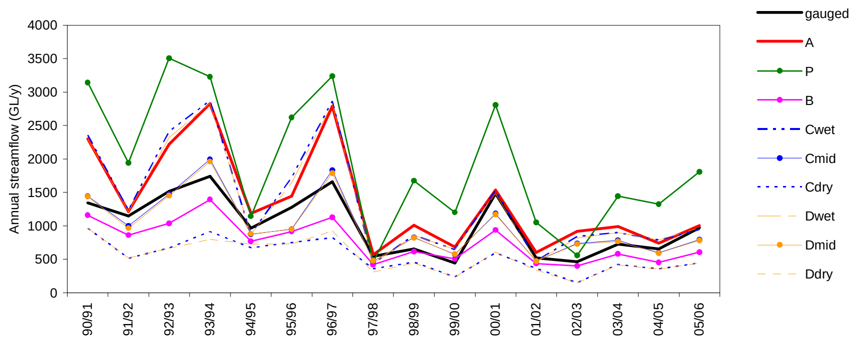
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	<0
Log-normalised	0.61	0.35
Ranked	0.67	0.81
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	<0	<0
Log-normalised	0.42	<0
Ranked	0.88	0.66

Definitions:
- low flows (flows<10% percentile) : 15.7 GL/mo
- high flows (flows>90% percentile) : 193.3 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.5	0.3	1.1	0.1	1.0	1.0	0.1	1.0
Monthly streamflow	3.4	0.3	1.1	0.3	0.4	1.0	0.3	0.4



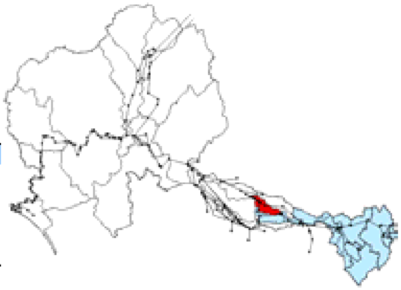


Downstream gauge	409023 Edward @ D/S Steven Weir	Reach 15a
Upstream gauge	409047 Edward @ Toonalook	

Reach length (km)	74
Area (km^2)	1257
Outflow/inflow ratio	0.86
Net losing reach	

Land use	ha	%
Dryland	98,040	78
Irrigable area	-	-
Open water*	-	-
River and wetlands	27,620	22
Open water*	-	-

* averages for 1990–2006



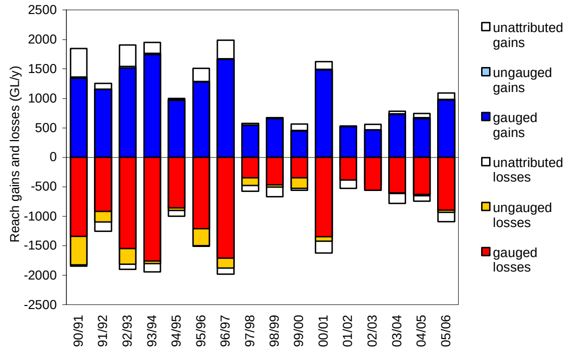
This is a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are some recorded diversions, and ungauged losses.

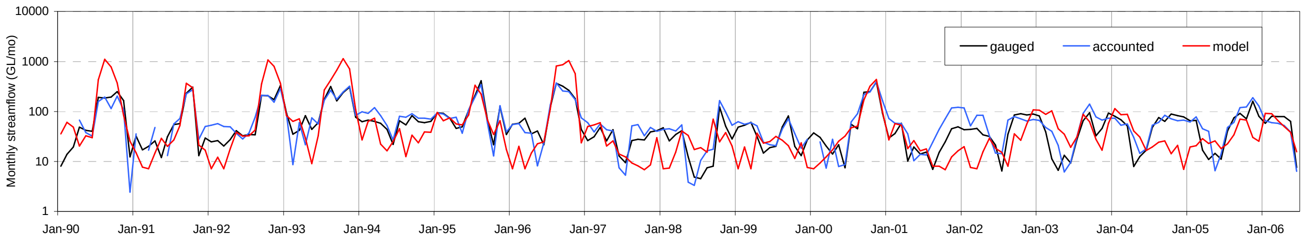
Baseline model performance is very poor. Accounting explains observed flows very well.

The projected changes are generally less than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.76	0.70	0.73
Attributed	0.77	0.96	0.86
Fraction of variance			
Gauged	0.87	0.90	0.89
Attributed	0.87	0.99	0.93



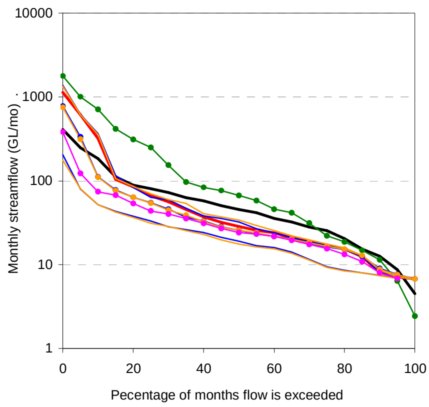
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	**-0.60**	-0.31	-0.06	-0.18	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.71**	**-0.58**	-0.31	-0.30	
Distributary outflows	**-0.83**	-0.30	-0.22	-0.19	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.42	-0.26	-0.23	-0.27	



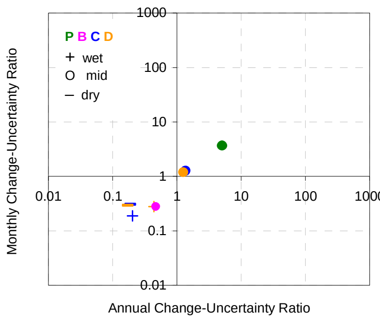
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1376	1005	370
Tributary inflows	0	0	0
Local inflows	0	12	-12
Unattributed gains and noise	-	310	-310
Losses	GL/y	GL/y	GL/y
Main stem outflows	1230	860	370
Distributary outflows	0	75	-75
Net diversions	0	298	-298
River flux to groundwater	0	-	0
River and floodplain losses	0	37	-37
Unspecified losses	0	-	0
Unattributed losses and noise	-	58	-58
	145	0	145

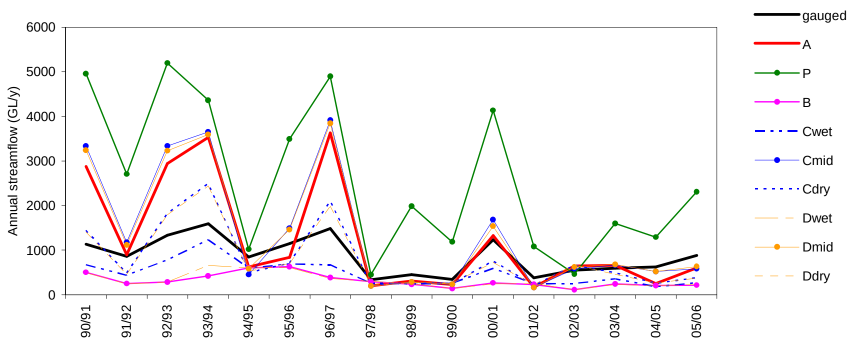
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.78
Log-normalised	0.08	-
Ranked	0.24	0.47
Low flows only	<0	<0
High flows only	<0	0.27
Annual		
Normal	<0	0.65
Log-normalised	<0	0.04
Ranked	0.81	0.91

Definitions:
- low flows (flows<10% percentile) : 12.6 GL/mo
- high flows (flows>90% percentile) : 183.6 GL/mo



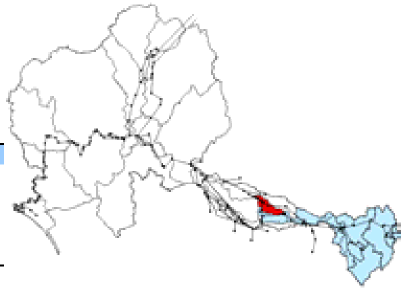
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	5.0	0.2	1.4	0.2	0.4	1.3	0.2	0.5
Monthly streamflow	3.7	0.2	1.3	0.3	0.3	1.2	0.3	0.3





Downstream gauge	409019 Wakool @ D/S Offtake Regulator	Reach 15b
Upstream gauge	409047 Edward @ Toonalook	

Reach length (km)	74
Area (km^2)	1257
Outflow/inflow ratio	0.07
Net losing reach	



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

Most of the inflows are gauged. There are few recorded diversions and some ungauged losses.

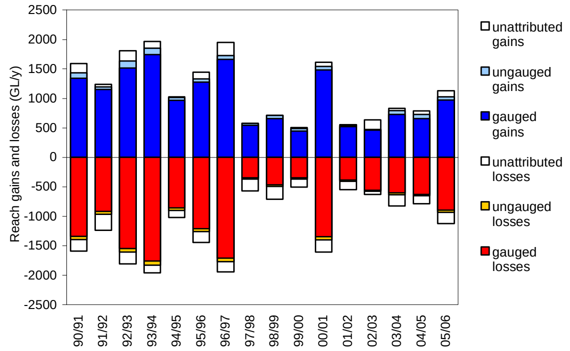
Baseline model performance is good Accounting also explains observed flows extremely well.

The projected changes are generally greater than river model uncertainty, except for the Cwet and Dwet scenarios where projected changes are similar to or less than river model uncertainty.

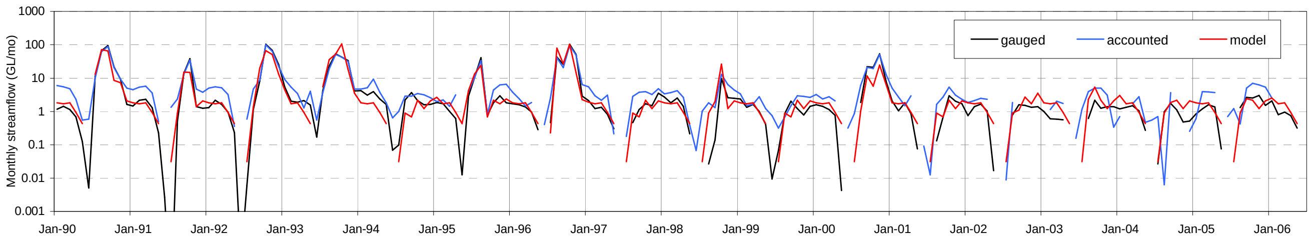
Land use	ha	%
Dryland	98,040	78
Irrigable area	-	-
Open water*	-	-
River and wetlands	27,620	22
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.88	0.82	0.85
Attributed	0.93	0.85	0.89
Fraction of variance			
Gauged	0.96	0.97	0.96
Attributed	0.97	0.97	0.97



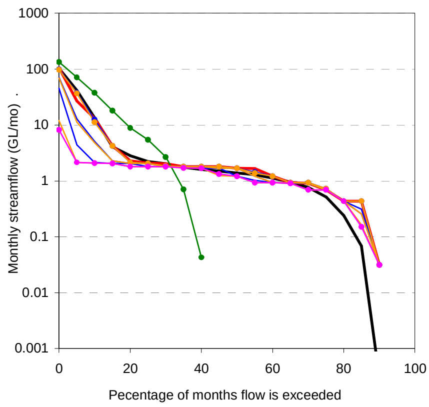
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.60	-0.31	-0.06	-0.18	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.83	-0.30	-0.22	-0.19	
Distributary outflows	-0.71	-0.58	-0.31	-0.30	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.42	-0.26	-0.23	-0.27	Adjusted 406.7%



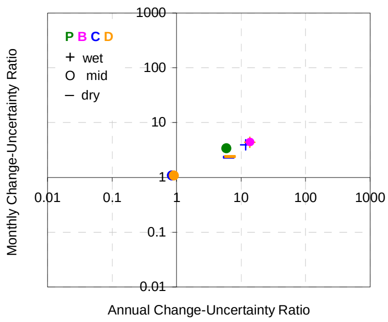
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1376	1005	370
Tributary inflows	0	0	0
Local inflows	0	59	-59
Unattributed gains and noise	-	81	-81
Losses	GL/y	GL/y	GL/y
Main stem outflows	69	75	-6
Distributary outflows	0	860	-860
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	38	-38
Unspecified losses	0	-	0
Unattributed losses and noise	-	172	-172
	1306	0	1306

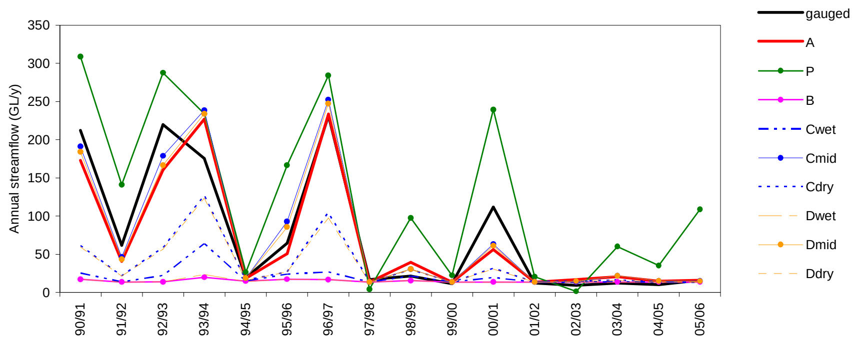
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.76	0.98
Log-normalised	-	-
Ranked	0.63	0.65
Low flows only	<0	<0
High flows only	0.20	0.98
Annual		
Normal	0.89	0.98
Log-normalised	0.91	0.63
Ranked	0.74	0.96

Definitions:
- low flows (flows<10% percentile) : 0.0 GL/mo
- high flows (flows>90% percentile) : 13.6 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.0	11.8	0.9	6.4	13.7	0.9	6.7	13.8
Monthly streamflow	3.4	3.9	1.1	2.3	4.4	1.1	2.4	4.4



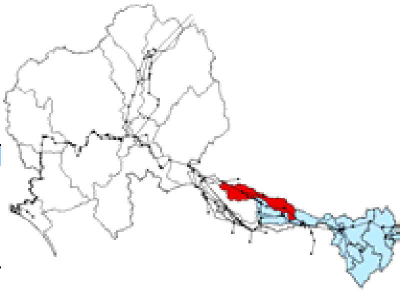


Downstream gauge	409014 Edward @ Moulamein	Reach 16
Upstream gauge	409023 Edward @ D/S Steven Weir	

Reach length (km)	76
Area (km^2)	4429
Outflow/inflow ratio	1.08
Net gaining reach	

Land use	ha	%
Dryland	397,819	90
Irrigable area	-	-
Open water*	-	-
River and wetlands	45,070	10
Open water*	-	-

* averages for 1990–2006



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

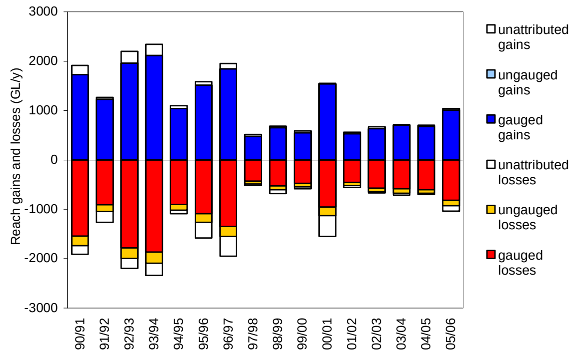
Most of the inflows are gauged. There are some recorded diversions and ungauged losses are large.

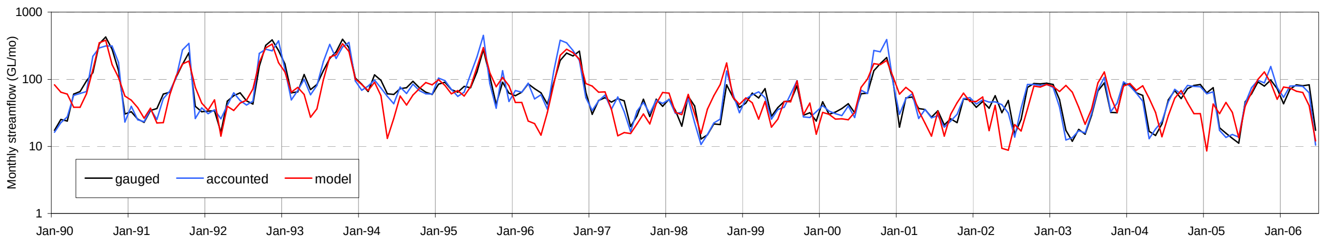
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are generally greater than river model uncertainty, except for the Cwet and Dwet scenarios in which projected changes are similar to or less than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.94	0.77	0.85
Attributed	0.94	0.87	0.91
Fraction of variance			
Gauged	0.98	0.84	0.91
Attributed	0.98	0.90	0.94

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.18	-0.02	**-0.86**	**-0.58**	
Tributary inflows	**-0.54**	-0.31	-0.46	-0.13	
Main gauge outflows	**-0.59**	-0.24	-0.48	-0.32	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.15	-0.05	-0.37	-0.19	Adjusted -100.0%

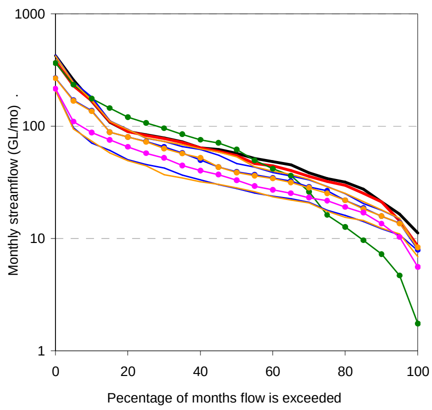




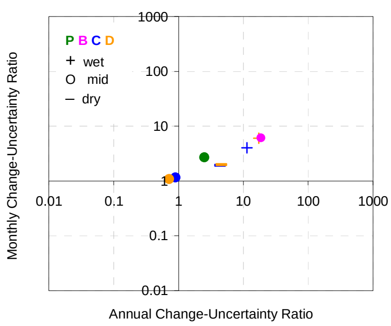
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1230	860	370
Tributary inflows	0	275	-275
Local inflows	0	0	0
Unattributed gains and noise	-	76	-76
Losses	GL/y	GL/y	GL/y
Main stem outflows	890	931	-41
Distributary outflows	0	0	0
Net diversions	0	9	-9
River flux to groundwater	0	-	0
River and floodplain losses	0	119	-119
Unspecified losses	0	-	0
Unattributed losses and noise	-	152	-152
	340	0	340

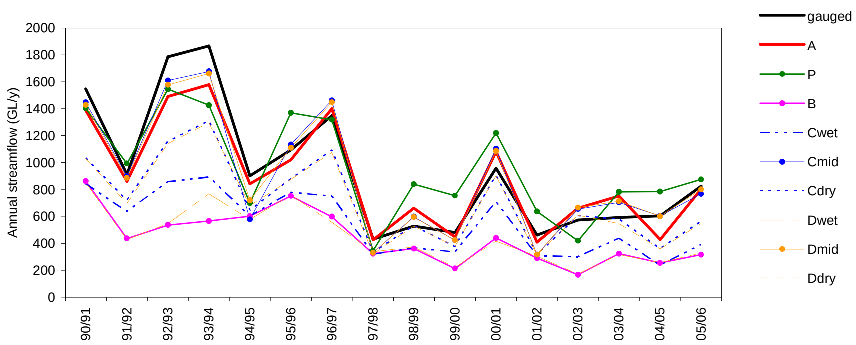
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.86	0.73
Log-normalised	0.48	0.90
Ranked	0.43	0.93
Low flows only	<0	<0
High flows only	0.60	<0
Annual		
Normal	0.91	0.90
Log-normalised	0.90	0.93
Ranked	0.92	0.98

Definitions:
- low flows (flows<10% percentile) : 21.2 GL/mo
- high flows (flows>90% percentile) : 166.6 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	2.5	11.3	0.9	4.4	17.3	0.7	4.6	18.6
Monthly streamflow	2.7	4.0	1.2	1.9	6.0	1.1	2.0	6.1



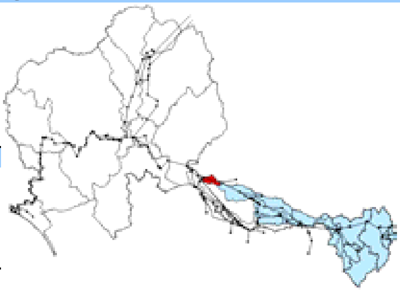


Downstream gauge	409035 Edward @ Leiwah	Reach 17
Upstream gauge	409014 Edward @ Moulamein	

Reach length (km)	58
Area (km^2)	519
Outflow/inflow ratio	0.95
Net losing reach	

Land use	ha	%
Dryland	47,852	92
Irrigable area	-	-
Open water*	-	-
River and wetlands	4,070	8
Open water*	-	-

* averages for 1990–2006



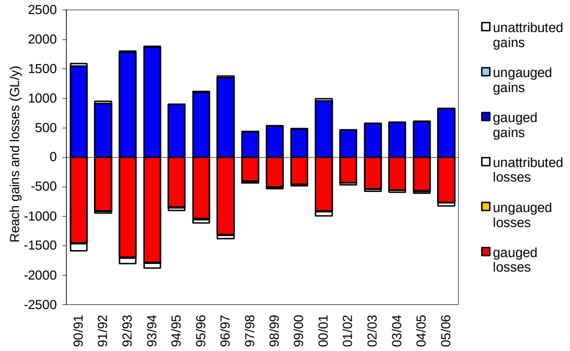
This is a slightly losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are some recorded diversions, and ungauged losses.

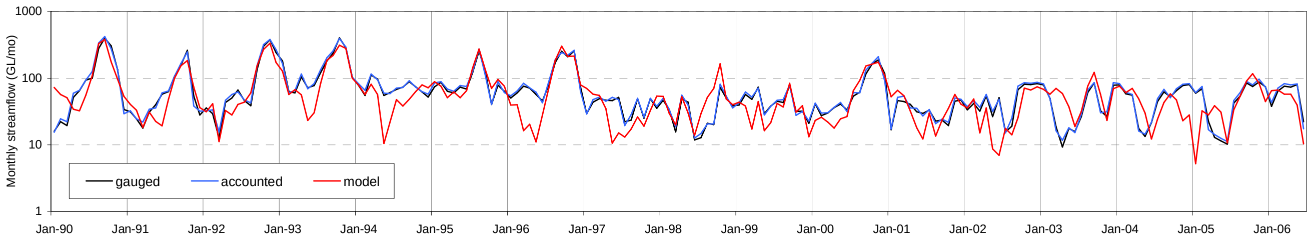
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are greater than river model uncertainty, except for the Cwet abd Dwet scenarios in which the projected changes are similar to or less than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.98	0.93	0.96
Attributed	0.98	0.95	0.97
Fraction of variance			
Gauged	1.00	0.99	0.99
Attributed	1.00	0.99	1.00



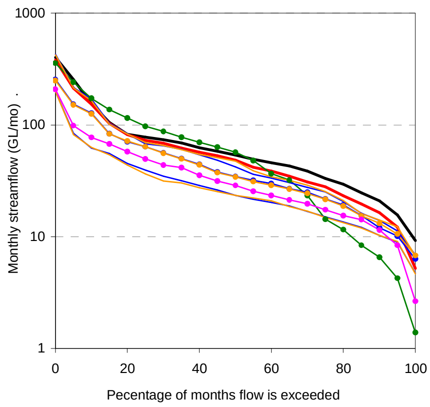
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.21	-0.02	**-0.59**	-0.49	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.29	-0.06	**-0.50**	-0.41	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.02	-0.07	-0.28	-0.20	Adjusted -100.0%



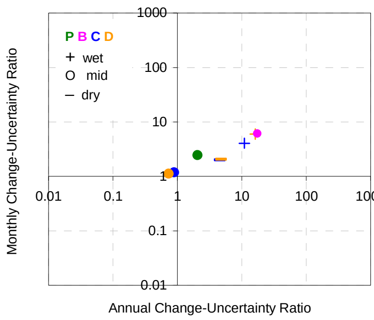
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	890	931	-41
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	15	-15
Losses	GL/y	GL/y	GL/y
Main stem outflows	808	883	-75
Distributary outflows	0	0	0
Net diversions	0	8	-8
River flux to groundwater	0	-	0
River and floodplain losses	0	6	-6
Unspecified losses	0	-	0
Unattributed losses and noise	-	49	-49
	82	0	82

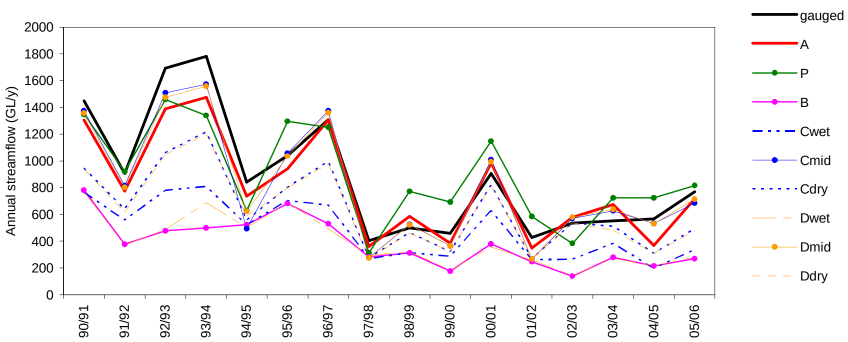
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.85	0.99
Log-normalised	0.40	0.98
Ranked	0.42	0.98
Low flows only	<0	0.57
High flows only	0.54	0.92
Annual		
Normal	0.89	0.99
Log-normalised	0.87	0.99
Ranked	0.92	1.00

Definitions:
- low flows (flows<10% percentile) : 20.9 GL/mo
- high flows (flows>90% percentile) : 155.2 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	2.0	10.9	0.9	4.5	16.3	0.7	4.7	17.4
Monthly streamflow	2.5	4.1	1.2	2.0	6.0	1.1	2.1	6.1



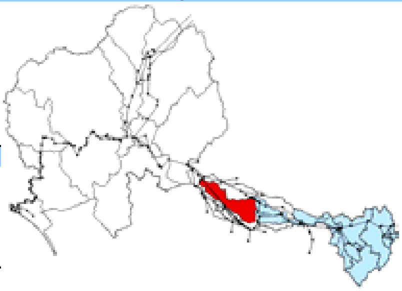


Downstream gauge	409013 Wakool @ Stoney Crossing	Reach 18
Upstream gauge	409019 Wakool @ D/S Offtake Regulator	

Reach length (km)	214
Area (km^2)	4416
Outflow/inflow ratio	17.07
Net gaining reach	

Land use	ha	%
Dryland	335,167	76
Irrigable area	-	-
Open water*	-	-
River and wetlands	106,410	24
Open water*	-	-

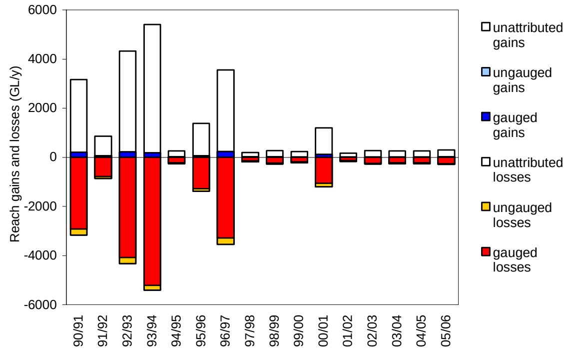
* averages for 1990–2006



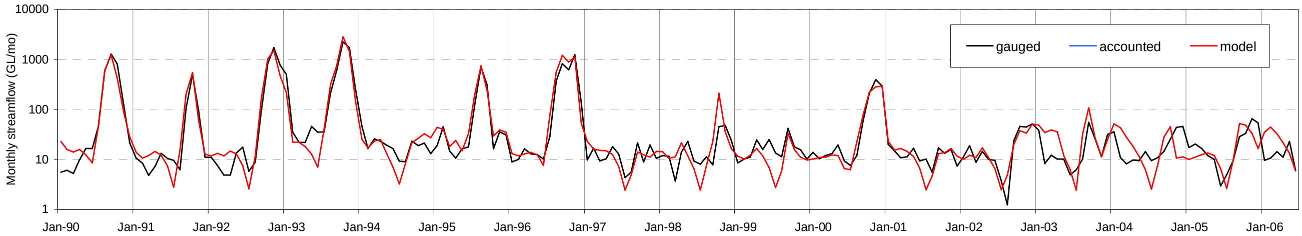
Accounts cannot be established for this reach. The gauged outflows are much greater (by an order of magnitude) than the inflows. The inflows, however, match the outflows of the reach above. It appears that the outflow gauge may be faulty.

Comparisons of model performance appear not to be meaningful.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.05	0.93	0.49
Attributed	0.05	1.00	0.53
Fraction of variance			
Gauged	0.08	1.00	0.54
Attributed	0.08	1.00	0.54



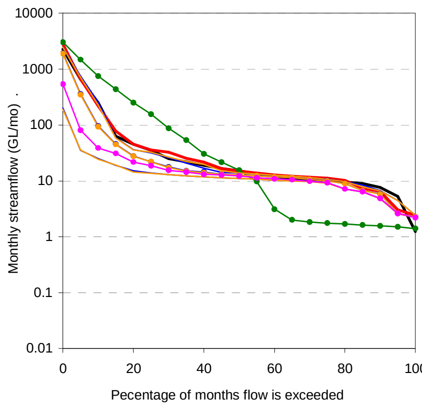
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.73**	-0.50	-	-	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-1.00**	**-0.99**	-	-	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.51**	-0.38	-	-	Adjusted -100.0%



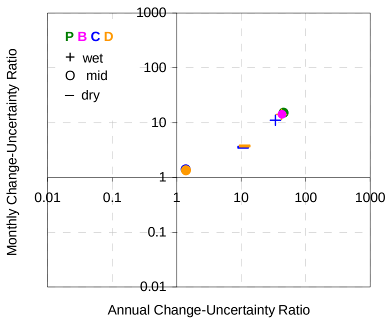
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	69	75	-6
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	1306	-1306
Losses	GL/y	GL/y	GL/y
Main stem outflows	1314	1284	30
Distributary outflows	0	0	0
Net diversions	0	22	-22
River flux to groundwater	0	-	0
River and floodplain losses	0	75	-75
Unspecified losses	0	-	0
Unattributed losses and noise	-	0	0
	-1245	0	-1245

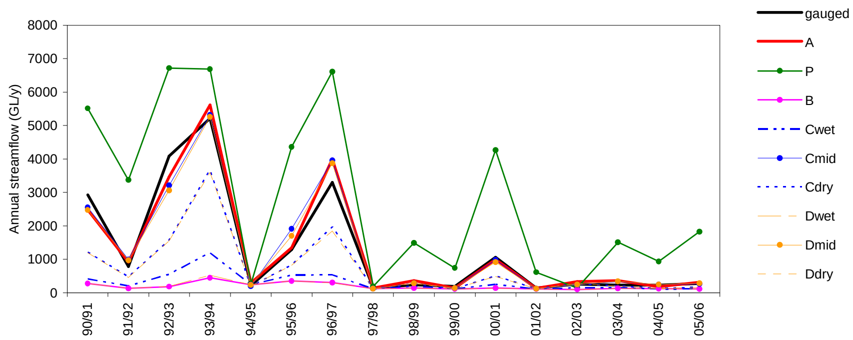
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	<0
Log-normalised	0.80	-
Ranked	0.46	<0
Low flows only	<0	<0
High flows only	0.81	<0
Annual		
Normal	0.97	<0
Log-normalised	0.97	-
Ranked	0.91	<0

Definitions:
- low flows (flows<10% percentile) : 7.6 GL/mo
- high flows (flows>90% percentile) : 251.7 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	45.6	33.7	1.4	10.7	42.4	1.4	11.3	42.9
Monthly streamflow	15.1	11.1	1.4	3.5	14.0	1.3	3.7	14.1



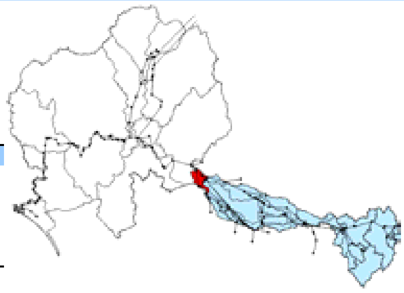


Downstream gauge	414200 Murray @ Below Wakool Junction	Reach 19
Upstream gauge	409204 Murray @ Swan Hill	

Reach length (km)	145
Area (km^2)	1053
Outflow/inflow ratio	1.67
Net gaining reach	

Land use	ha	%
Dryland	83,262	79
Irrigable area	-	-
Open water*	-	-
River and wetlands	22,080	21
Open water*	-	-

* averages for 1990–2006



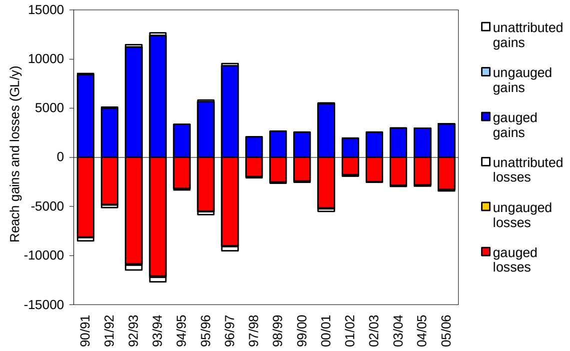
This is a strongly gaining reach. Flows are dominated by runoff immediately following rain.

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

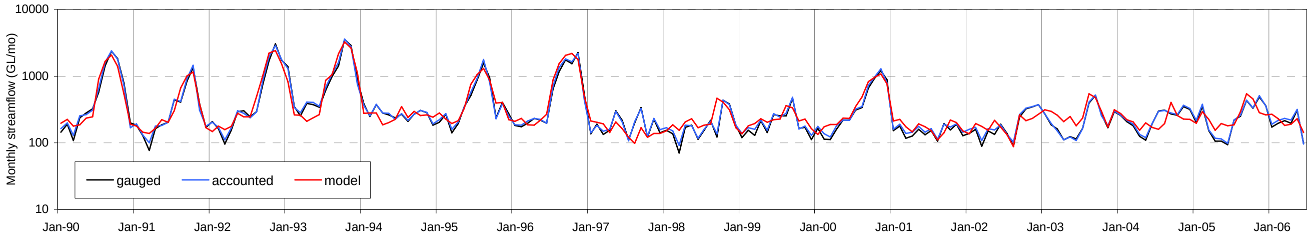
Baseline model performance is excellent. Accounting also explains observed flows very well.

The projected changes are much greater than river model uncertainty.

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



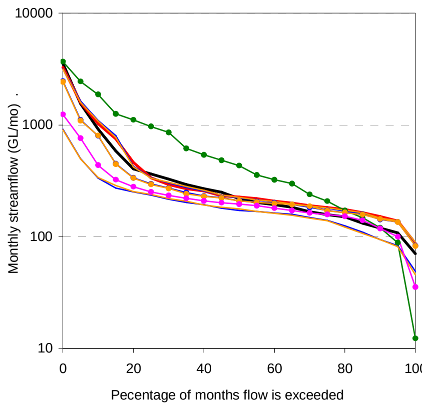
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.27	-0.23	**-0.70**	-0.13	
Tributary inflows	-0.41	-0.25	-0.45	-0.18	
Main gauge outflows	-0.44	-0.31	**-0.50**	-0.07	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.02	-0.04	-0.44	-0.12	



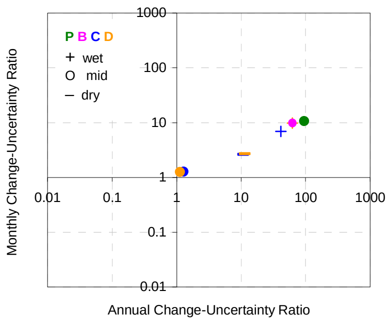
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	3134	2938	196
Tributary inflows	0	2168	-2168
Local inflows	0	5	-5
Unattributed gains and noise	-	84	-84
Losses	GL/y	GL/y	GL/y
Main stem outflows	5080	4921	160
Distributary outflows	0	0	0
Net diversions	0	2	-2
River flux to groundwater	0	-	0
River and floodplain losses	0	54	-54
Unspecified losses	0	-	0
Unattributed losses and noise	-	219	-219
	-1946	0	-1946

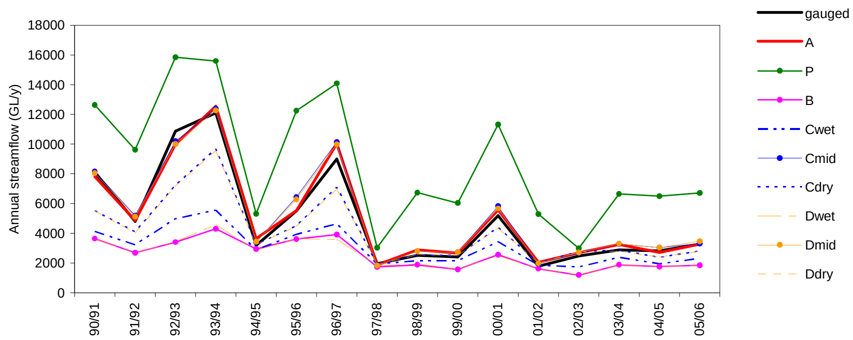
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.92	0.99
Log-normalised	0.84	0.99
Ranked	0.64	0.99
Low flows only	<0	<0
High flows only	0.71	0.97
Annual		
Normal	0.98	1.00
Log-normalised	0.98	1.00
Ranked	0.97	0.99

Definitions:
- low flows (flows<10% percentile) : 119.0 GL/mo
- high flows (flows>90% percentile) : 916.5 GL/mo



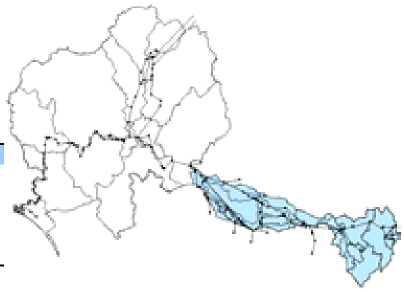
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	94.2	41.5	1.3	10.8	61.8	1.1	11.4	62.2
Monthly streamflow	10.7	6.9	1.3	2.6	9.8	1.3	2.7	9.9





Downstream gauge	414201 Murray @ Boundary Bend	Reach 20
Upstream gauge	414200 Murray @ Below Wakool Junction	

Reach length (km)	396
Area (km^2)	0
Outflow/inflow ratio	1.15
Net gaining reach	



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

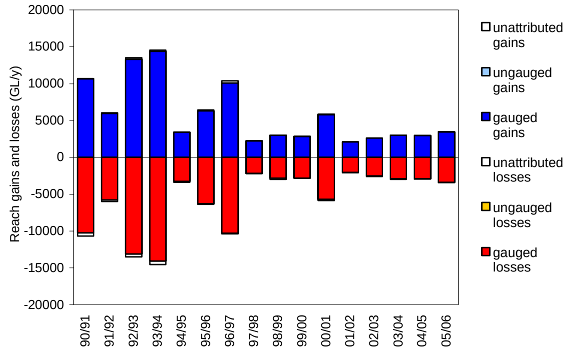
Most of the inflows are gauged. There are no recorded diversions and ungauged losses are modest

there are no model results for this reach. Accounting also explains observed flows extremely well.

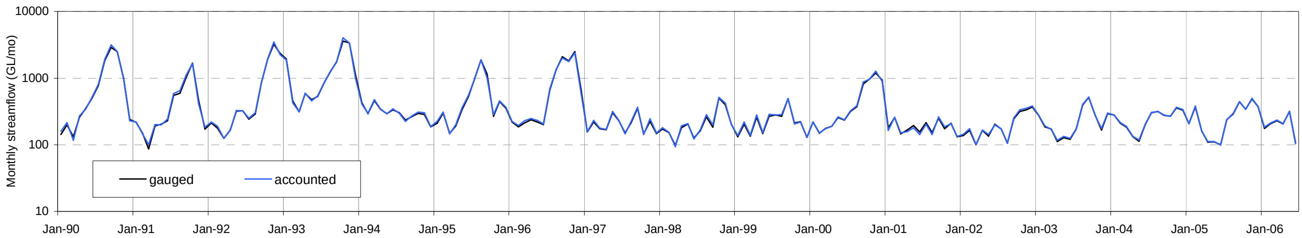
Land use		ha	%
Dryland	-	90	50
Irrigable area		-	-
Open water*		-	-
River and wetlands		90	50
Open water*		-	-

* averages for 1990–2006

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



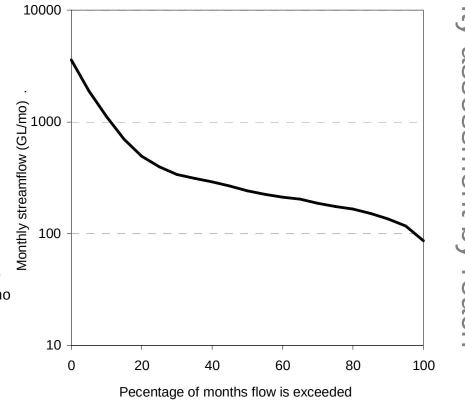
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.38	-0.18	**-0.63**	-0.28	
Tributary inflows	-0.27	-0.26	**-0.54**	-0.19	
Main gauge outflows	-0.42	-0.22	**-0.58**	-0.25	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.00	-	-0.00	-	Adjusted -100.0%



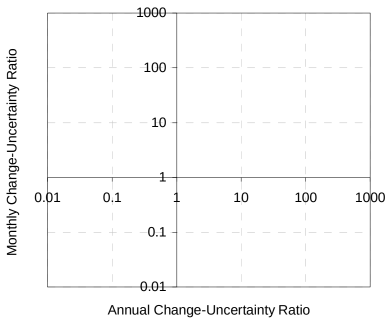
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5080	4921	160
Tributary inflows	0	816	-816
Local inflows	0	0	0
Unattributed gains and noise	-	71	-71
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	5655	-5655
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	153	-153
	5080	0	5080

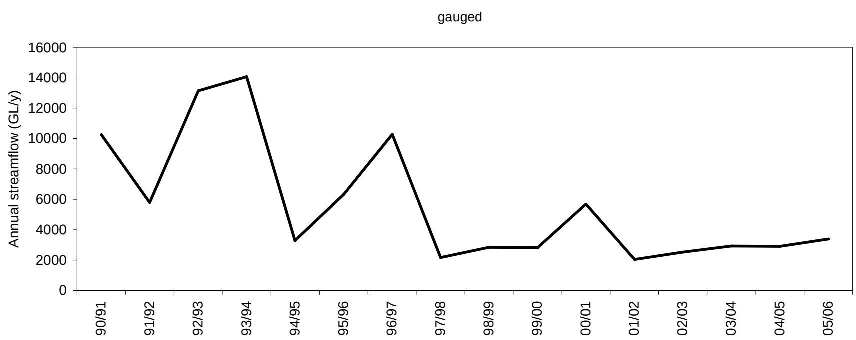
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.99
Log-normalised	-	-
Ranked	<0	0.99
Low flows only	<0	0.89
High flows only	<0	0.96
Annual		
Normal	<0	1.00
Log-normalised	-	-
Ranked	<0	0.98

Definitions:
- low flows (flows<10% percentile) : 135.5 GL/mo
- high flows (flows>90% percentile) : 1115.5 GL/mo



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



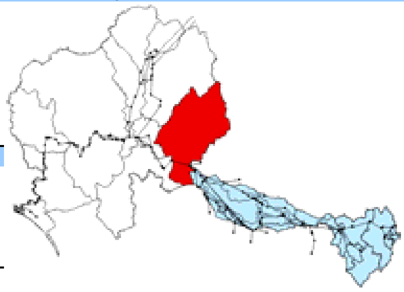


Downstream gauge	414203 Murray @ Euston Weir	Reach 21
Upstream gauge	414201 Murray @ Boundary Bend	

Reach length (km)	19
Area (km^2)	21736
Outflow/inflow ratio	1.00
Net gaining reach	

Land use	ha	%
Dryland	1,952,980	90
Irrigable area	-	-
Open water*	-	-
River and wetlands	220,630	10
Open water*	-	-

* averages for 1990–2006



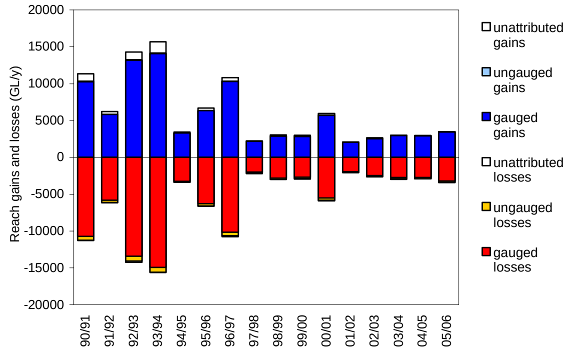
This is neither a gaining nor a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are some recorded diversions and ungauged losses are small.

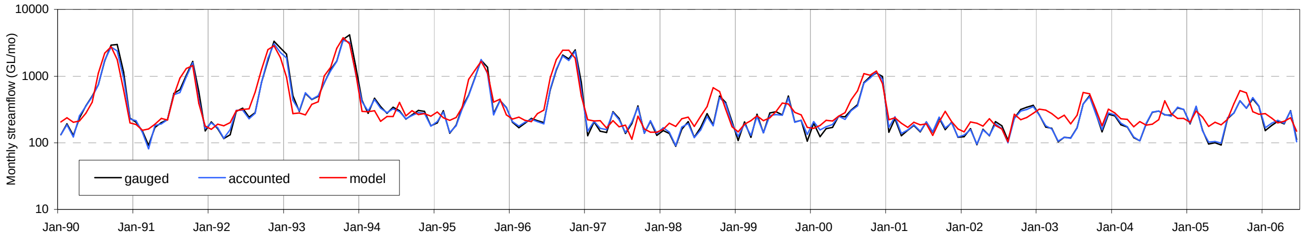
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

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



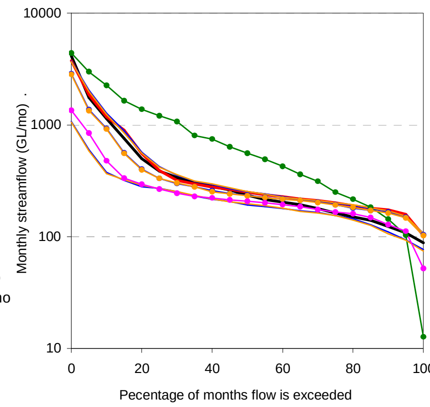
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	**-0.54**	-0.40	-0.33	-0.04	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.63**	-0.44	-0.26	-0.03	
Distributary outflows	-	-	-	-	
Recorded diversions	-0.21	-0.11	-0.01	-0.05	
Estimated local runoff	-0.15	-0.07	-0.31	-0.15	Adjusted -34.6%



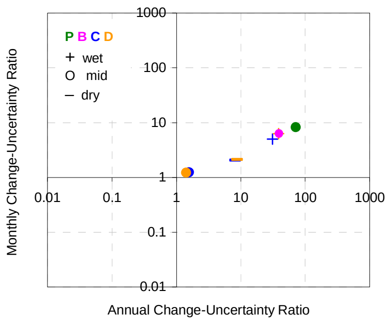
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	5655	-5655
Tributary inflows	0	0	0
Local inflows	0	36	-36
Unattributed gains and noise	-	356	-356
Losses	GL/y	GL/y	GL/y
Main stem outflows	5897	5683	214
Distributary outflows	0	0	0
Net diversions	0	36	-36
River flux to groundwater	0	-	0
River and floodplain losses	0	274	-274
Unspecified losses	0	-	0
Unattributed losses and noise	-	54	-54
	-5897	0	-5897

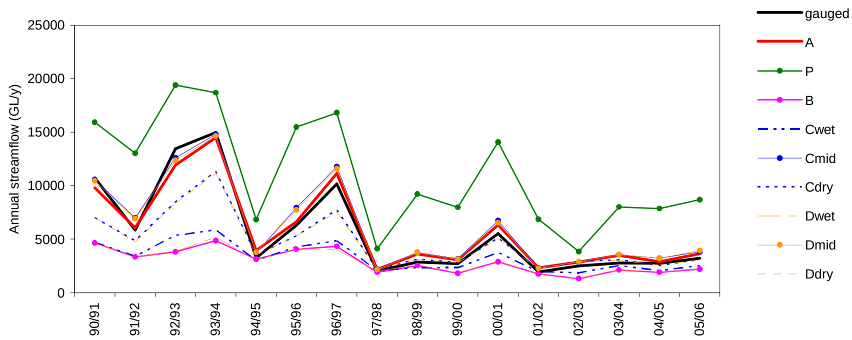
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.87	0.98
Log-normalised	0.83	0.99
Ranked	0.66	0.99
Low flows only	<0	0.58
High flows only	0.43	0.87
Annual		
Normal	0.97	0.98
Log-normalised	0.96	0.99
Ranked	0.98	0.95

Definitions:
- low flows (flows<10% percentile) : 123.4 GL/mo
- high flows (flows>90% percentile) : 1141.4 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	71.2	30.9	1.6	8.2	38.6	1.4	8.7	39.2
Monthly streamflow	8.2	5.0	1.2	2.1	6.3	1.2	2.1	6.3



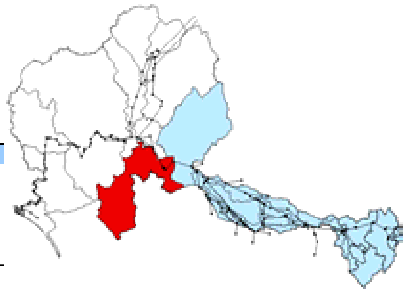


Downstream gauge	414207 Murray @ Colignan	Reach 22
Upstream gauge	414201 Murray @ Euston Weir	

Reach length (km)	100
Area (km^2)	16293
Outflow/inflow ratio	0.94
Net losing reach	

Land use	ha	%
Dryland	1,601,060	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	28,190	2
Open water*	-	-

* averages for 1990–2006



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

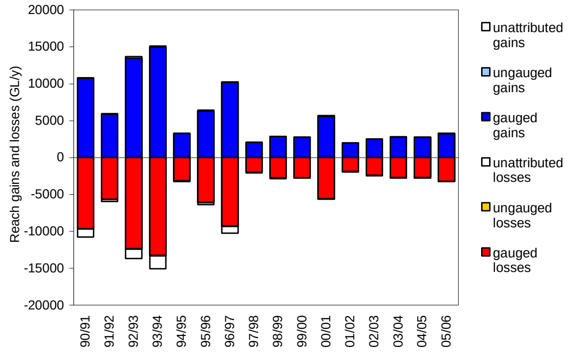
Most of the inflows are gauged. There are no recorded diversions and ungauged losses are modest

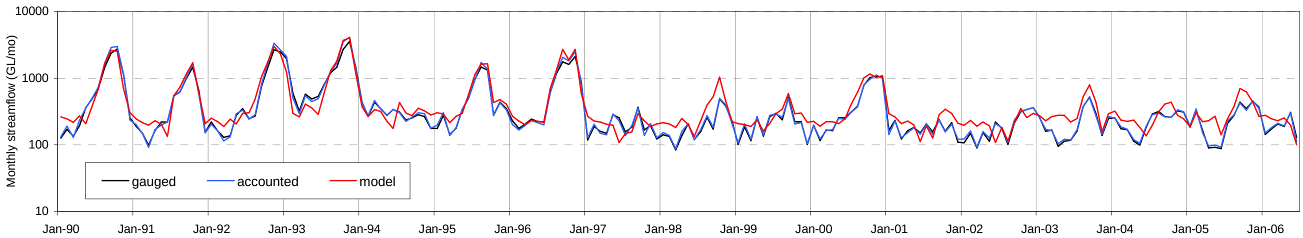
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally greater than river model uncertainty, except for the Cwet and Dwet scenarios where they are similar to model uncertainty.

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

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.00	-0.09	**-0.89**	-0.36	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.05	-0.16	**-0.84**	-0.30	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.12	-0.14	-0.29	-0.29	Adjusted -100.0%

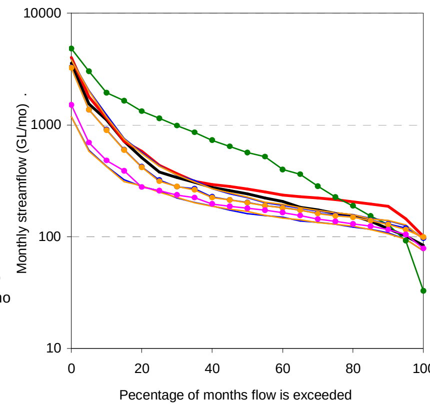




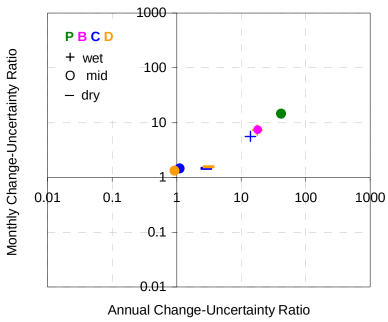
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5897	5683	214
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	80	-80
Losses	GL/y	GL/y	GL/y
Main stem outflows	6050	5339	711
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	36	-36
Unspecified losses	0	-	0
Unattributed losses and noise	-	387	-387
	-153	0	-153

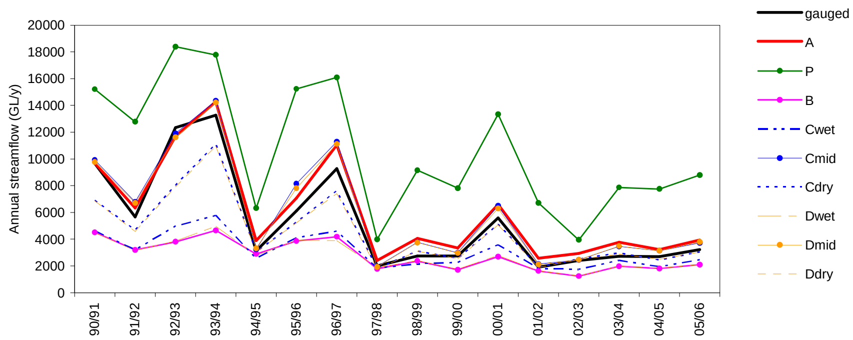
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.90	0.96
Log-normalised	0.78	0.99
Ranked	0.59	0.99
Low flows only	<0	0.49
High flows only	0.56	0.74
Annual		
Normal	0.94	0.98
Log-normalised	0.89	0.99
Ranked	0.96	0.98

Definitions:
- low flows (flows<10% percentile) : 117.8 GL/mo
- high flows (flows>90% percentile) : 1108.8 GL/mo



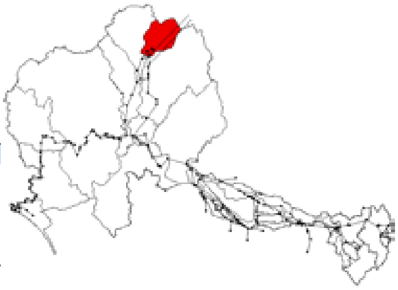
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	41.7	14.0	1.1	2.9	17.8	0.9	3.1	18.1
Monthly streamflow	14.5	5.6	1.5	1.5	7.3	1.3	1.6	7.5





Downstream gauge	425012 Darling @ Weir 32	Reach 23
Upstream gauge	425008 Darling @ Wilcannia	

Reach length (km)	192
Area (km^2)	5073
Outflow/inflow ratio	0.76
Net losing reach	



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

Most of the inflows are gauged. There are no recorded diversions and ungauged losses are large

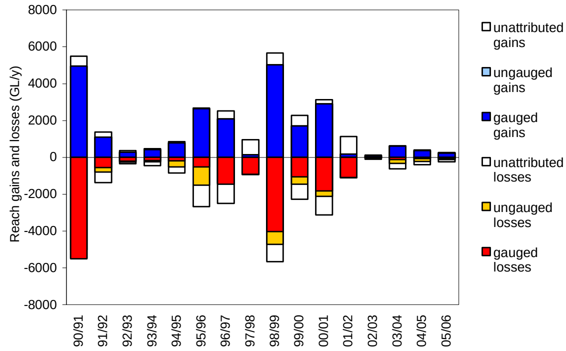
Baseline model performance is reasonable to good. Accounting also explains observed flows reasonably well to well.

The projected changes are greater than river model uncertainty in several scenarios, but are less than river model uncertainty for the B and Cmid scenarios, and for monthly preojected changes in several scenarios.

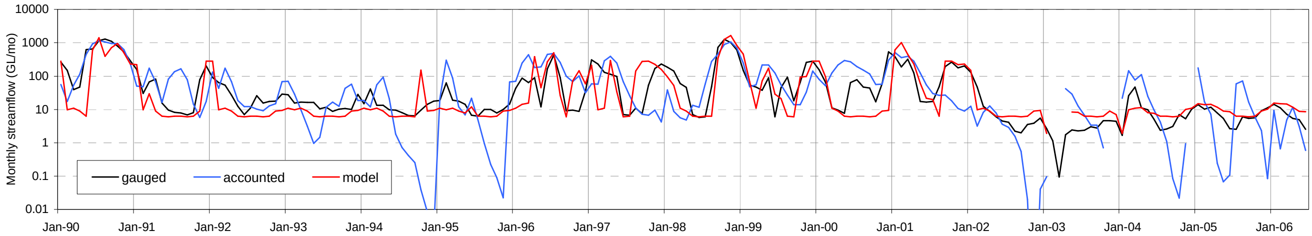
Land use	ha	%
Dryland	365,011	72
Irrigable area	-	-
Open water*	-	-
River and wetlands	142,280	28
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.82	0.62	0.72
Attributed	0.82	0.76	0.79
Fraction of variance			
Gauged	0.94	0.73	0.84
Attributed	0.94	0.94	0.94



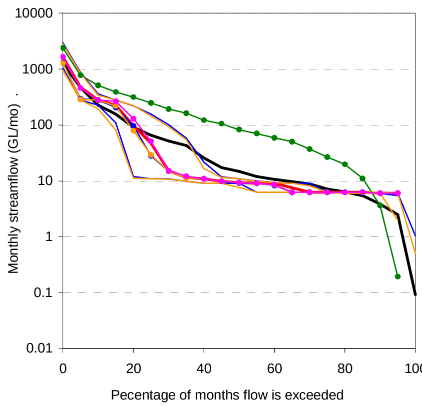
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.02	-0.18	**-0.66**	**-0.74**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.44	-0.50	-0.13	-0.15	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.05	-0.02	-0.01	-0.07	Adjusted -100.0%



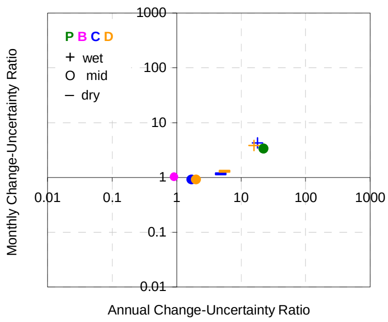
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	1465	-1465
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	327	-327
Losses	GL/y	GL/y	GL/y
Main stem outflows	1172	1120	52
Distributary outflows	0	0	0
Net diversions	0	56	-56
River flux to groundwater	0	-	0
River and floodplain losses	0	181	-181
Unspecified losses	0	-	0
Unattributed losses and noise	-	436	-436
	-1172	0	-1172

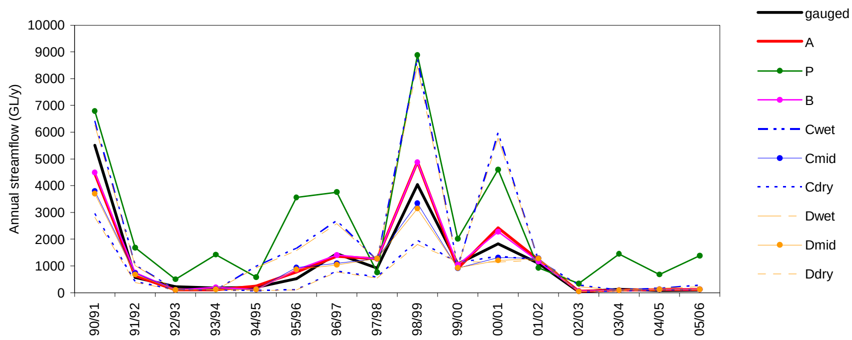
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.62	0.77
Log-normalised	-	-
Ranked	0.46	0.06
Low flows only	<0	<0
High flows only	0.15	0.76
Annual		
Normal	0.93	0.89
Log-normalised	0.93	0.19
Ranked	0.87	0.30

Definitions:
- low flows (flows<10% percentile) : 3.9 GL/mo
- high flows (flows>90% percentile) : 226.5 GL/mo



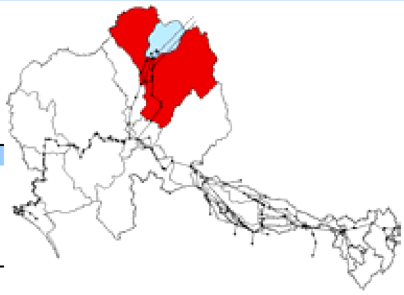
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	22.4	0.9	17.9	1.7	4.8	15.8	2.0	5.5
Monthly streamflow	3.4	1.0	4.2	0.9	1.2	3.8	0.9	1.3





Downstream gauge	425007 Darling @ Burtundy	Reach 24a
Upstream gauge	425012 Darling @ Weir 32	

Reach length (km)	358
Area (km^2)	32897
Outflow/inflow ratio	0.77
Net losing reach	



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

Most of the inflows are gauged. There are few recorded diversions and ungauged losses are small.

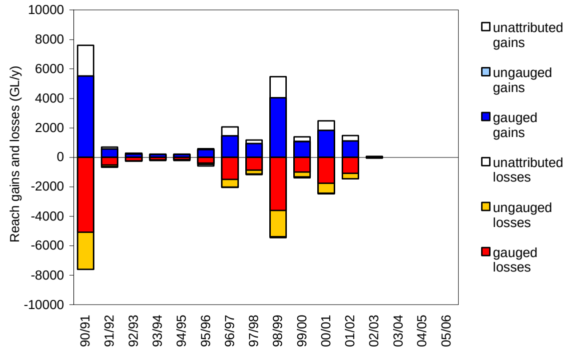
Baseline model performance is good. Accounting also explains observed flows very well.

The projected changes are generally greater or much greater than river model uncertainty.

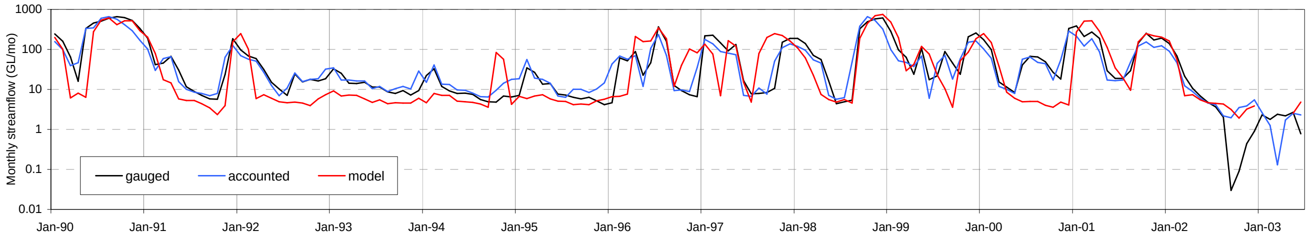
Land use	ha	%
Dryland	2,871,560	87
Irrigable area	-	-
Open water*	-	-
River and wetlands	418,090	13
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.74	0.69	0.72
Attributed	0.74	0.98	0.86
Fraction of variance			
Gauged	0.91	0.87	0.89
Attributed	0.91	1.00	0.95



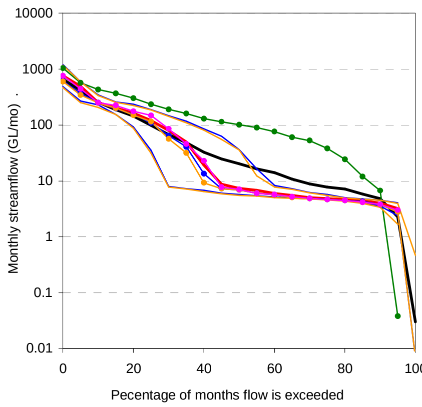
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.22	-0.10	**-0.69**	-0.49	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.42	-0.31	-0.47	-0.26	
Distributary outflows	-0.30	-0.28	-0.33	-0.07	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.00	-0.13	-0.00	-0.21	Adjusted -97.2%



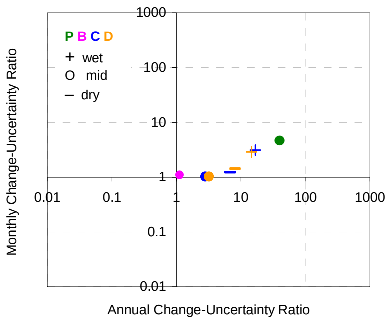
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1418	1356	62
Tributary inflows	0	0	0
Local inflows	0	3	-3
Unattributed gains and noise	-	469	-469
Losses	GL/y	GL/y	GL/y
Main stem outflows	1065	1042	23
Distributary outflows	0	223	-223
Net diversions	0	13	-13
River flux to groundwater	0	-	0
River and floodplain losses	0	515	-515
Unspecified losses	0	-	0
Unattributed losses and noise	-	36	-36
	353	0	353

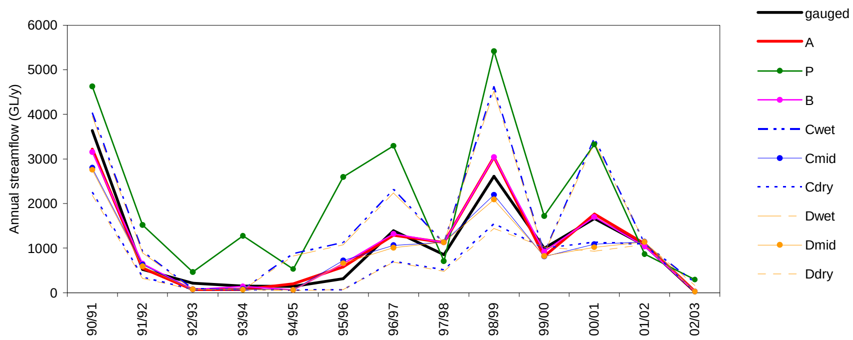
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.74	0.85
Log-normalised	-	-
Ranked	0.51	0.84
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	0.96	0.91
Log-normalised	0.90	0.97
Ranked	0.92	0.99

Definitions:
- low flows (flows<10% percentile) : 4.8 GL/mo
- high flows (flows>90% percentile) : 254.9 GL/mo



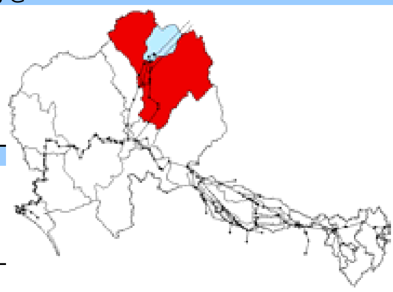
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	39.8	1.1	16.7	2.8	6.8	14.7	3.2	8.1
Monthly streamflow	4.6	1.1	3.1	1.0	1.2	2.9	1.0	1.4





Downstream gauge	425007 Great Darling Anabraanch @ Wycot	Reach 24b
Upstream gauge	425012 Darling @ Weir 32	

Reach length (km)	358
Area (km^2)	32897
Outflow/inflow ratio	0.16
Net losing reach	



Land use	ha	%
Dryland	2,871,560	87
Irrigable area	-	-
Open water*	-	-
River and wetlands	418,090	13
Open water*	-	-

* averages for 1990–2006

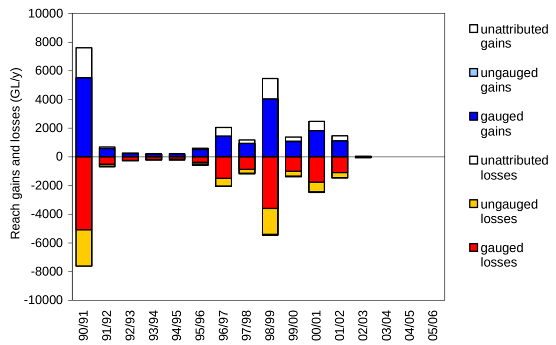
This is a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are few recorded diversions and ungauged losses are small.

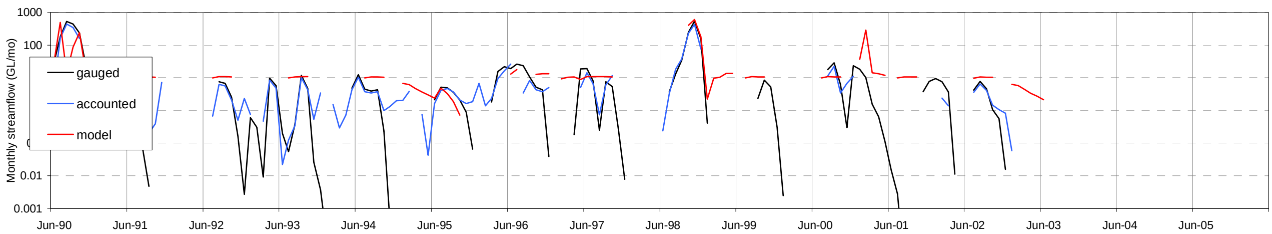
Baseline model performance is poor. Accounting also explains observed flows very well.

The projected changes are greater than river model uncertainty in some scenarios, but similar or less than model uncertainty in the B, Cmid and Dmid scenarios and in the monthly projected changes of the Cdry and Ddry scenarios.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.74	0.69	0.72
Attributed	0.75	0.98	0.86
Fraction of variance			
Gauged	0.91	0.87	0.89
Attributed	0.91	1.00	0.95



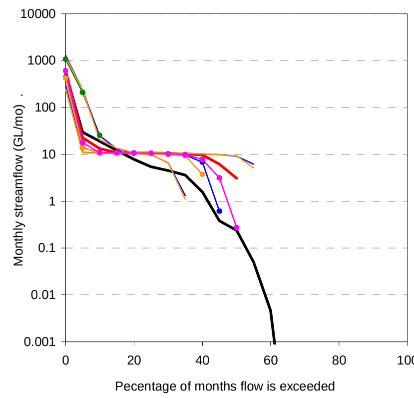
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.22	-0.10	**-0.69**	-0.49	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.30	-0.28	-0.33	-0.07	
Distributary outflows	-0.42	-0.31	-0.47	-0.26	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.00	-0.13	-0.00	-0.21	Adjusted -97.4%



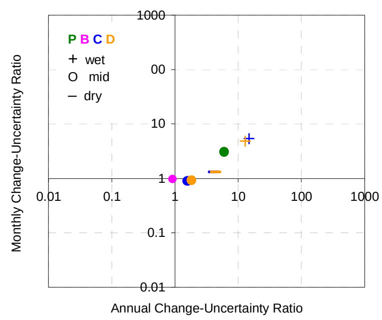
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	1418	1356	62
Tributary inflows	0	0	0
Local inflows	0	3	-3
Unattributed gains and noise	-	464	-464
Losses	GL/y	GL/y	GL/y
Main stem outflows	236	223	14
Distributary outflows	0	1042	-1042
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	517	-517
Unspecified losses	0	-	0
Unattributed losses and noise	-	41	-41
	1181	0	1181

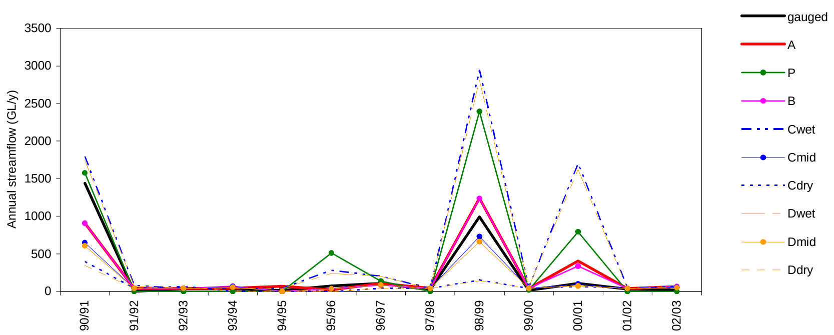
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.32	0.94
Log-normalised	-	-
Ranked	0.05	<0
Low flows only	-	-
High flows only	0.09	0.93
Annual		
Normal	0.82	0.91
Log-normalised	0.38	#NUM!
Ranked	0.14	0.20

Definitions:
- low flows (flows<10% percentile) : 0.0 GL/mo
- high flows (flows>90% percentile) : 18.9 GL/mo



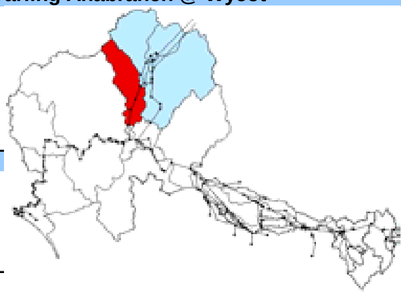
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.0	0.9	14.8	1.6	4.1	12.9	1.8	4.4
Monthly streamflow	3.1	1.0	5.4	0.9	1.3	4.8	0.9	1.3





Downstream gauge	425011 Great Darling Anabranch @ Bulpunga	Reach 25
Upstream gauge	425007 Great Darling Anabranch @ Wycot	

Reach length (km)	201
Area (km^2)	9090
Outflow/inflow ratio	0.37
Net losing reach	



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

Most of the inflows are gauged. There are no recorded diversions and ungauged losses are large

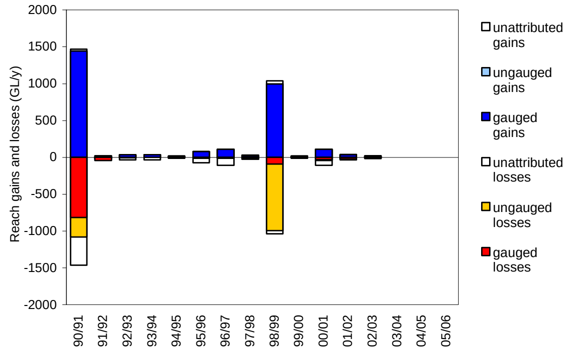
Baseline model performance is very poor. Accounting explains observed flows well.

The projected changes are generally similar to or less than river model uncertainty.

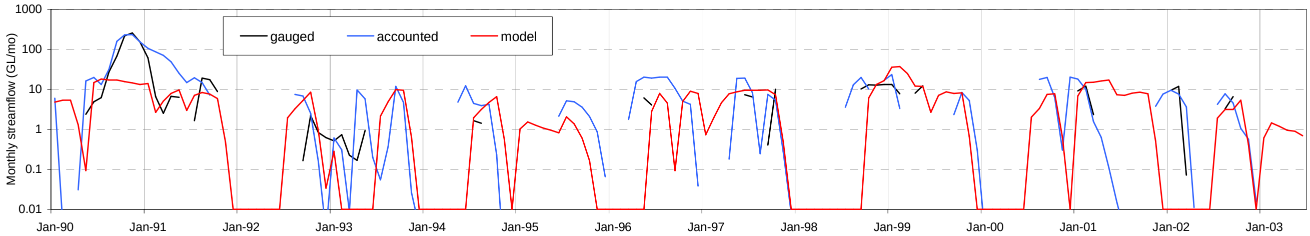
Land use	ha	%
Dryland	821,442	90
Irrigable area	-	-
Open water*	-	-
River and wetlands	87,600	10
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.85	0.31	0.58
Attributed	0.85	0.81	0.83
Fraction of variance			
Gauged	1.00	0.07	0.53
Attributed	1.00	0.98	0.99



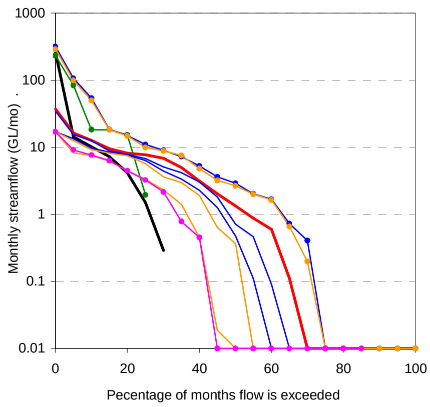
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.01	-0.06	**-0.97**	**-0.90**	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.80**	**-0.66**	-0.13	-0.21	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.03	-0.13	-0.05	-0.09	Adjusted -100.0%



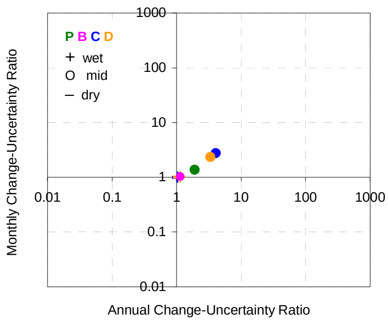
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	236	223	14
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	38	-38
Losses	GL/y	GL/y	GL/y
Main stem outflows	53	82	-29
Distributary outflows	0	0	0
Net diversions	0	40	-40
River flux to groundwater	0	-	0
River and floodplain losses	0	89	-89
Unspecified losses	0	-	0
Unattributed losses and noise	-	50	-50
	183	0	183

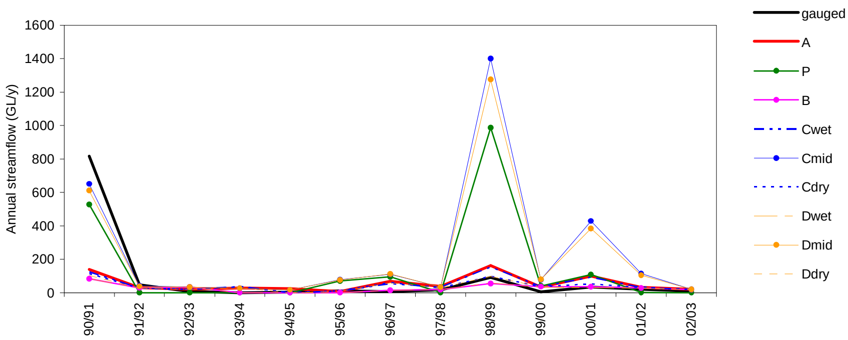
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.09	0.79
Log-normalised	-	-
Ranked	<0	<0
Low flows only	-	-
High flows only	<0	0.89
Annual		
Normal	0.20	0.79
Log-normalised	0.03	-
Ranked	0.14	0.03

Definitions:
- low flows (flows<10% percentile) : 0.0 GL/mo
- high flows (flows>90% percentile) : 10.1 GL/mo



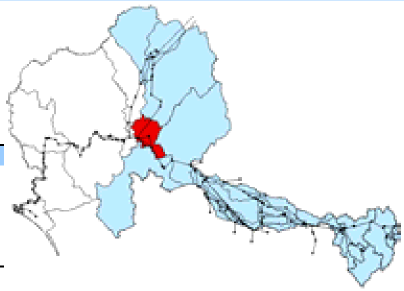
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.9	1.0	4.1	1.0	1.1	3.4	1.1	1.1
Monthly streamflow	1.4	1.0	2.8	1.0	1.0	2.3	1.0	1.0





Downstream gauge	425010 Murray @ Wentworth	Reach 26
Upstream gauge	414207 Murray @ Colignan	

Reach length (km)	265
Area (km^2)	3933
Outflow/inflow ratio	1.18
Net gaining reach	



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

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

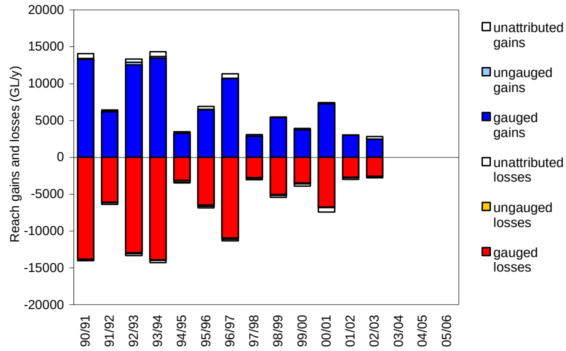
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

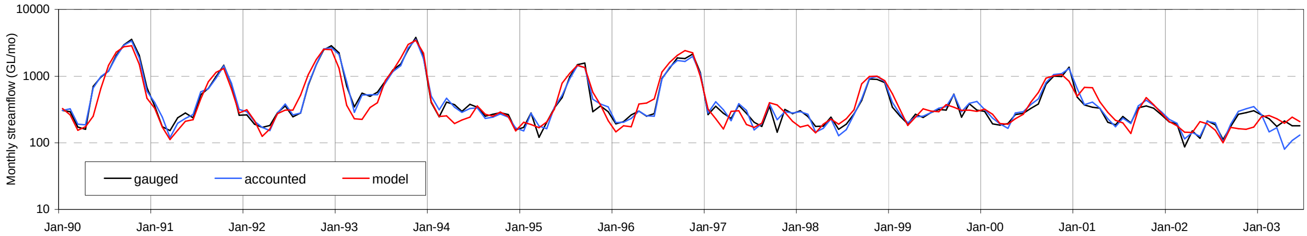
Land use	ha	%
Dryland	358,822	91
Irrigable area	-	-
Open water*	-	-
River and wetlands	34,480	9
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.94	0.96	0.95
Attributed	0.96	0.97	0.96
Fraction of variance			
Gauged	0.99	0.99	0.99
Attributed	0.99	1.00	1.00



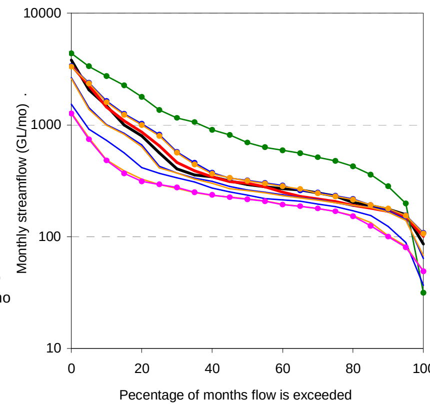
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.52	-0.22	-0.21	-0.00	
Tributary inflows	-0.02	-0.30	-0.23	-0.38	
Main gauge outflows	-0.59	-0.20	-0.17	-0.15	
Distributary outflows	-	-	-	-	
Recorded diversions	-0.20	-0.02	-0.24	-0.28	
Estimated local runoff	-0.31	-0.03	-0.23	-0.10	Adjusted 981.0%



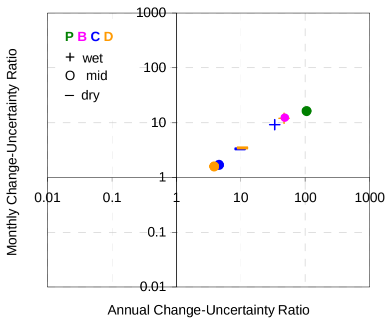
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	6607	5906	700
Tributary inflows	0	1042	-1042
Local inflows	0	111	-111
Unattributed gains and noise	-	322	-322
Losses	GL/y	GL/y	GL/y
Main stem outflows	7007	6971	36
Distributary outflows	0	0	0
Net diversions	0	134	-134
River flux to groundwater	0	-	0
River and floodplain losses	0	77	-77
Unspecified losses	0	-	0
Unattributed losses and noise	-	199	-199
	-401	0	-401

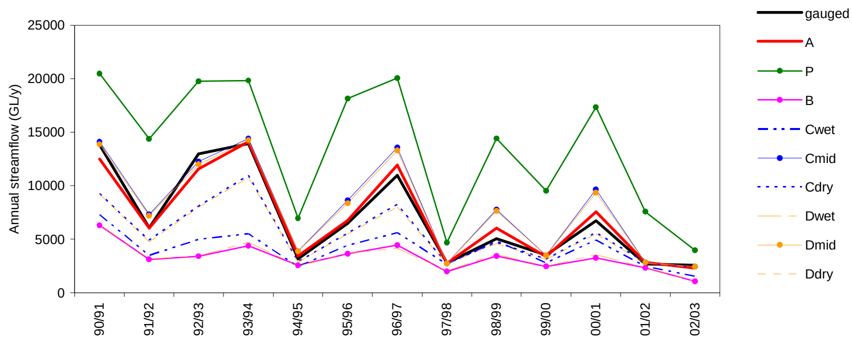
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	0.99
Log-normalised	0.86	0.96
Ranked	0.70	0.94
Low flows only	<0	<0
High flows only	0.64	0.95
Annual		
Normal	0.97	0.99
Log-normalised	0.98	0.99
Ranked	0.96	0.99

Definitions:
- low flows (flows<10% percentile) : 176.9 GL/mo
- high flows (flows>90% percentile) : 1487.2 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	104.8	33.6	4.6	9.7	47.0	3.8	10.6	48.1
Monthly streamflow	16.3	9.1	1.7	3.3	12.0	1.6	3.4	12.3



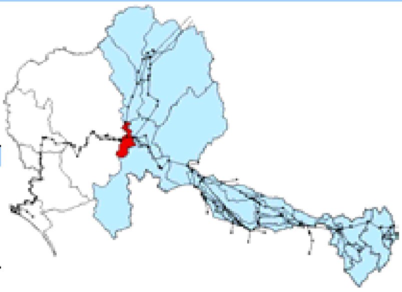


Downstream gauge	**426505 Murray @ Lock 9**	**Reach 27**
Upstream gauge	**414210 Murray @ Wentworth**	

Reach length (km)	128
Area (km^2)	1657
Outflow/inflow ratio	0.72
Net losing reach	

Land use	ha	%
Dryland	153,924	93
Irrigable area	-	-
Open water*	-	-
River and wetlands	11,820	7
Open water*	-	-

* averages for 1990–2006



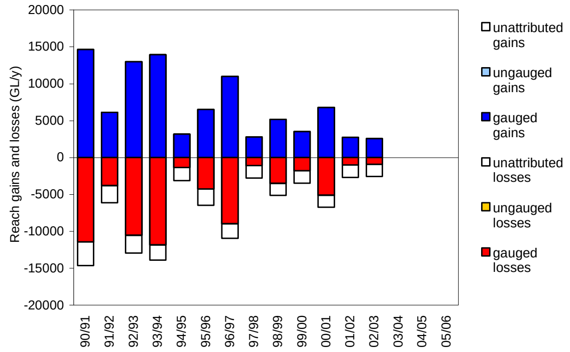
This is a strongly losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are no recorded diversions and ungauged losses are very large

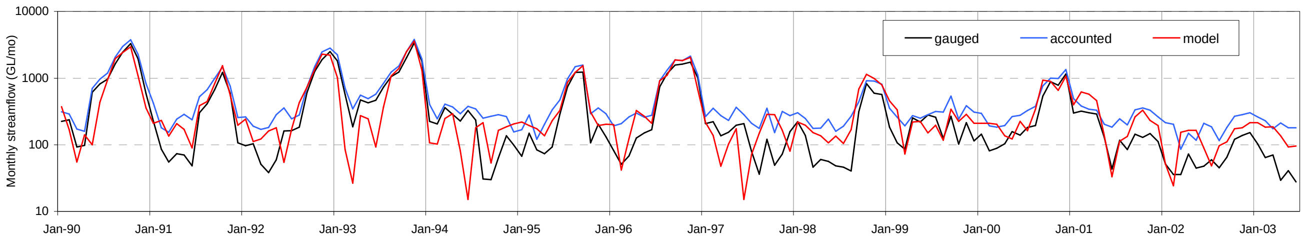
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are much greater than river model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	1.00	0.72	0.86
Attributed	1.00	0.72	0.86
Fraction of variance			
Gauged	1.00	0.98	0.99
Attributed	1.00	0.98	0.99



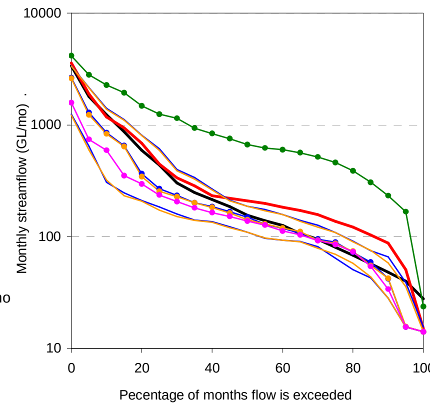
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-	-	**-0.78**	**-0.56**	
Tributary inflows	-	-	-0.34	-0.20	
Main gauge outflows	-	-	**-0.71**	-0.26	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-	-	-0.38	-0.28	Adjusted -100.0%



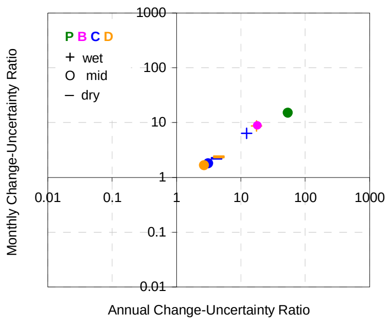
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	7007	6971	36
Tributary inflows	0	82	-82
Local inflows	0	0	0
Unattributed gains and noise	-	0	0
Losses	GL/y	GL/y	GL/y
Main stem outflows	5548	5047	501
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	18	-18
Unspecified losses	0	-	0
Unattributed losses and noise	-	1989	-1989
	1460	0	1460

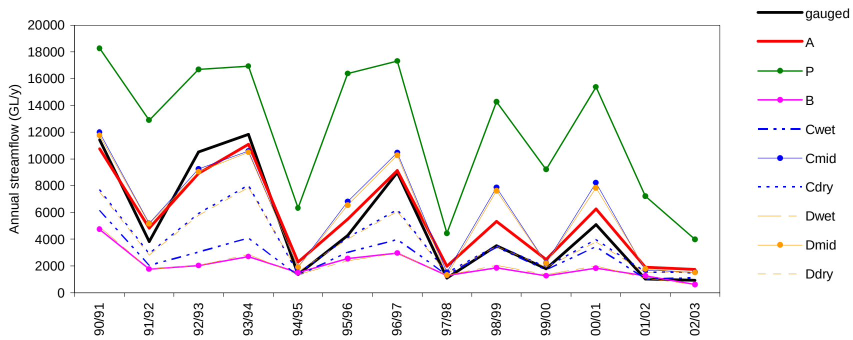
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.90	0.90
Log-normalised	0.57	0.49
Ranked	0.46	0.82
Low flows only	<0	<0
High flows only	0.62	0.67
Annual		
Normal	0.93	0.74
Log-normalised	0.83	0.57
Ranked	0.98	0.99

Definitions:
- low flows (flows<10% percentile) : 47.9 GL/mo
- high flows (flows>90% percentile) : 1227.0 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	53.6	12.3	3.1	4.2	17.5	2.7	4.6	17.9
Monthly streamflow	15.1	6.3	1.8	2.2	8.7	1.7	2.4	8.8



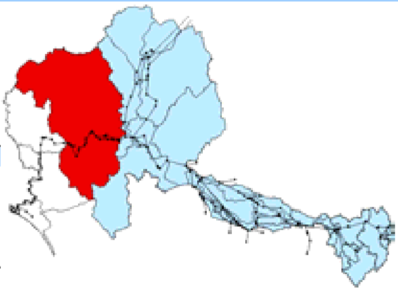


Downstream gauge	426528 Murray @ Overland Corner	Reach 28
Upstream gauge	426505 Murray @ Lock 9	

Reach length (km)	348
Area (km^2)	50812
Outflow/inflow ratio	1.22
Net gaining reach	

Land use	ha	%
Dryland	4,978,900	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	102,340	2
Open water*	-	-

* averages for 1990–2006

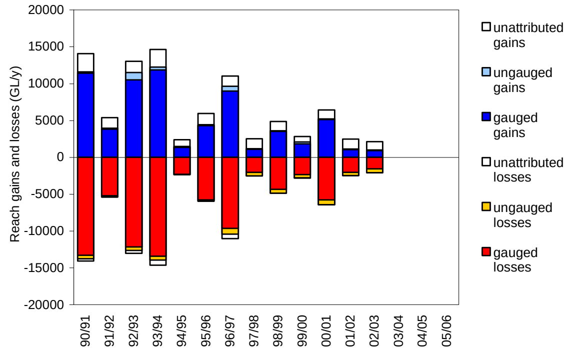


This is a gaining reach. Flows are dominated by inflows from upstream.

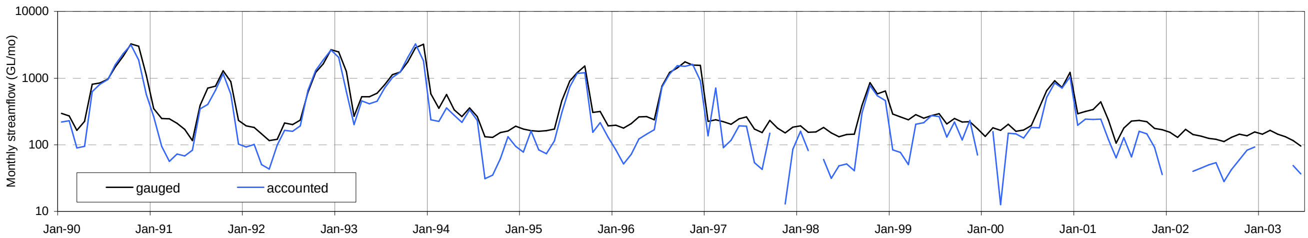
Most of the inflows are gauged. There are some recorded diversions and ungauged losses are modest

No modelling results are available for this reach. Accounting explains observed flows very well.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.75	0.91	0.83
Attributed	0.79	0.98	0.88
Fraction of variance			
Gauged	0.93	0.99	0.96
Attributed	0.94	0.99	0.97



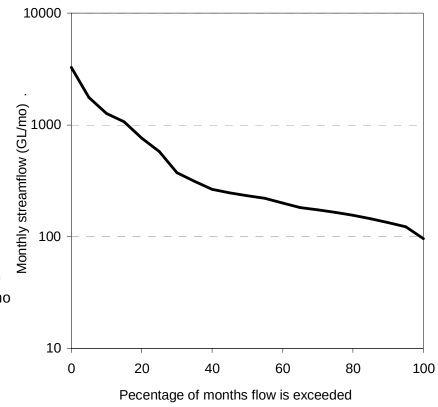
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.20	-0.26	**-0.63**	-0.43	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.47	-0.03	-0.48	-0.37	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.18	-0.04	-0.06	-0.17	Adjusted 65.8%



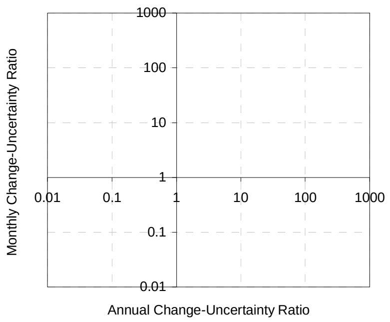
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	5548	5047	501
Tributary inflows	0	0	0
Local inflows	0	252	-252
Unattributed gains and noise	-	1447	-1447
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	6156	-6156
Distributary outflows	0	0	0
Net diversions	0	219	-219
River flux to groundwater	0	-	0
River and floodplain losses	0	217	-217
Unspecified losses	0	-	0
Unattributed losses and noise	-	154	-154
	5548	0	5548

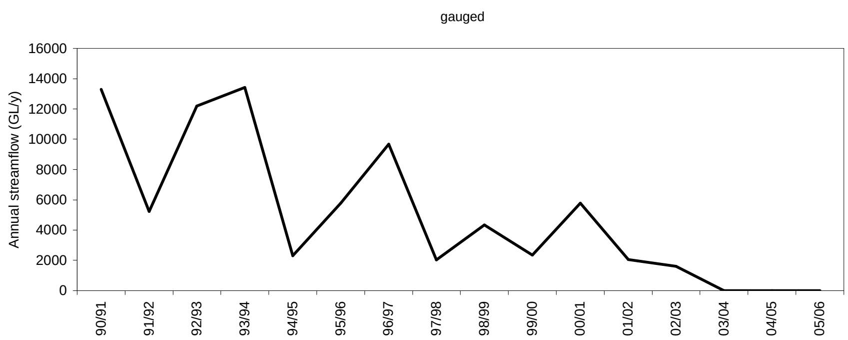
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.89
Log-normalised	-	-
Ranked	<0	0.84
Low flows only	<0	<0
High flows only	<0	0.43
Annual		
Normal	<0	0.93
Log-normalised	-	-
Ranked	<0	0.99

Definitions:
- low flows (flows<10% percentile) : 133.7 GL/mo
- high flows (flows>90% percentile) : 1267.8 GL/mo



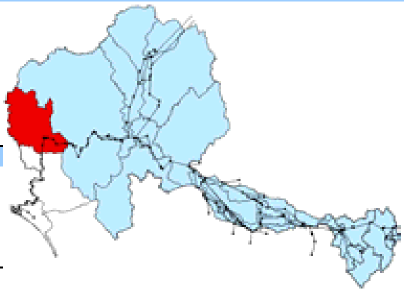
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow								
Monthly streamflow								





Downstream gauge	426903 Murray @ Lock 1	Reach 29
Upstream gauge	426528 Murray @ Overland Corner	

Reach length (km)	143
Area (km^2)	12908
Outflow/inflow ratio	0.93
Net losing reach	



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

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

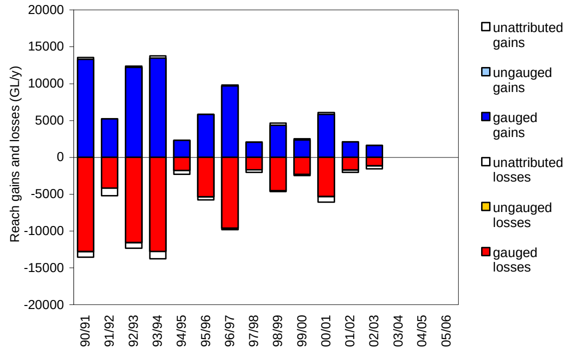
Baseline model performance is very good. Accounting also explains observed flows extremely well.

The projected changes are generally much greater than river model uncertainty.

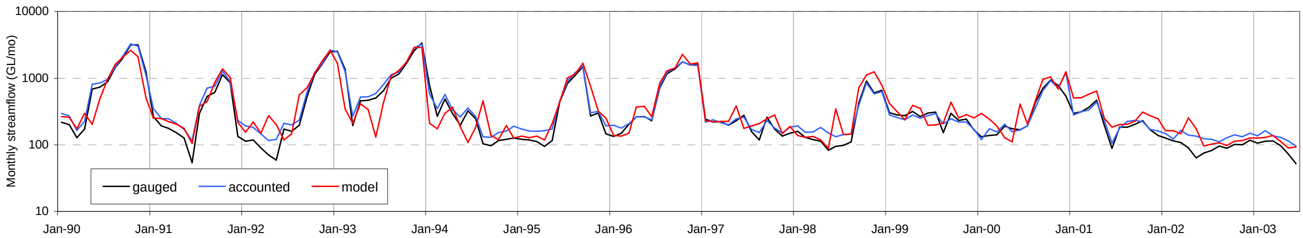
Land use	ha	%
Dryland	1,282,050	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	8,770	1
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.98	0.91	0.95
Attributed	0.98	0.92	0.95
Fraction of variance			
Gauged	1.00	0.99	0.99
Attributed	1.00	0.99	0.99



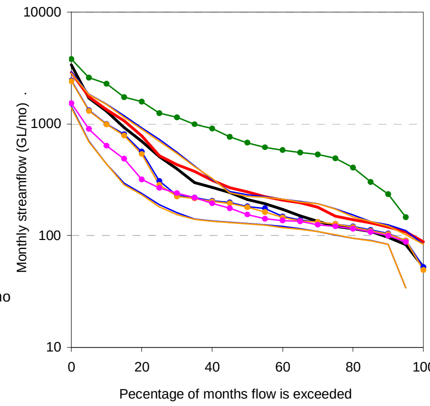
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.36	-0.36	-0.28	-0.12	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.43	-0.42	-0.17	-0.04	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.10	-0.01	-0.06	-0.07	Adjusted -100.0%



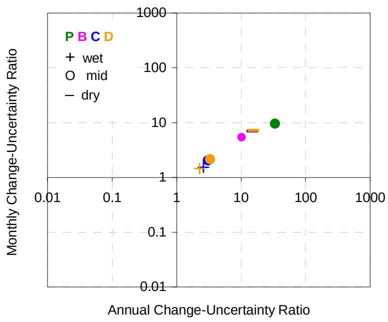
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	6156	-6156
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	131	-131
Losses	GL/y	GL/y	GL/y
Main stem outflows	6153	5746	407
Distributary outflows	0	0	0
Net diversions	0	17	-17
River flux to groundwater	0	-	0
River and floodplain losses	0	12	-12
Unspecified losses	0	-	0
Unattributed losses and noise	-	511	-511
	-6153	0	-6153

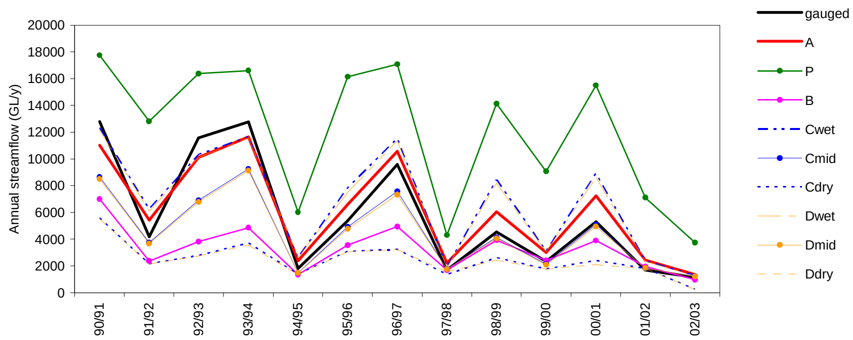
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.88	0.98
Log-normalised	0.78	0.93
Ranked	0.67	0.95
Low flows only	<0	<0
High flows only	0.71	0.97
Annual		
Normal	0.92	0.99
Log-normalised	0.92	0.97
Ranked	0.93	0.98

Definitions:
- low flows (flows<10% percentile) : 96.2 GL/mo
- high flows (flows>90% percentile) : 1298.9 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	33.4	10.2	2.6	3.1	14.9	2.3	3.3	15.4
Monthly streamflow	9.5	5.4	1.5	2.0	7.0	1.5	2.1	7.2





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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.