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Water Availability in the Loddon-Avoca

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

May 2008

Murray-Darling Basin Sustainable Yields Project acknowledgments

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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 Loddon-Avoca region. While key aspects of the assessment and modelling methods used in the project are contained in this report, fuller methodological descriptions will be provided in a series of project technical reports.

The Loddon-Avoca region is in northern Victoria and covers 2.3 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the Loddon and Avoca Rivers. The population is 142,000 or 7.2 percent of the MDB total, concentrated in the centres of Bendigo, St Arnaud, Charlton and Boort. Over 80 percent of the region is used for dryland agriculture, primarily cereal cropping and grazing. An extensive area of the riverine plain is irrigated from Boort to the Murray River and dairying predominates. Approximately 127,000 ha were irrigated in 2000 including 106,600 ha for pastures and hay and 16,000 ha for cereal production. The Kerang Wetlands that spans the boundary of the Loddon and Murray regions is listed as a Ramsar site of international significance. A number of other sites within the region are nationally important. The region uses 0.8 percent of the surface water diverted for irrigation in the MDB and 1.7 percent of the total groundwater used in the MDB. Water from the Campaspe and Goulburn River systems delivered via the Waranga Western Channel supplements water sourced from within the Loddon-Avoca region. The Nyah area in the north-west is serviced directly from the Murray River and use in this area is considered in the report for the Murray region.

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 against which other scenarios are compared.

Historical climate and current development (Scenario A)

The annual rainfall and modelled runoff averaged over the region is 430 mm and 21 mm, respectively. Rainfall is generally higher in the winter half of the year and most of the runoff occurs in winter and early spring. The Loddon-Avoca region generates about 1.7 percent of total MDB runoff.

Current average surface water availability for the Loddon-Avoca region is 285 GL/year – 201 GL/year generated from runoff in the Loddon catchment and 84 GL/year from runoff generated in the Avoca catchment. On average, 349 GL/year are diverted for use in the Loddon catchment (including channel and pipe losses); there are no surface water diversions in the Avoca catchment. Around 92 GL/year (of the total 349 GL/year diverted for use) are sourced within the region, thus the level of surface water use is 32 percent. This is a high level of development. The other 257 GL/year that is diverted for use is supported by the 264 GL/year transferred from the Goulburn-Broken region via the Campaspe region by means of the Waranga Western Channel. This water use (and the associated water availability) is accounted at the point of diversion (in the Goulburn-Broken region) not at the points of use (in the Loddon-Avoca and other regions).

Reliability of supply is determined separately for high reliability water shares (HRWS) and low reliability water shares (LRWS) and is reported for allocations in February. In the regulated Loddon system, a 100 percent HRWS allocation occurs in 92 percent of years and the minimum HRWS allocation is 58 percent. A 100 percent LRWS allocation occurs in 42 percent of years and a zero LRWS allocation occurs in 24 percent of years.

Groundwater extraction in the Loddon-Avoca Region for 2004/05 is estimated to be 29 GL. About 64 percent of this extraction was from the Mid-Loddon Groundwater Management Unit (GMU). Groundwater use represents 9 percent of total current water use on average and 14 percent of total water use in years of lowest surface water use. Extraction is currently at a medium level of development (30 to 70 percent of recharge) for all GMUs in the region.

Modelling suggests that historical groundwater extraction has and will continue to impact on streamflow in the region. The eventual impact on streamflow will be a loss to groundwater of 5.4 GL/year compared to that included in current river planning models.

Mid-Loddon GMU water levels in the confined Calivil Formation and Renmark Formations have fallen between 1 and 5 m since the mid 1990s. Similar declines in Shepparton Formation water levels are attributed to downward leakage caused by pumping in the underlying Calivil Formation. Falls of up to 10 m have occurred since the mid-1990s in the fractured basalt aquifers of Spring Hill GMU.

Water resources development has decreased the frequency and magnitude of small winter floods that benefit riparian and floodplain ecosystems along the lower Loddon River. The average period between small winter floods has increased from around 10 months to 18 months and the average annual flooding volume of small winter floods has halved. These changes are likely to have had significant ecological impacts. Additionally, the percentage of months with undesirably low flows in the lower Loddon River during the winter–spring period has increased from 21 to 31 percent. This has degraded native fish habitat with consequences for native fish populations.

Recent climate and current development (Scenario B)

The average annual rainfall and runoff over the past ten years (1997 to 2006) are 11 percent and 52 percent lower respectively than the long-term (1895 to 2006) average values. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 average at a significance level of $\alpha = 0.2$ and the 1997 to 2006 runoff is statistically different to the 1895 to 1996 average at a significance level of $\alpha = 0.05$.

If the climate of the last ten years were to continue, average surface water availability would be reduced by 50 percent and total end-of-system flows would be reduced by 71 percent. The volume of water diverted for use within the region would be reduced by 28 percent. A 100 percent HRWS allocation would occur in 47 percent of years and the minimum HRWS allocation would be 1 percent. A 100 percent LRWS allocation would occur in 2 percent of years and a zero LRWS allocation would occur in 88 percent of years. Transfers from the Campaspe region via the Waranga Western Channel would be reduced by 24 percent. The relative level of surface water use would rise to a very high 41 percent.

Under a long-term continuation of the recent (1997 to 2006) climate the average period between small winter floods which benefit the lower river riparian and floodplain systems would increase by 43 percent and the average volume of these floods would decrease by 65 percent. The total flooding volume would be thus 75 percent lower or 13 percent of the without-development value. This climate would also lead to undesirably low flow conditions in 58 percent of winter–spring months further degrading native fish habitat.

Future climate and current development (Scenario C)

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Loddon-Avoca will decrease significantly. Under the best estimate (median) 2030 climate average annual runoff would be reduced by 16 percent. The extreme estimates from the high global warming scenario range from a 43 percent reduction to no change in mean annual runoff.

Under the best estimate (median) 2030 climate, average surface water availability in the region would be reduced by 18 percent and total end-of-system flows would be reduced by 27 percent. The volume of water diverted for use within the region would be reduced by 6 percent. A 100 percent HRWS allocation would occur in 83 percent of years and the minimum HRWS allocation would be 15 percent. A 100 percent LRWS allocation would occur in 21 percent of years and a zero LRWS allocation would occur in 36 percent of years. Transfers from the Waranga Western Channel would be reduced by 4 percent. The relative level of surface water use would increase to 35 percent.

Under the wet 2030 climate extreme, average surface water availability in the region would be reduced by 5 percent and total end-of-system flows would be reduced by 6 percent. The volume of water diverted for use within the region and the reliability of supply would not be greatly impacted, and there would be no significant change in Waranga Western Channel transfers. Under the dry 2030 climate extreme, water resources conditions will be broadly equivalent to a continuation of the recent climate.

Under the best estimate 2030 climate the average period between ecologically beneficial small winter floods would not change greatly. However, floods would be smaller such that the average annual volume would be reduced by 32 percent.

This climate would lead to undesirably low flow conditions that degrade fish habitat in 37 percent of winter–spring months. Under the dry 2030 climate extreme conditions would be similar to a continuation of the recent climate. The wet 2030 climate extreme would lead to conditions similar to those under the historical climate and current development.

Future climate and future development (Scenario D)

The projected 2030 growth in commercial forestry plantations is negligible. The total farm dam storage capacity is projected to increase by 3070 ML (3 percent) by 2030. This would reduce average annual runoff by about 1 percent. The best estimate of the combined impact of climate change and farm dam development would be a 17 percent reduction in average annual runoff. Extreme estimates range from a 44 to a 1 percent reduction.

Groundwater extraction in the region is expected to approximately double by 2030 to be 59 GL/year. The total eventual impact of groundwater extraction at projected 2030 levels would be an average streamflow reduction of 17 GL/year. Groundwater extraction under the best estimate 2030 climate would remain medium for the Mid-Loddon GMU and for the proposed Avoca GMU, but would be high for the Spring Hill GMU and very high for the Upper Loddon GMU where extraction would exceed recharge.

Projected future development would have minor impacts on streamflow and surface water use, and minimal impact on the frequency of environmentally important flows in the lower Loddon River.

Uncertainty

The runoff estimates for the Loddon-Avoca region are relatively good because there are many gauged catchments in the region from which to estimate the model parameter values. The largest source of uncertainty for future climate results 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). There are also considerable uncertainties associated with the projections of future increases in commercial forestry plantations and farm dam development and the impact of these developments on runoff. The increase in farm dams is estimated based on the current policy controls in Victoria that limit further farm dam development to stock and domestic dams and an assumption that growth in stock and domestic dam storage will be proportional to the rate of rural population growth. There is uncertainty both as to how land holders will respond to these policies and how governments may set policies in the future.

The model used for the Loddon-Avoca region, while well suited for the purpose of this project, requires some caution in interpreting the absolute and the relative changes in flow patterns and average flows in the Loddon below Loddon Weir. It reproduces observed streamflow patterns very well and produces estimates of water balance terms that agreed well with water balance accounts. The projected changes in flows due to climate change are greater than model noise under the dry extreme and best estimate 2030 climates, but similar to model noise for the wet extreme. The model provides strong evidence of changes in flow pattern due to water resources development, but the projected changes due to future development are negligible.

The groundwater assessments made for the Loddon-Avoca region applied a model constructed specifically for this project and subjected to rigorous internal review. However, only as it is used more widely, will it receive more thorough external peer review. Monitoring and extraction data is not as good as for some other areas such as the Namoi. Flows across boundaries represent about 12 percent of the modelled groundwater balance. The model is adequate for providing information on water availability in the context of this project, but less reliable for local management requirements. The model reached a dynamic equilibrium under both current and future extraction rates. The level of reliability of predictions could be improved to ‘very thorough’ by recognising the importance of the Calivil Formation as a groundwater resource.

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).

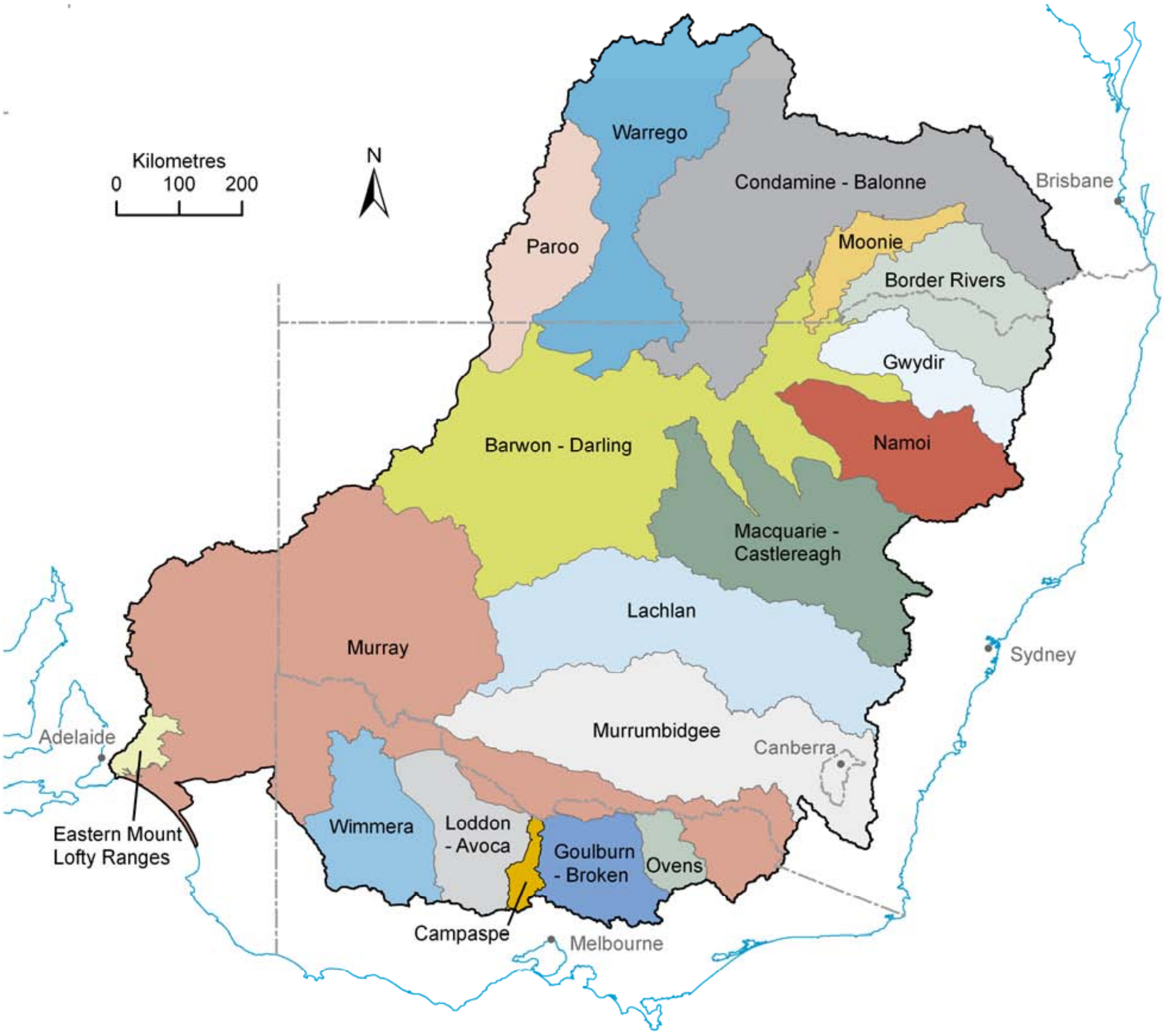

Figure 1-1. Region by region map of the Murray-Darling Basin

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 Figure 1-2. This also indicates in which chapters of this report the different aspects of the project assessments and results are presented.

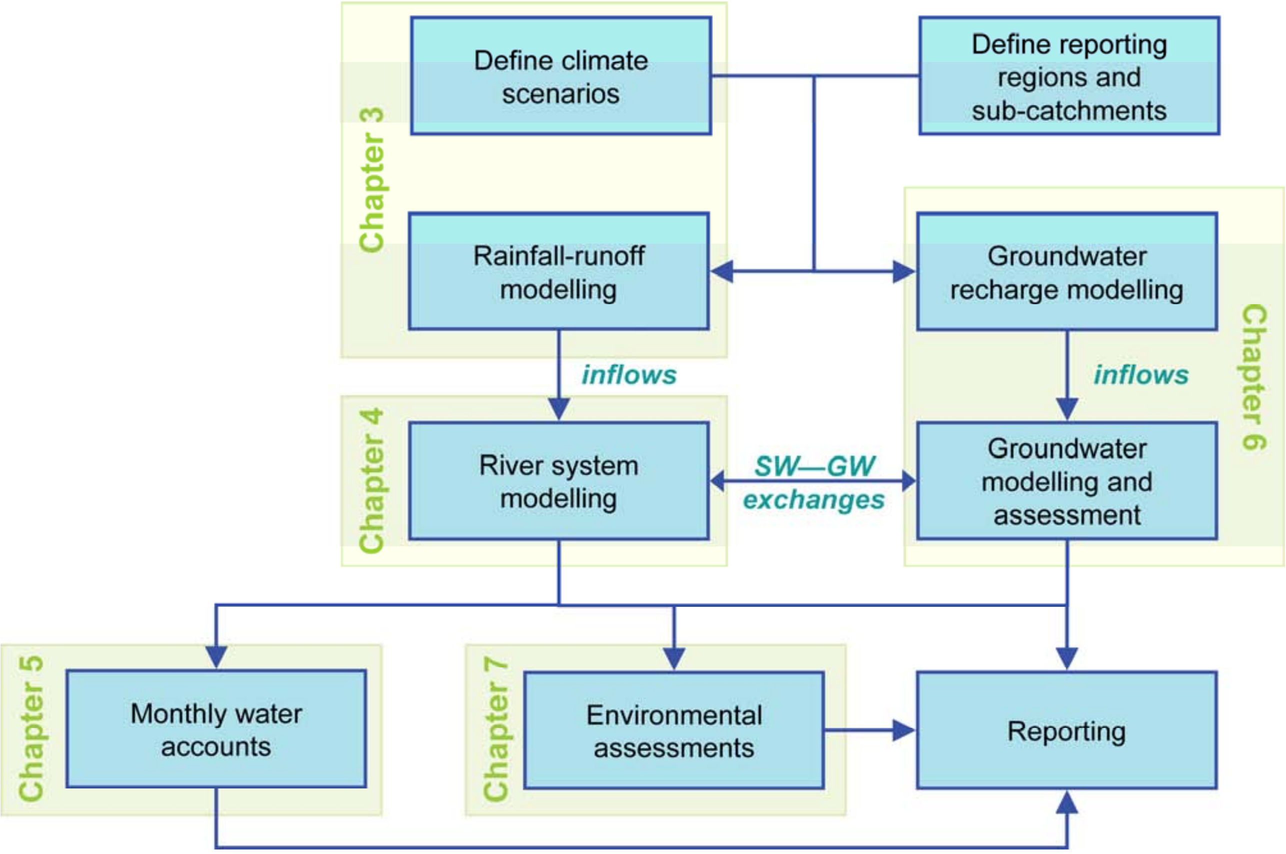

Figure 1-2. Methodological framework for the Murray-Darling Basin Sustainable Yields Project

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° x 0.05° (5 km x 5 km) grid across the continent (Jeffrey et al., 2001; and www.nrm.qld.gov.au/silo). Areal potential evapotranspiration (PET) data are calculated from the SILO climate surface using Morton's wet environment evapotranspiration algorithms (www.bom.gov.au/climate/averages; and Chiew and Leahy, 2003).

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

1.3.2 Recent climate and current development

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

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

1.3.3 Future climate and current development

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

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

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

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

1.3.4 Future climate and future development

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

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

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

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

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

1.4 Rainfall-runoff modelling

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

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

The model is calibrated against 1975 to 2006 streamflow data from about 200 unregulated catchments of 50 km^2 to 2000 km^2 across the MDB (calibration catchments). Although unregulated, streamflow in these catchments for the calibration period may in fact reflect some 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 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 more accurate 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 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; www.toolkit.net.au/fcfc).

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

1.5 River system modelling

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

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

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

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

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

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

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

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

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

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

1.5.1 Surface–groundwater interactions

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

The river models used by State agencies have typically been calibrated by State agencies to achieve mass balance within calibration reaches over relatively short time periods. When the models are run for extended periods the relationships derived during calibration are assumed to hold for the full modelling period. In many cases, however, the calibration period is a period of changing groundwater extraction and a period of changing impact of this extraction on the river system. That is, the calibration period is often one of changing hydrologic relationships, a period when 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.

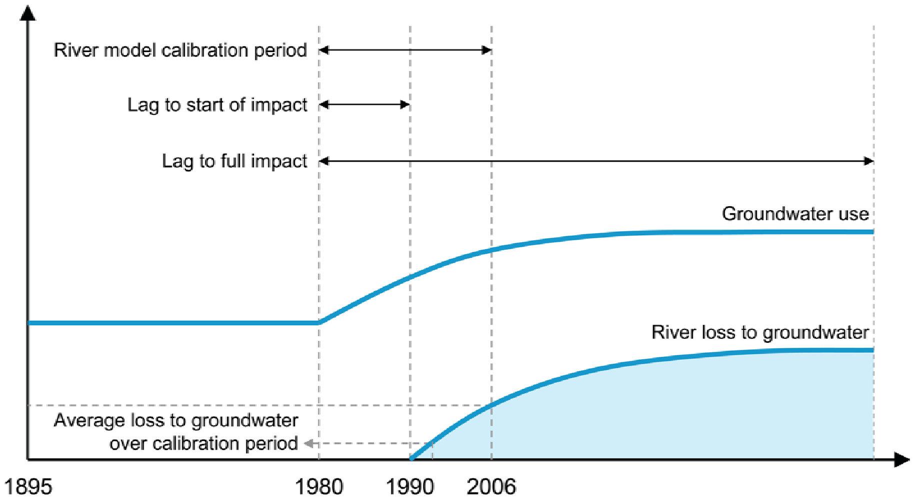

Figure 1-3. Timeline of groundwater use and resultant impact on river

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 may be used internally in conceptual water balance models of wetland and irrigation water use that include a simulated storage.

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 a comparison of apparent ungauged gains and losses 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 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, Water, Heritage and the Arts 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 Loddon-Avoca region is in northern Victoria and covers 2.3 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the Loddon and Avoca Rivers. The population is 142,000 or 7.2 percent of the MDB total, concentrated in the centres of Bendigo, St Arnaud, Charlton and Boort. Over 80 percent of the region is used for dryland agriculture, primarily cereal cropping and grazing. An extensive area of the riverine plain is irrigated from Boort to the Murray River and dairying predominates. Approximately 127,000 ha were irrigated in 2000 including 106,600 ha for pastures and hay and 16,000 ha for cereal production. The Kerang Wetlands within the north of the region is listed as a Ramsar site of international significance and a number of other sites have national importance.

The region generates approximately 1.7 percent of the runoff within the MDB. The total annual licensed water diversions within the region were around 101 GL/year, including urban entitlements of 7 GL, in 2000. Slightly less than 80 percent of the total diversions for irrigation were sourced from surface water. Water from the Campaspe and Goulburn river systems delivered by the Western Waranga Channel supplements water sourced from within the Loddon-Avoca region. The Nyah area in the north-west is serviced directly from the Murray River. The region uses 0.8 percent of the surface water diverted for irrigation in the MDB and 1.7 percent of the total groundwater used in the MDB. Small dams with their own catchment area in the upper part of the region have an estimated storage capacity of 98 GL.

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

2.1 The region

The Loddon-Avoca region is entirely located in northern Victoria and covers 24,918 km^2 or 2.3 percent of the MDB. It is bounded to the east by the Campaspe region, to the north by the Murray River, to the west by the Wimmera region and forms the southern edge of the MDB. The region spans from the foothills of the Great Dividing Range near Daylesford and Creswick in central Victoria to the riverine plains in northern Victoria and the floodplain of the Murray River.

The major water resources in the Loddon-Avoca region include the Loddon and Avoca rivers, fractured rock and alluvial aquifers and water storages. Both private and public infrastructure is associated with these water resources including the Tullaroop and Cairn Curran dams. The average annual rainfall is 430 mm varying from nearly 800 mm in the south to 300 mm in the north. Rainfall varies considerably between years and winter is typically the wettest season. Despite this variability, the region’s average annual rainfall has remained relatively consistent over the past 111 years. The average annual rainfall over the ten-year period 1997 to 2006 is around 11 percent lower than the long-term (1895 to 2006) average values.

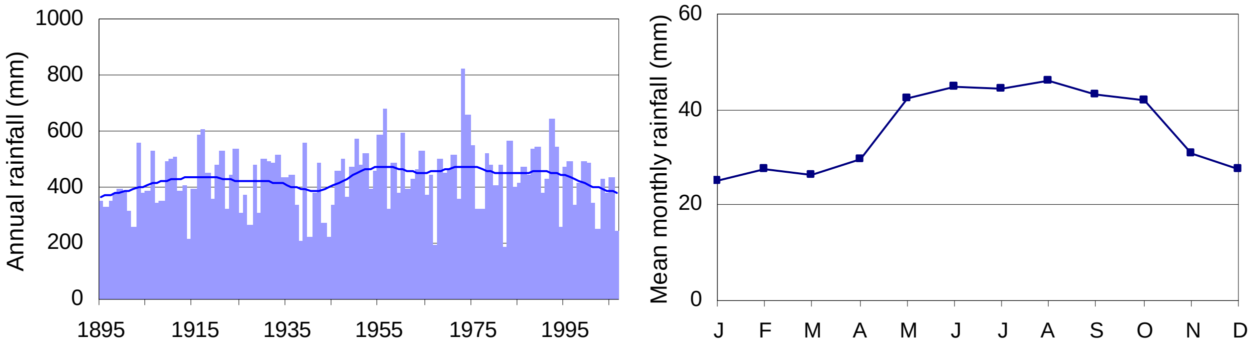


Figure 2-1. 1895–2006 annual and monthly rainfall averaged over the region. The curve on the annual graph shows the low frequency variability.

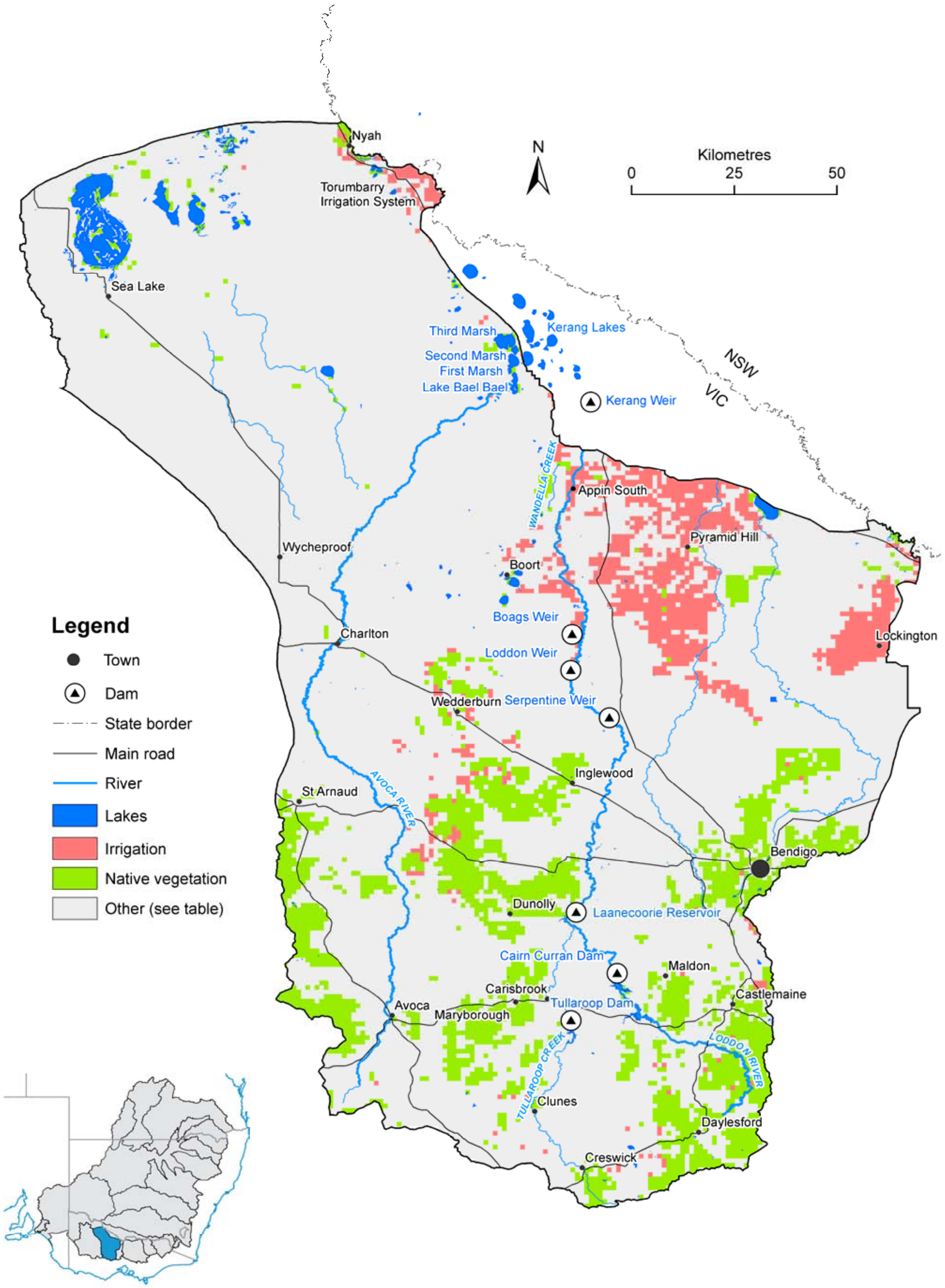


Figure 2-2. Map of dominant land uses of the Loddon-Avoca region with inset showing the region's location within the Murray-Darling Basin

The Loddon-Avoca region contributes around 1.7 percent of the total runoff in the MDB from 2.3 percent of the total area of the MDB. The average annual modelled runoff over the region for the 111-year period is 21 mm and mostly occurs in winter and early spring. The average annual modelled runoff over the ten-year period 1997 to 2006 was 52 percent lower than the long-term (1895 to 2006) average values. The runoff estimates in the Loddon-Avoca region are relatively good, particularly in the south because there are many gauged catchments from which to estimate the model parameter values.

The regional population is approximately 142,000 (7.2 percent of the MDB) and the largest towns are Bendigo, Charlton, St Arnaud and Creswick. The dominant land use is dryland agriculture, characterised by broadacre land uses, primarily cropping and grazing. Land close to the major centres is increasingly being developed for horticulture, new and emerging agricultural commodities and as 'rural living' zones.

Irrigation areas cover much of the northern riverine plains between Boort and Lockington. Dairying and mixed cereal and livestock farming are the main irrigated enterprises. There are three irrigation areas within the Loddon-Avoca region. The main irrigation area is the Boort Pyramid Irrigation Area which covers 166,215 ha of which 126,400 ha is suitable for irrigation. It extends from the Waranga Western Channel in the south, to the Macorna Channel in the north. Some 1250 properties are serviced in this area via a network of natural waterways (150 km) and constructed distribution channels (1391 km). The Rochester-Campaspe Irrigation Area is located in the north-east of the region near Lockington. Irrigation water for this area is sourced from the Campaspe and Goulburn rivers as described in the Campaspe regional report (CSIRO, 2008a). The Nyah irrigation district is located in the far north-west of the region and water is sourced from the Murray River, primarily for horticultural production. This irrigation district is reported in the Murray regional report (CSIRO, 2008b).

There were around 127,000 ha of mainly irrigated dairy pasture and hay production in 2000. There are small areas of irrigated winter cereal crops grown in the north-west of the region and small areas of horticulture in the southern areas. The land use area (Table 2-1) is 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 Loddon-Avoca region

Land use	Area		
	percent		ha
Dryland crops	32.1%		800,500
Dryland pasture	49.4%		1,229,000
Irrigated crops	5.1%		127,000
Cereals		*12.5%*	*16,000*
Horticulture		*2.0%*	*2,600*
Orchards		*1.0%*	*1,200*
Pasture and hay		*84.0%*	*106,600*
Vine fruits		*0.5%*	*600*
Native vegetation	11.0%		274,000
Plantation forests	0.4%		10,800
Urban	0.8%		19,200
Water	1.2%		29,600
Total	**100.0%**		**2,490,100**

Source: BRS, 2005.

The region is covered by the North Central Catchment Management Authority (CMA), established in 1997 under the Catchment and Land Protection Act 1994 to achieve effective integration and delivery of land and water management programs in this area of Victoria. The North Central CMA region includes two major river basins: the Campaspe and Loddon.

In 2002, the Victorian Government released the Victorian River Health Strategy (DNRE, 2002) which provides a statewide policy framework for managing the health of Victoria’s rivers, floodplains and estuaries. Within this statewide context, regional strategies aim to identify the environmental, social or economic water services (or assets) in each region, their value to the state and the region, and the issues that threaten these services. They also establish priority areas for restoration, and provide an integrated program for river restoration at the regional level. The North Central

River Health Strategy (NCCMA, 2005) forms a key component of the North Central Regional Catchment Strategy (NCCMA, 2003) which is the primary integrated planning framework for natural resource management in the North Central region. It is an overarching strategic document that supports several action plans and provides a mechanism to deliver a coordinated approach to catchment management to achieve the vision, priorities and objectives of the community.

The North Central CMA coordinates and monitors the implementation of the Strategy. The Strategy takes an assets-based approach to natural resource management, examining how the region's key natural resource assets – land, water, biodiversity and climate – can be enhanced and how the threats they face can be addressed. The region's human and social assets are also identified and include the protection of high priority water and biodiversity assets through the management of water resources, waterways and wetlands while maintaining sustainable economic use of the region's water assets.

The goal of the Strategy is that water will be shared equitably between environmental and consumptive uses, water quality will match users' requirements and water will be used efficiently. Targets include to:

- reduce the frequency and duration of algal blooms as per the nutrient management plan targets for each river system
- achieve agreed MDB 2015 within-valley and end-of-valley water quality targets. Meet Waters of Victoria State Environment Protection Policy (SEPP) chemical and physical water quality objectives on a high proportion of the region's streams. Meet water quality targets for regional River Health and Water Quality Strategies
- meet SEPP Groundwater water quality objectives
- have full compliance with MDBC Cap on diversions and with Living Murray and other environmental flow allocations
- avoid long term reduction in level or pressure of water resource aquifers within groundwater management or water supply protection areas
- reduce the amount of water lost by evaporation and seepage during transportation and storage to realistic target figures to be developed by each water authority
- reduce per capita urban consumption
- improve environmental and economic measures of water use efficiency on irrigated land.

Another goal of the Strategy is that waterways and wetlands will be managed to enhance their environmental function and, where appropriate, provide opportunities for economic, recreational and amenity use. Targets include:

- significant improvements achieved in environmental flow regimes of 5 high value reaches currently flow stressed through Bulk Entitlement, Stream Flow Management Plan and the Living Murray Processes
- an increase of 300 km in the length of rivers in excellent or good condition, as assessed by the Index of Stream Condition (ISC)
- improvement of one point in ISC riparian condition score for at least 500 km of stream length
- overall improvement in ISC rating of 1000 km of streams
- 95 percent of all upland and 60 percent of all lowland monitoring sites will meet State Environmental Protection Policy environmental quality objectives
- improvement in condition of high environmental value wetlands, as measured by the Index of Wetland Condition (in development)
- no further decline in the extent of wetlands within the region
- reduce long-term average annual economic losses due to flooding relative to the no-intervention scenario.

The Loddon River is listed as a flow-stressed river in the Victorian River Health Strategy. In particular Section 6.3.3 of the Strategy highlights the Government's aims and principles to achieve ecologically healthy condition for flow-stressed rivers, such as the Loddon River. It is on this basis, and in light of the significant environmental, social and economic values associated with the river, that significant investment has been directed at the Loddon River in recent years. This has included funding for the Loddon Stressed River Restoration project, which has funded river restoration activities including fencing, extensive revegetation, river resnagging, erosion control, river blackfish surveys and refurbishment of the Loddon Weir to pass environmental flows.

A management plan (NCCMA, 2007) was developed by the regional community to build on the success of previous salinity management and regional development plans. It sets regional directions and targets that integrate the land, water, environmental and people assets to achieve a sustainable and viable future based around protecting the irrigation region's most important natural assets. The plan is built on five recurring themes: land management, water management, biodiversity enhancement, community capacity and planning and development. Each theme has 30-year aspirational goals to improve the condition of natural resources. Each goal is associated with a resource condition target. Resource condition targets have 20-year timeframes and are more specific than aspirational goals.

The completion of these key planning documents has provided a more strategic direction and justification for the delivery of onground work, including the establishment of both short and long-term output and outcome-based targets.

2.2 Environmental description

There are five main and two smaller bioregions (DSE, 2007a) within the Loddon region:

- a small area of the Murray Fans Bioregion adjacent to the Murray River in the north
- the Victorian Riverina Bioregion is predominant in the northern area and surrounds the Northern Inland Slopes Bioregion near Pyramid Hill
- the Murray Mallee Bioregion is present in the north-west
- the Goldfields Bioregion within the central portion of the region
- the Central Victorian Uplands Bioregion in the south
- a small area of the Victorian Volcanic Plain Bioregion in the far south.

The Murray Fans Bioregion is characterised by a flat to gently undulating landscape with red brown earths and texture contrast soils. The vegetation is a mosaic of Plains Grassy Woodland, Pine Box Woodland, Riverina Plains Grassy Woodland and Riverina Grassy Woodland ecosystems.

The Victorian Riverina Bioregion is characterised by flat to gently undulating landscape on recent unconsolidated sediments with former stream channels and wide floodplain areas associated with major river systems and prior streams. Red brown earths and texture contrast soils dominate. The vegetation is predominantly 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 (DSE, 2007a).

The Northern Inland Slopes Bioregion covers a small area of the region in the north central area known as the Terric Terric and Pyramid Hill. It consists of foothill slopes and minor ranges which protrude through and are 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.

The Murray Mallee Bioregion 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. The vegetation is dominated by East/West-Dune Mallee with some Chenopod Mallee and Shallow-Sand Mallee.

The Goldfields Bioregion has a variety of relatively poor yellow, grey and brown texture contrast soils which are dominated by Box Ironbark Forest, Heathy Dry Forest and Grassy Dry Forest ecosystems. Low lying corridors of alluvial valleys and basaltic plains are dominated by Plains Grassy Woodland and Low Rises Grassy Woodland/Alluvial Terraces Herb-rich Woodland Mosaic ecosystems. The granitic and sedimentary terrain is dominated by Grassy Woodlands much of which has been cleared (DSE, 2007a).

Low-lying corridors of valleys and plains within the Central Victorian Uplands Bioregion are dominated by Plains Grassy Woodland and Valley Grassy Forest ecosystems on the fertile plains and Grassy Woodland and Floodplain Riparian Woodland ecosystems on the river courses and Herb-rich Foothill Forest and Shrubby Foothill Forest ecosystems on the more fertile slopes with outwash. The less fertile hills support Grassy Dry Forest and Heathy Dry Forest ecosystems on the less fertile hills (DSE, 2007a).

The Victorian Volcanic Plain Bioregion is dominated by extensive flat to undulating basaltic plains with stony rises, old lava flows, numerous volcanic cones and old eruption points and is dotted with shallow lakes. The soils are variable ranging from red texture contrast soils on the higher fertile plain and scoraceous material that supports Plains Grassy Woodland, Plains Grassland/Plains Grassy Woodland Mosaic and Plains Grassland. Calcareous sodic texture contrast soils grading to yellow acidic earths are present on the intermediate plain. On the stony rises (volcanic outcrop) the stony earths support Stoney Rises Herb-rich Woodland, Basalt Shrubby Woodland and Herb-rich Foothill Forest ecosystems (DSE, 2007a).

Native vegetation in particular is poorly represented in all but the Central Victorian Uplands, Goldfields and Murray Fans bioregions. Many ecological communities retain less than 1 percent of their original distribution. Woodlands and grassy woodlands, which occupied the areas most readily developed for agriculture, have especially poor representation. The region retains some extensive Box Ironbark and River Red Rum. Habitat loss (in extent and quality) due to agricultural and urban development, weed invasion and impacts from pest animals, mining and changing water regimes, has caused 100 species of native animal and around 300 species of native plant to be threatened by extinction (NCCMA, 2003).

The wetlands within the region that have national importance or international importance are detailed in Table 2-2. The Kerang Wetlands are classified as Ramsar sites of international significance within the region and are associated with the Loddon River. The Kerang Wetlands Ramsar site also receives flows from the Avoca system. Four of the 22 Kerang wetlands are listed in Table 2-2 and the remaining wetlands are described within the Murray region.

Wetlands may be regionally important depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

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

Site Code	Directory of Important Wetlands in Australia name	Area(1)	Ramsar sites
		ha	
VIC006	Bunguluke Wetlands, Tyrrell Creek & Lalbert Creek Floodplain	530	none
VIC013	Lake Lalbert	500	none
VIC015	Lake Tyrrell	20,860	none
VIC038	First Marsh (The Marsh)	780	none
VIC044	Kow Swamp #	2,724	none
VIC045	Lake Bael Bael	648	yes*
VIC047	Lake Cullen #	632	yes*
VIC054	Second Marsh (Middle Marsh)	233	yes*
VIC055	Tang Tang Swamp	103	none
VIC056	Third Marsh (Top Marsh)	946	yes*
VIC061	Woolshed Swamp	353	none
VIC138	Merin Merin Swamp	215	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.

* Kerang Wetlands Ramsar site, 3811.3 ha within the region of a total area of 9419 ha.

sites also extend into the Murray region.

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

The hydrology of the Kerang wetlands was modified by changes in river diversions, construction of levee banks, localised drainage and use of the lakes as part of the water supply and salt disposal systems for the Torrumbarry Irrigation System. The individual shallow swamps and lakes of this system range in salinity from freshwater marshes to highly saline lakes. Permanent wetlands are the dominant type within the area. This is due to a constantly available water supply. Of the 22 wetlands within the Kerang Wetlands system, seven are State Wildlife Reserves, eight are Water Supply Reserves, three are Salinity Disposal Reserves and 4 are Crown Land without specific reservation.

The Kerang Lakes have undergone significant changes in water regime since the development of the Torrumbarry Irrigation System in 1896. Land salinisation became a major problem after a system upgrade in 1923 and shallow water tables became widespread leading to an increase in the salinity levels in many of the wetlands. Saline groundwater intrusion from local and regional groundwater tables, saline irrigation tailwater disposal to wetlands and the isolation of wetlands from the natural flood flows is causing increases in lake salinity and associated changes in biota (Ramsar Convention Secretariat, 1999).

Specific flow requirements exist for several reaches of the Loddon River between Cairn Curran Dam and Kerang Weir and also for the Tullaroop Creek between Tullaroop Dam and Laanecoorie Reservoir. Those for the Loddon River are detailed in Chapter 7. A number of recommendations were made for environmental flows within the Loddon River system by the Loddon River Environmental Flows Scientific Panel (LREFSP, 2002). Chapter 7 details selected recommendations used as the basis of the impact assessment by this project.

Lake Tyrrell is one of the largest salt lakes in Victoria, covering 20,820 ha. It is the terminal lake of the Tyrrell Creek system which flows infrequently, and is a natural depression that is a discharge area for saline ground water. Salt deposits are harvested from the lake and most of the lake is a wildlife reserve.

2.3 Surface water resources

2.3.1 Rivers and storages

The Loddon River flows in a northerly direction from its headwaters in the Great Dividing Range near Daylesford. A number of small tributaries, including the Tullaroop and Bet Bet creeks join with the Loddon River near Laanecoorie south-west of Bendigo. The Loddon River then flows northerly and joins the Murray River near Kerang, downstream of Torrumbarry Weir.

The Avoca River (further to the west) flows in a northerly direction from its headwaters in the central highlands near the township of Ampitheatre. The Avoca River has the fifth largest catchment area in the state mostly on the northern plains. The Avoca River discharges into the Avoca Marshes and Lake Boga near Swan Hill. There are no major water storages on the River and a small number of weirs that have local importance (NCCMA, 2007). The Avoca outfall discharges floodwaters from Top Marsh into the Avoca Floodway: a broad area of land bounded generally by the Murray Valley Highway to the south and the No 7 Channel to the north.

The major water storages in the region include Cairn Curran Dam on the Loddon River, constructed in 1956 with a capacity of 148 GL, the Tullaroop Dam on Tullaroop Creek constructed in 1959 with a storage capacity of 74 GL and the Laanecoorie Reservoir at the confluence of Bet Bet Creek and the Loddon River with an 8 GL storage capacity (GMW, 2007a). Storage capacity of small farm dams with their own catchment used for irrigation and stock and domestic purposes is estimated to be 98 GL (VicMap, 2007).

2.3.2 Surface water management institutional arrangements

Water for consumptive use is taken from water bodies under entitlements issued by government and authorised under the Water Act 1989. The Victorian Government retains the overall right to the use, flow and control of all surface water. The Minister for Water is responsible for allocating water at the bulk level through the granting of bulk entitlements for consumptive use and Environmental Water Reserves and has allocated responsibilities for the operational management of the Environmental Water Reserve to catchment management authorities. Where appropriate, provision is made for other non-consumptive uses including recreation. Rights are allocated to private consumers for uses including irrigation and rural domestic and stock use. Generally, water for consumptive use is allocated to water authorities (through the granting of bulk entitlements) who then distribute the water to their customers and to individuals through a licence. 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. Water previously available as irrigation sales water was converted into independent entitlement under the Sales Water Reform Package (DSE, 2007b).

The surface water resources of the Loddon-Avoca region are covered by bulk entitlements for water allocation from the Loddon River and its tributaries and for all urban water use (Table 2-3). In addition, there are private diverter licences in unregulated parts of the region. In 2005/06 there was 51.867 GL of bulk entitlement – including the environment entitlement – and 27.04 GL of licensed private diversion entitlement from unregulated streams within the region.

Table 2-3. Summary of surface water sharing arrangements

Water products	Priority of access	Allocated entitlement
		ML/y
Basic rights		
Stock and domestic rights		Not stated
Native title		None
Extraction shares		
Total extraction limit		75,211
Urban bulk entitlements	high	6,759$^{(1)}$
Industry bulk entitlements	high	0
Rural bulk entitlements	high and low	41,408$^{(2)}$
Unregulated river licences	low	27,044$^{(3)}$
Environmental provisions		
Total environmental share		Not stated
Environmental entitlement	low	3,700
Additional environmental passing flows	high	2,500

Source: DSE, 2006.

(1) Urban bulk entitlements: sum of bulk entitlements to Central Highlands Water, Coliban Water and Grampians Wimmera Mallee Water.

(2) Rural bulk entitlements: Bulk entitlement to Goulburn-Murray Water and this maximum does not include supplementary water defined in the Goulburn-Murray Water Bulk Entitlement. This supplement averages about 80 GL/y

(3) Unregulated river licences: Sum of individual licences including irrigation farm dams

Formal rights to water for environmental use were established under the Victorian Water (Resources Management) Act 2005 which provides for water to be provided under Environmental Water Reserves. The Environmental Water Reserve for the Loddon Basin includes the Loddon River Environmental Reserve held by the Minister for the Environment of 2 GL as well as passing flows released as a condition of consumptive bulk entitlements held by Central Highlands Water and Goulburn Murray Water and all other water in the catchment not allocated for consumptive use (DSE, 2007c). The Environmental Water Reserve for the Avoca Basin includes passing flows released as a condition of consumptive bulk entitlements held by Central Highlands Water and all other water in the catchment not allocated for consumptive use. No basic rights are quantified in water management plans, but diversions are allowed under the Water Act 1989. There is also harvesting of runoff water in farm dams (DSE, 2007c).

Central Highlands Water, GWM Water (previously known as Grampians Wimmera Mallee Water), Goulburn-Murray Water and Coliban Water are responsible for the urban water supply in the Loddon region. Goulburn-Murray Water supplies Coliban Water and GWM Water with supplies for those towns supplied from the Goulburn-Murray irrigation channels and the Wimmera Mallee channel system. Bendigo is supplied by Coliban Water with water sourced from the Campaspe region (DSE, 2007c).

Goulburn-Murray Water is also responsible for managing groundwater and surface water licensed diversions from the Loddon catchment. Goulburn-Murray Water operates Cairn Curran Dam, and Coliban Water operates the Tullaroop Dam and Laanecoorie Reservoir. The North Central CMA is responsible for waterway management (DSE, 2007c).

The MDB long-term Cap on surface water diversions has been set at 2034 GL for the combined Goulburn, Loddon and Broken river systems.

Under recent water reforms, traditional water entitlements of water rights (including domestic and stock allowances and take-and-use licences for regulated water systems managed by Goulburn-Murray Water) have been unbundled to create a water share/delivery share in districts, or extraction share on waterways and a water-use licence. A water share is a legally recognised, secure share of the water available to be taken from a water system. The delivery share provides an entitlement to have water delivered to land in an irrigation district and a water use licence allows an irrigator to use water for irrigation (DSE, 2008).

2.3.3 Water products and use

Regional consumptive use of water greatly exceeds the volume harvested. More than 75 percent of consumptive use comes from water imported from the Goulburn and upper Murray catchments. Some water used in the west of the region is imported from the Wimmera system (NCCMA, 2007).

Water supplies for the Boort Pyramid Irrigation Area are augmented from the Goulburn River system. Despite the distance (more than 350 km by river and channel), Lake Eildon is a major water resource for the Boort Pyramid Irrigation Area. Water stored in Lake Eildon is diverted at Goulburn Weir near Nagambie into the Cattanach and Stuart Murray canals. The Cattanach Canal delivers water to Waranga Basin, which has a capacity of 432.4 GL.

Water released from Waranga Basin into the Waranga Western Channel supplies the Pyramid Hill district east of the Loddon River. The Boort district is supplied via the Loddon River and additional supplies are regulated through the Waranga Western Channel to the Loddon Weir at Fernihurst. This water supplements the limited capacity of the Loddon storages and improves water quality. Pumped supplies are also drawn from the Loddon River and Serpentine Creek (GMW, 2007b).

Surface water diversions and groundwater extractions since the early 1960s increased within the region as irrigated crop production grew. The relatively low annual diversion volumes (Table 2-3) recorded in recent years reflect the drought conditions experienced. Annual urban water use is generally around 7 GL.

The majority of the irrigation water is used within the Pyramid Boort Irrigation Area for dairy pasture and hay production. The annual use is strongly influenced by the availability of low reliability water allocations which, prior to the unbundling reform process, were referred to as ‘sales’ water.

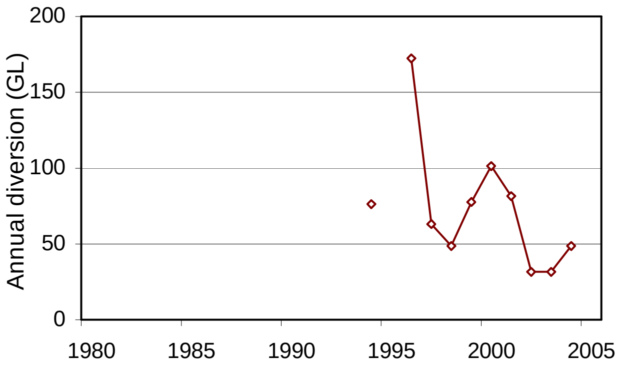


Figure 2-3. Historical surface water diversions from the Loddon River catchment

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, 2007.

2.4 Groundwater

2.4.1 Groundwater management units – the hydrogeology and connectivity

The Loddon-Avoca region is divided into two zones: the upper catchment – dominated by the fractured rock aquifers (including basalts) of the North Central Highlands – and the lower catchment which is dominated by sedimentary deposits of the MDB.

Ordovician bedrocks underlie the region and are locally overlain and deeply dissected by Newer Volcanic basalts. The broad, low volcanic plateau forms the main divide in the Ballarat region and narrows to tongues of basalt that extend along the Loddon Valley and its upper tributaries. The fractured basalt aquifer is recharged directly through numerous volcanic cones and via infiltration through fractures. However, lava vents are the main recharge source for the aquifer system. Groundwater flow typically radiates outward from the elevated recharge sources into the plains and groundwater flows from south to north. Groundwater quality of the Newer Volcanic basalt aquifers is highly variable depending on proximity to the recharge area. Groundwater is of good quality (<560 mg/L Total Dissolved Solids or TDS) around volcanic vents and increases to over 3360 mg/L TDS in low recharge areas. Groundwater quality of the basalt in the Daylesford area is good, averaging around 200 mg/L TDS (Heislers, 1993).

Weathered Ordovician bedrock is an important source of mineral water in the Daylesford area. The Ordovician bedrock is intruded by granite (Harcourt Batholith) and fresh springs (100 to 300 µS/cm EC) and saline discharge (5,000 to 10,000 µS/cm EC) occur in close proximity (Kevin, 1992). High recharge areas in the granitic landscape typically match areas of shallow sands of high hydraulic conductivity and good quality groundwater.

The Avoca Deep Lead is a confined to semi-confined aquifer incised within Ordovician bedrock and the basalts. Tertiary-aged White Hills Gravels follow generally the present course of the Avoca River and associated tributaries. A higher energy environment caused streams to erode through the White Hills Gravels and Ordovician bedrock and subsequently deposit reworked gravels and bedrock at the base of the palaeo-valleys. These sediments comprise the Calivil Formation which is associated with the Avoca Deep Lead. Overlying the deep leads within the palaeo-valleys are the Quaternary aged Shepparton Formation alluvial sediments that make up the surface geology in most of the area. Quaternary aged Newer Volcanic basalt up to 50 m thick overlies the bedrock and deep leads but it is limited to the eastern margin of the area. Regional groundwater flows predominantly north with some flows to the east and west that join the main aquifer flow path. The hydraulic connection between the shallow aquifers and the Avoca Deep Lead aquifer is significant (SKM, 2005b).

The deep leads are generally thin in the highland reaches and tend to broaden to the north. Recharge to the deep lead aquifer occurs from two main sources: periodic leakages from overlying formations and direct rainfall recharge where the Calivil Formation outcrops in the highland tracts of the catchment. Yields of good quality (<1500 mg/L TDS) groundwater exist in the Calivil-Renmark aquifer along the tract of the Loddon Deep Lead. Salinities within the Calivil Formation range from 900 to 1200 mg/L TDS in the upland areas to 2000 mg/L TDS in the mid-catchment and then deteriorate to 9000 mg/L TDS within the discharge zone on the lower Loddon Plain (URS, 2006).

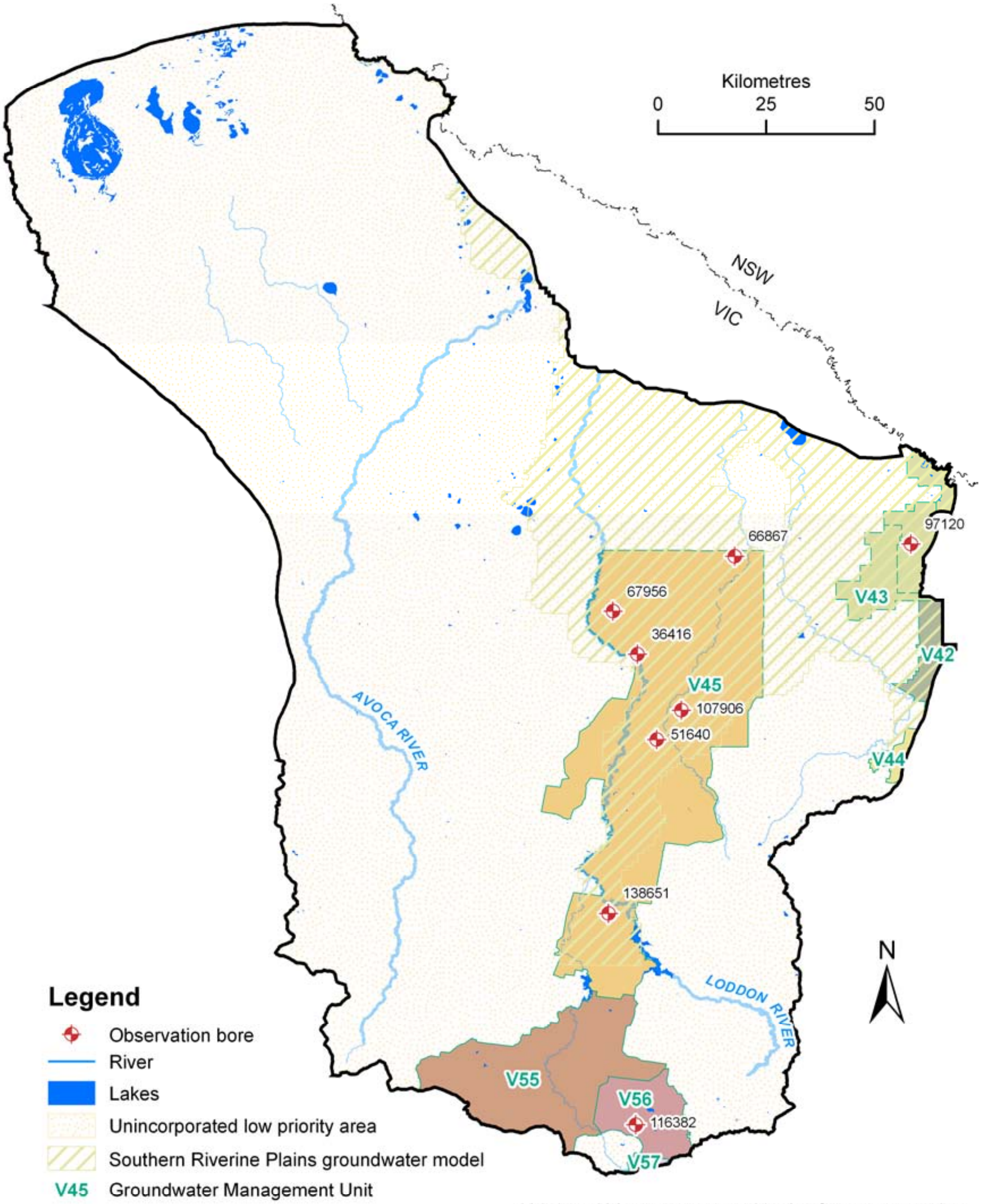
The aquifers within the region are divided into a number of groundwater management units (GMUs) for management purposes. These units are three-dimensional in nature. The GMUs relevant to the region are:

- Mid-Loddon Water Supply Protection Area (WSPA) (V45, referred to as the Mid-Loddon GMU). This is a relatively new WSPA which replaced the Ascot and Moolort WSPAs in April 2004
- Upper Loddon WSPA (V55, referred to as the Upper Loddon GMU)
- Spring Hill WSPA (V56, referred to as the Spring Hill GMU)
- proposed Avoca GMU
- Ellesmere GMA (V44, referred to as the Ellesmere GMU)
- Campaspe Deep Lead WSPA (V42, referred to as the Campaspe Deep Lead GMU)
- Shepparton WSPA (V43, referred to as the Shepparton GMU)
- Bungaree GMA (V57, referred to as the Bungaree GMU).

Only the first four GMUs are assessed in this report. The Ellesmere and Campaspe Deep Lead GMUs are assessed in the Campaspe region and the Shepparton GMU is assessed in the Broken-Goulburn region. The Bungaree GMU is not assessed as it has no recorded groundwater extraction. The GMUs do not cover the entire region. Those areas not covered are referred to as ‘unincorporated areas’. The term WSPA refers to regulatory matters not the groundwater assessment.

The Spring Hill and Upper Loddon GMUs represent the Newer Volcanic basalt aquifers. They are assessed as low 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. They have therefore been analysed using a simple water balance approach. The Mid-Loddon GMU has been classified as medium priority due to the greater level of development in this area.

Groundwater entitlements and 2004/2005 usage for each of the GMUs and the unincorporated areas is summarised in Table 2-4. Estimates of unmetered use were applied to the proposed Avoca GMU, unmetered bores in the Mid-Loddon GMU, Upper Loddon GMU and the unincorporated areas outside of the GMUs.



* V42 and V44 are assessed in the Campaspe region
** V43 is assessed in the Goulburn-Broken region
*** V57 is not assessed

Figure 2-4. Map of groundwater management units within the Loddon-Avoca region

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

Code	Name	Priority	Total entitlement	Current extraction[1] (2004/05)	Permissible consumptive volume[2]	Recharge[3]
			GL/y			
V45	Mid-Loddon WSPA	medium	34.05	18.1	37.2 (proposed)	20.96
V55	Upper Loddon WSPA	low	13.04	6.67	13.6 (proposed)	11.9
V56	Spring Hill WSPA	very low	4.91	1.64	5.1 (proposed)	5.1
-	Proposed Avoca GMU	-	1.34	0.98	none as yet	2.5
-	Unincorporated Areas[4]	-	2.84	1.94	none	45.8

(1) Source: Department of Sustainability and Environment Victoria (DSE, 2006). These volumes include estimated stock and domestic use of: 0.47 GL/year for the Mid-Loddon GMU, 0.46 GL/year for the Upper Loddon GMU, 0.27 GL/year for the Spring Hill GMU, 0.20 GL/year for the proposed Avoca GMU and 0.67 GL/year for unincorporated areas.

The installation of bore meters has not been completed in the Mid-Loddon GMU or the Upper Loddon GMU, where 2 and 4 GL/year respectively of licensed extractions have been estimated.

(2) Source: DSE, 2006.

(3) Recharge estimates include rainfall recharge only, except for Mid-Loddon GMU which is sourced from the Riverine Plains model and includes all forms of recharge.

(4) The unincorporated portion of the region represents those water resources where groundwater salinity is less than 1500mg/L Total Dissolved Solids (TDS), and covers an area of 1450 km^2.

2.4.2 Water management institutional arrangements

Goulburn-Murray Water is responsible for groundwater licensing within the region. A Groundwater Management Plan exists for the Spring Hill GMU. New licences are embargoed within the Upper Loddon and the Mid-Loddon GMUs until groundwater management plans are drafted. Allocation limits in these areas are based on the historical rate of groundwater extraction (GMW, 2006).

The proposed Avoca GMU extends from Avoca in the south to Archdale Junction in the north and represents the Deep Lead aquifer between 10 to 70 m in depth. Groundwater licences are generally for stock and domestic use, irrigation purposes, and urban supply to the Avoca township. Metering is incomplete.

Permissible Annual Volumes for groundwater were developed using estimates of the available resource during the 1990s. Permissible Annual Volumes have been superseded by Permissible Consumptive Volumes that are issued through Ministerial Order. Ongoing hydrogeological investigations inform Permissible Consumptive Volume development. The Permissible Consumptive Volumes currently proposed are 37.2 GL/year for the Mid-Loddon GMU, 13.6 GL for the Upper Loddon GMU and 5.1 GL/year for the Spring Hill GMU.

State legislation broadly controls groundwater extraction within the remainder of the catchment area and 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. A WSPA can be declared under the Water Act 1989 to protect the area’s groundwater or surface water resources through the development of a management plan that aims for equitable management and long-term sustainability (DSE, 2006). Table 2-5 provides a summary of groundwater management plans.

Table 2-5. Summary of the groundwater management plan for the Spring Hill GMU

Description	Spring Hill GMU
Year of plan	2002
Environmental provisions	
Planned share	none
Supplementary provisions	none
Adaptive provisions	none
Basic rights	
Domestic and stock rights	not licensed
Native title	none
Access licences	
Urban	none
Planned share	5.1 GL/y (the plan does not differentiate between urban, irrigation or commercial entitlements)
Announced allocation	

2.4.3 Water products and use

Groundwater extraction within the Loddon-Avoca region accounts for 1.7 percent of the MDB total. There is only limited information on rates of historical groundwater extraction without comprehensive metering. The Spring Hill and Mid-Loddon GMUs have been metered since 1999. Groundwater extraction grew significantly in the period from 2000/01 (around 20 GL) to 2002/03 (nearly 31 GL) followed by a smaller fall in 2004/05 back to around 29 GL (Figure 2-5).

Groundwater within the Loddon-Avoca region is used for urban, stock and domestic and irrigation purposes. There are also limited amounts of dairy and commercial users. Most irrigation (including surface water irrigation) is located along the middle reaches of the Loddon River and in the lower part of the region. It is also used to irrigate lucerne, potatoes, some vines and fodder crops. An urban licence exists for the township of Dean within the Spring Hill GMU. Supplies for the townships of Clunes, Waubra and Learmonth are drawn from the Upper Loddon GMU. Groundwater for the townships of Spring Hill and Allendale (located within the Spring Hill and Upper Loddon GMUs, respectively) comes from aquifers outside the depth limits of the GMUs.

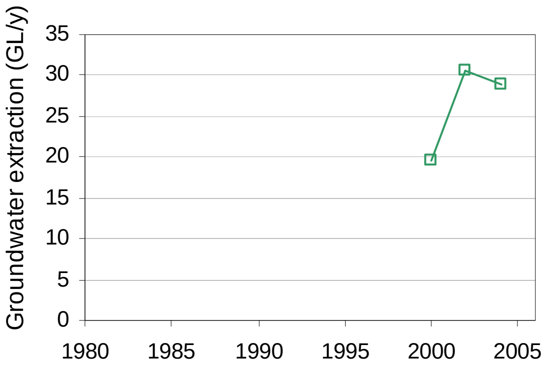


Figure 2-5. Annual groundwater extraction from Mid-Loddon, Spring Hill and Upper Loddon GMUs including metered and estimated volumes

2.5 References

BRS (2005) 1993, 1996, 1998 and 2000 Land Use of the Murray-Darling Basin, Version 2. Resource Identifier: ID01. Online digital dataset and spatial data layer.
File identifier: http://adl.brs.gov.au/findit/metadata_files/a_mdblur9abl_00711a00.xml
Product access: http://data.brs.gov.au/anrdl/a_mdblur9abl_00711a00.xml

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3 Rainfall-runoff modelling

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

3.1.2 Key messages

- The annual rainfall and modelled runoff averaged over the Loddon-Avoca region are 430 mm and 21 mm respectively. Rainfall is generally higher in the winter half of the year and most of the runoff occurs in winter and early spring. The Loddon-Avoca region covers 2.3 percent of the MDB and contributes about 1.7 percent of the total runoff in the MDB.
- The average annual rainfall and runoff over the ten-year period 1997 to 2006 are 11 percent and 52 percent lower respectively than the long-term (1895 to 2006) average values. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 average values at a significance level of $\alpha = 0.2$ and the 1997 to 2006 runoff is statistically different to the 1895 to 1996 average values at a significance level of $\alpha = 0.05$.
- Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Loddon-Avoca will decrease significantly. Under the best estimate (median) 2030 climate, average annual runoff would be reduced by 16 percent. The extreme estimates from the high global warming scenario range from a 43 percent reduction to no change in average annual runoff. The low global warming scenario ranges from a 14 percent reduction to no change.
- The projected growth in commercial forestry plantations is negligible. The total farm dam storage volume is projected to increase by 3070 ML (3 percent) by 2030. This projected increase in farm dams would reduce average annual runoff by about 1 percent, a relatively small change compared to the best estimate 2030 climate impact on runoff. The best estimate of the combined impact of climate change and farm dam development would be a 17 percent reduction in average annual runoff. Extreme estimates of the reduction range from 1 to 44 percent.

3.1.3 Uncertainty

- Scenario A – historical climate and current development
  The runoff estimates for the Loddon-Avoca region, particularly in the southern parts where most of the runoff occurs, are relatively good because there are many gauged catchments from which to estimate the model parameter values. Rainfall-runoff model verification analyses for the MDB indicate that the mean annual runoff estimated for individual ungauged catchments using optimised parameter values from a nearby catchment have an error of less than 20 percent in more than half the catchments and less than 50 percent in almost all the catchments (with similar amounts of underestimations and overestimations).

- Scenario B – recent climate and current development
  Scenario B modelling is carried out for the Loddon-Avoca region because the 1997 to 2006 rainfall and runoff are statistically significantly different to the 1895 to 2006 long-term averages. However, there is very large uncertainty in the interpretation of Scenario B results because it is based only on ten years of data. The rainfall-runoff modelling is carried out using 100 stochastic climate inputs based on 1997 to 2006 climate, and Scenario B is defined as the replicate that produced the 1997 to 2006 average annual runoff. This is then 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 development and the impact of these developments on runoff. The impact of commercial forestry plantations on runoff is not modelled because the Bureau of Rural Sciences projections indicate negligible growth in commercial forestry in the Loddon-Avoca region (BRS, 2005). The increase in farm dams is estimated using the current policy controls in Victoria that limit further farm dam development to stock and domestic dams and an assumption that growth in stock and domestic dam storage will be proportional to the rate of rural population growth. There is uncertainty both as to how landholders will respond to these policies and how governments may set policies in the future.

3.2 Modelling approach

3.2.1 Rainfall-runoff modelling – general approach

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

The lumped conceptual daily rainfall-runoff model SIMHYD is used with a Muskingum routing method to estimate daily runoff at 0.05^o grids (~ 5 km x 5 km) across the entire MDB for the four climate and development scenarios. The rainfall-runoff model is calibrated against 1975 to 2006 streamflow data from about 180 small and medium size unregulated MDB 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. Calibration includes a constraint to ensure that the total modelled runoff over the calibration period is within 5 percent of the total recorded runoff. The runoff for a 0.05^o grid cell in an ungauged subcatchment is modelled using optimised parameter values for a calibration catchment closest to that subcatchment. The rainfall-runoff model SIMHYD is used because it is simple, has relatively few parameters and provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire MDB and assessing the potential impacts of climate change and development scenarios on future runoff. Specific calibration of SIMHYD or more complex rainfall-runoff models in data-rich areas based on expert judgement and local knowledge (as done by some state agencies) would lead to better model calibration for the specific modelling objectives of the area.

3.2.2 Rainfall-runoff modelling for the Loddon-Avoca region

The rainfall-runoff modelling estimates runoff in 0.05^o grid cells in 16 subcatchments as defined for the river system modelling in Chapter 4 for the Loddon-Avoca region (Figure 3-1). Optimised parameter values from eight calibration catchments are used. Seven of these calibration catchments are in the Loddon-Avoca region and the other calibration catchment is in the Wimmera region to the west of the Loddon-Avoca region.

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

Future development of farm dams in Victoria is mainly limited to stock and domestic purposes (Victorian Government, 2004). The farm dam projection is dependent on two factors: projected growth rate in rural population (DSE, 2004) and current farm dam storage volume (estimated from VicMap 1:25,000 scale topographic mapping). There is a projected increase in rural population of about 9 percent in the Loddon-Avoca region by ~2030. The existing volume of farm dams, including both irrigation and stock and domestic farm dams, is about 98 GL. The projected increases in farm dam storage volume by ~2030 are given in Appendix A. The total increase in farm dam storage volume over the entire Loddon-Avoca region by ~2030 is 3.1 GL or about 3 percent of the existing total volume.

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

3.2.3 Model calibration

Figure 3-2 compares the modelled and observed monthly runoff and daily flow duration curves for the eight calibration catchments. The results indicate that the SIMHYD calibration reproduces the observed monthly runoff series and the daily flow duration characteristic (Nash-Sutcliffe E values generally greater than 0.7) 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. Therefore SIMHYD modelling of the medium and high runoff is considerably better than the simulation of low runoff. Optimisations to reduce overall error variance can underestimate high runoff and overestimate low runoff. This is evident in some of the scatter plots in Figure 3-2. The difference is accentuated in the daily flow duration curves because of the linear scale on the y-axis and normal probability scale on the x-axis. The disagreement between the modelled and observed daily runoff is discernable generally for runoff that is exceeded less than 0.1 or 1 percent of the time.

The runoff estimates for the Loddon-Avoca region, particularly in the southern parts where most of the runoff occurs, are relatively good because there are many calibration catchments from which to estimate the 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 are under or over estimated (when using optimised parameter values from a nearby catchment) by less than 20 percent in more than half the catchments and by less than 50 percent in almost all the catchments.

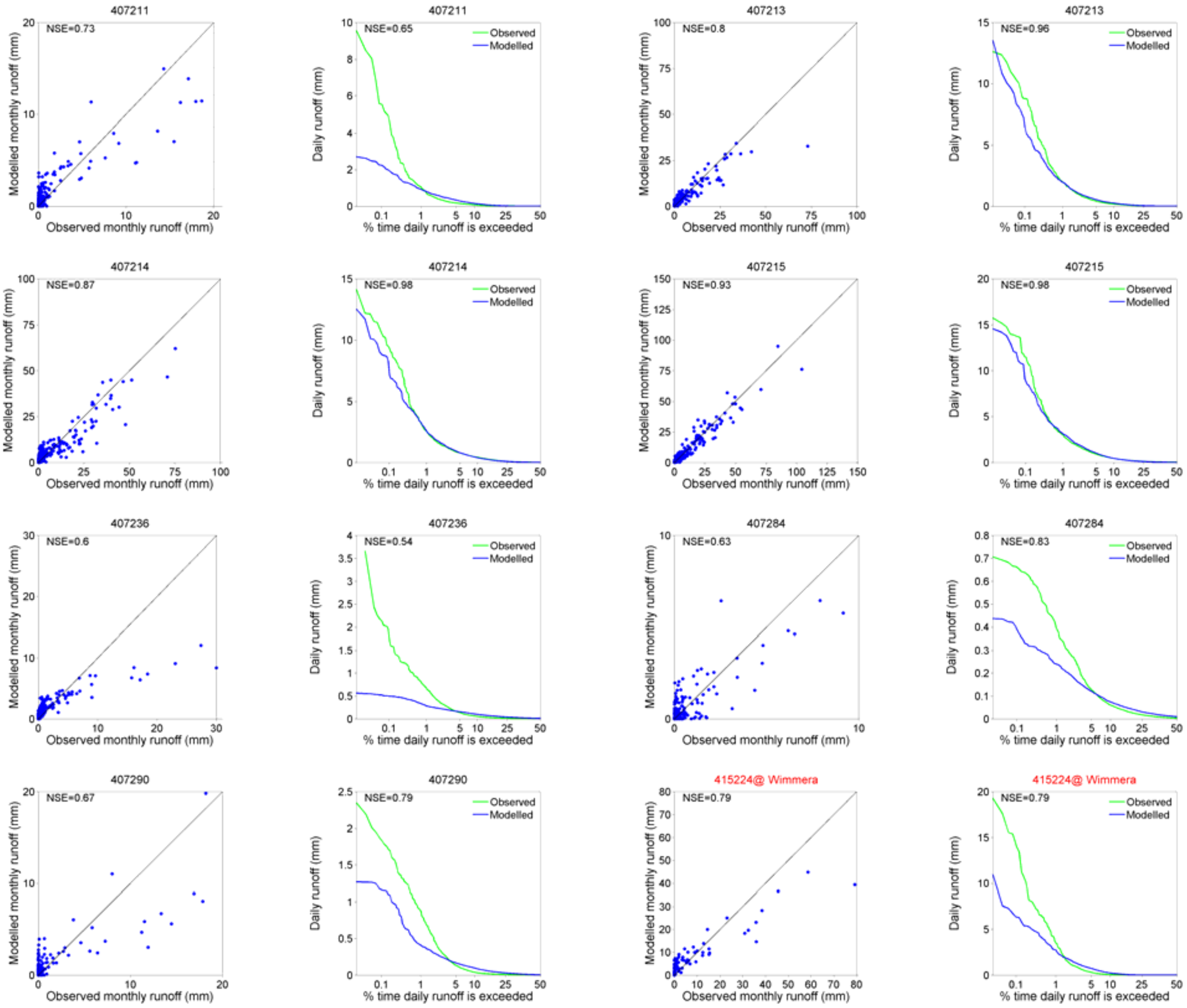

Figure 3-2. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

3.3 Modelling results

3.3.1 Scenario A – historical climate and current development

Figure 3-3 shows the spatial distribution of mean annual rainfall and modelled runoff for 1895 to 2006 across the Loddon-Avoca 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 Loddon-Avoca region are 430 mm and 21 mm respectively. The mean annual rainfall varies from about 800 mm in the south to 300 mm in the north. The modelled mean annual runoff varies from more than 60 mm in the south to less than 5 mm in the north. Rainfall is higher in the winter half of the year and most of the runoff occurs in winter and spring. The Loddon-Avoca region covers about 2.3 percent of the MDB and contributes about 1.7 percent of the total runoff in the MDB.

Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure 3-4). The coefficients of variation of annual rainfall and runoff averaged over the Loddon-Avoca region are 0.26 and 0.75 respectively, the same as the median values of the 18 MDB reporting regions. The tenth percentile, median and ninetieth percentile values across the 18 MDB regions are 0.22, 0.26 and 0.36 respectively for rainfall and 0.54, 0.75 and 1.19 for runoff.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 11 percent and 52 percent lower respectively than the long-term (1895 to 2006) mean values. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 rainfall at a significance level of α = 0.2 and the 1997 to 2006 runoff is statistically different to the 1895 to 1996 runoff at a significance level of α = 0.05 (with the Student-t and Rank-Sum tests). Scenario B modelling was done because of this significance. The Scenario B is a stochastic replicate selected such that its long-term (1895 to 2006) 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.

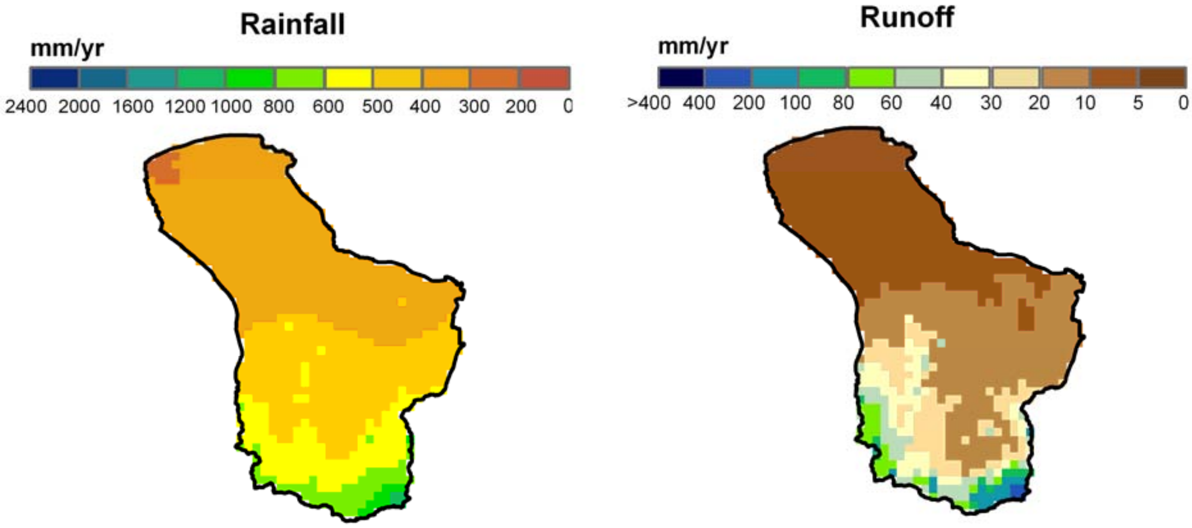

Figure 3-3. Spatial distribution of mean annual rainfall and modelled runoff averaged over 1895–2006

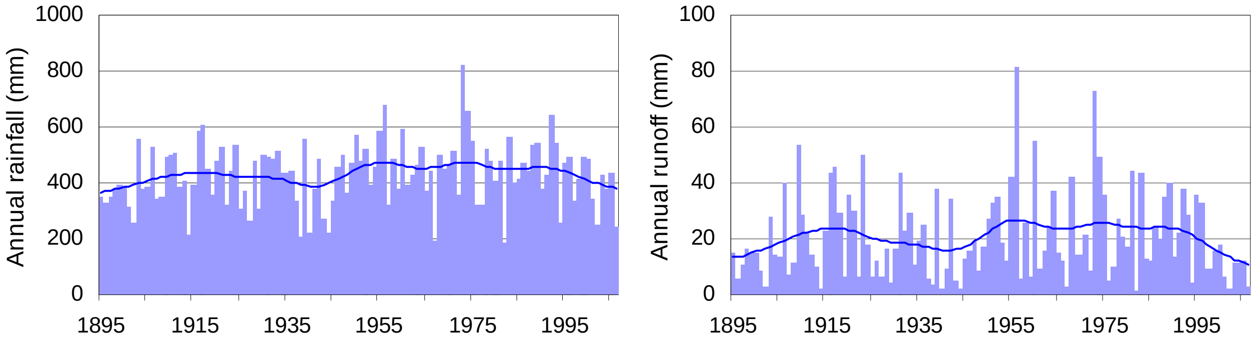

Figure 3-4. 1895–2006 annual rainfall and modelled runoff averaged over the region (the curve shows the low frequency variability)

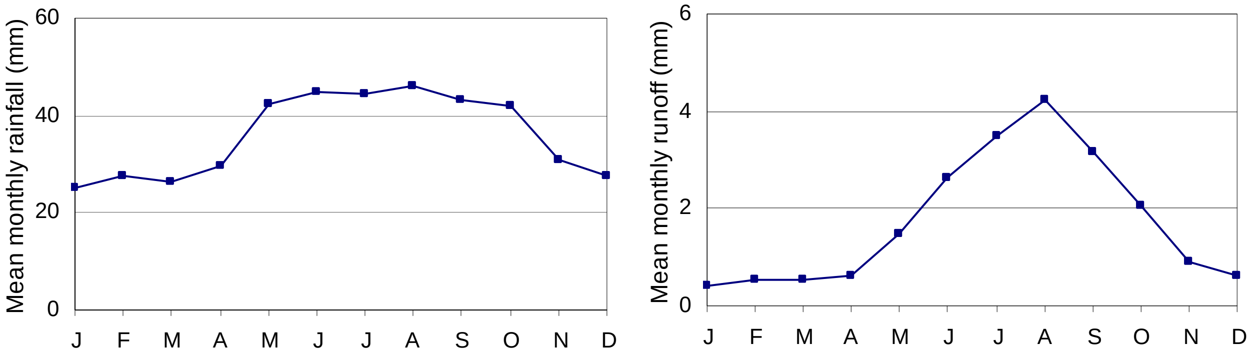

Figure 3-5. Mean monthly rainfall and modelled runoff (averaged over 1895–2006 for the region)

3.3.2 Scenario C – future climate and current development

Figure 3-6 shows the percentage change in the modelled mean annual runoff averaged over the Loddon-Avoca, Campaspe and Goulburn-Broken regions, for 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 runoff and mean annual rainfall from the corresponding GCMs are also tabulated in Table 3-1. The Loddon-Avoca, Campaspe and Goulburn-Broken regions are aggregated in this way because the river model for this area – the Goulburn Simulation Model (Chapter 4) – covers all three regions. So the choice of scenarios for the river system modelling (and linked groundwater modelling) uses the rainfall-runoff modelling results for the three combined regions.

The plot and table indicate that climate change would significantly reduce runoff across the Loddon-Avoca, Campaspe and Goulburn-Broken regions. All the modelling results show a decrease in runoff. Rainfall-runoff modelling for the high global warming scenario (with climate change projections from 60 percent of the GCMs) indicates a decrease in mean annual runoff greater than 10 percent.

The biggest increase and decrease in runoff come from the high global warming scenario because of the large variation between GCM simulations and the method used to obtain the climate change scenarios (Section 1.3.3). Only results from scenarios Cdry, Cmid and Cwet are shown in subsequent reporting. Scenario Cdry results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Scenario Cwet results from the second highest increase in mean annual runoff from the high global warming scenario are used. Scenario Cmid results from the median mean annual runoff from the medium global warming scenario are used. These are shown in bold in Table 3-1. Scenario Cdry, Cmid and Cwet indicate a -44, -14 and -2 percent change in mean annual runoff. The range using the low global warming scenario is -14 to -1 percent.

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

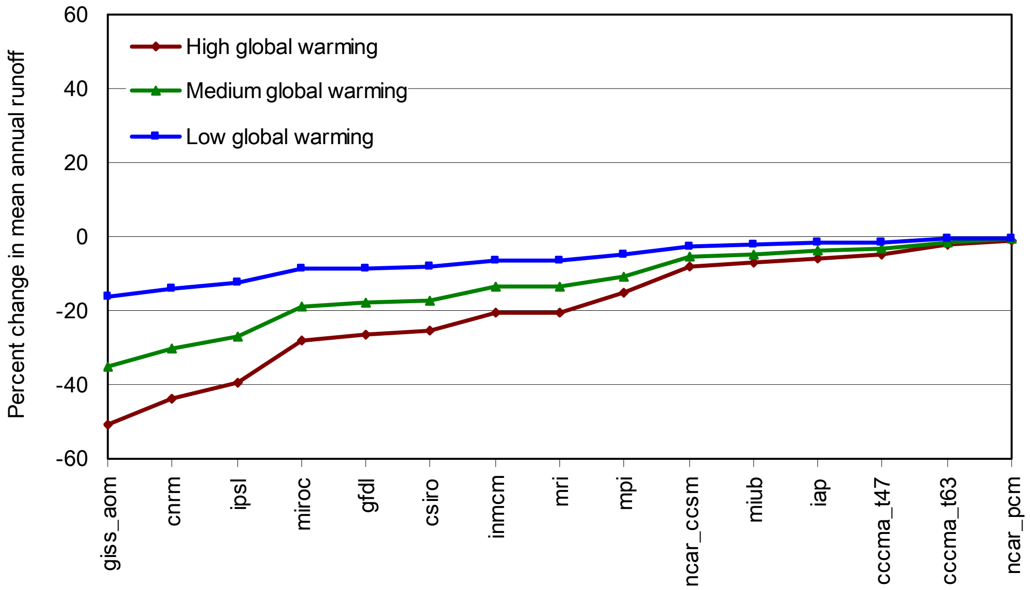

Figure 3-6. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A runoff for the Loddon-Avoca, Campaspe and Goulburn-Broken regions

Table 3-1. Summary results under the 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and runoff for Scenario C relative to Scenario A) for the Loddon-Avoca, Campaspe and Goulburn-Broken regions

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Runoff	GCM	Rainfall	Runoff	GCM	Rainfall	Runoff
giss_aom	-22	-51	giss_aom	-14	-35	giss_aom	-6	-16
cnrm	**-18**	**-44**	cnrm	-11	-30	cnrm	-5	-14
ipsl	-19	-40	ipsl	-12	-27	ipsl	-5	-13
miroc	-7	-28	miroc	-5	-19	miroc	-2	-9
gfdl	-11	-26	gfdl	-7	-18	gfdl	-3	-8
csiro	-10	-26	csiro	-6	-17	csiro	-3	-8
inmcm	-6	-21	mri	-5	-14	mri	-2	-6
mri	-7	-20	**inmcm**	**-4**	**-14**	inmcm	-2	-6
mpi	-6	-15	mpi	-4	-11	mpi	-2	-5
ncar_ccsm	0	-8	ncar_ccsm	0	-5	ncar_ccsm	0	-2
miub	-1	-7	miub	-1	-5	miub	0	-2
iap	-3	-6	iap	-2	-4	iap	-1	-2
cccma_t47	-1	-5	cccma_t47	-1	-3	cccma_t47	0	-1
cccma_t63	**1**	**-2**	cccma_t63	0	-1	cccma_t63	0	-1
ncar_pcm	2	-1	ncar_pcm	1	-1	ncar_pcm	1	0

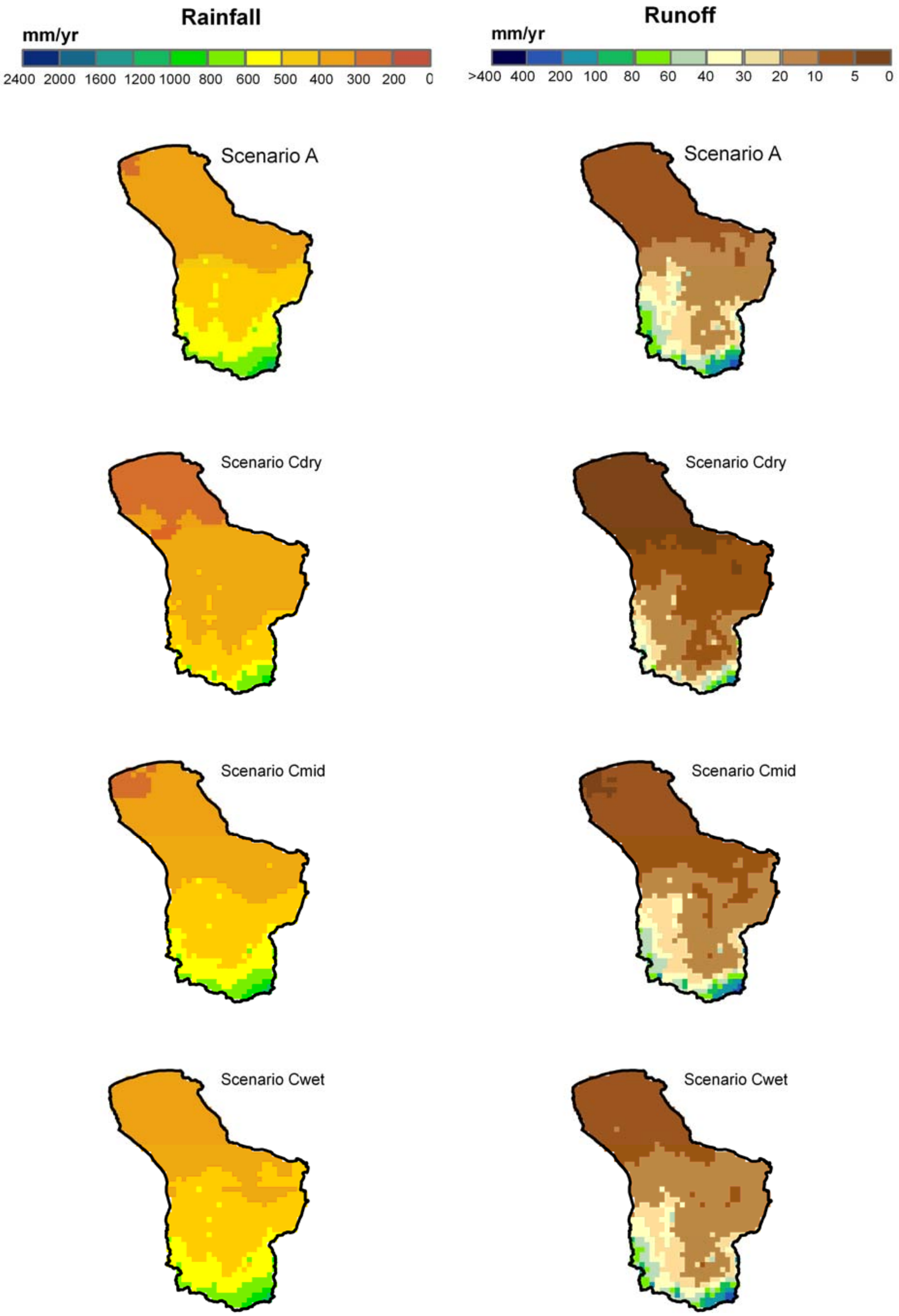

Figure 3-7. Mean annual rainfall and modelled runoff under scenarios A, Cdry, Cmid and Cwet

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 Loddon-Avoca region), and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios C and D relative to Scenario A. 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 Loddon-Avoca 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. The comparison of monthly and daily results under Scenario Cmid relative to Scenario A should be interpreted cautiously as Scenario Cmid is chosen using mean annual runoff (Section 3.3.2). However, the ‘C range’ results shown in Figure 3-8 use the second driest and second wettest results for each month separately from the high global warming scenario. The C range results shown in Figure 3-9 are based on the second lowest and second highest daily rainfall and runoff results at each of the rainfall and runoff percentiles from the high global warming scenario. The lower and upper limits of C range are therefore not the same as Scenario Cdry and Cwet reported elsewhere and used in the river system and groundwater models.

Figure 3-8 indicates that the GCM projections show a bigger decrease in the winter-half rainfall compared to summer-half rainfall and this translates to an even bigger percent runoff reduction in the winter half when most of the runoff in the Loddon-Avoca region occurs. Although all 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 percent of the time will be more intense (Figure 3-9).

The mean annual runoff over the ten-year period 1997 to 2006 is 52 percent lower than the long-term (1895 to 2006) mean values. One-hundred replicates of 112-year daily climate sequences are generated for Scenario B modelling using the 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. The change in rainfall has little meaning and is therefore not shown in Table 3-2 because the replicate is chosen using mean annual runoff.

The modelling results indicate a median estimate of -16 percent change in mean annual runoff over the Loddon-Avoca region by ~2030 (Scenario C). However, there is considerable uncertainty in the climate change impact estimate. Extreme estimates range from -43 percent to 0 percent change in mean annual runoff. These values are very similar to (but not the same as) the values in Section 3.3.2 because the values in Section 3.3.2 show results for the combined Loddon-Avoca, Campaspe and Goulburn-Broken regions.

The projected growth in commercial forestry plantations is negligible. The total farm dam storage volume in the entire Loddon-Avoca region is projected to increase by 3.1 GL by ~2030. The median estimate of the combined impact of climate change and farm dam development is a 17 percent reduction in mean annual runoff. Extreme estimates range from -44 to -1 percent.

Table 3-2. Water balance over the entire region under scenarios A, B, C and D

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	430	21	409
		percent change from Scenario A	
B	–	-52%	–
Cdry	-16%	-43%	-15%
Cmid	-4%	-16%	-3%
Cwet	2%	0%	2%
Ddry	-16%	-44%	-15%
Dmid	-4%	-17%	-3%
Dwet	2%	-1%	2%

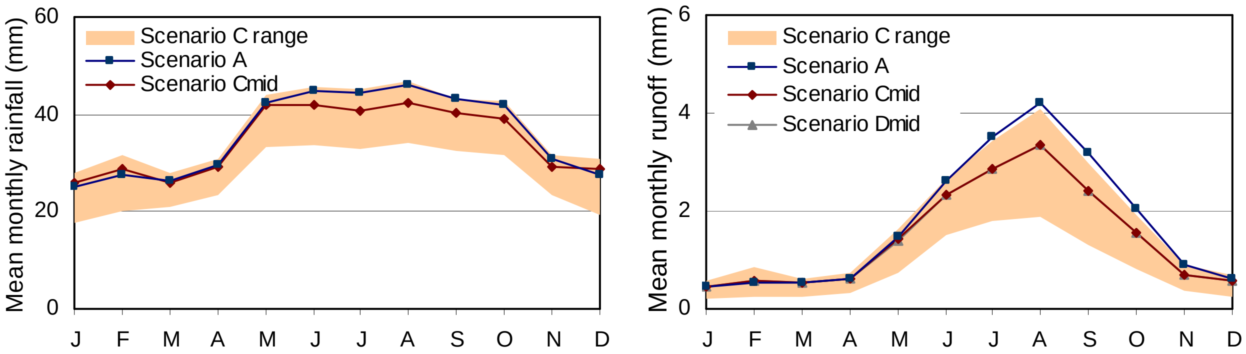

Figure 3-8. Mean monthly rainfall and modelled runoff under scenarios A, C and D averaged over 1895–2006 across the region (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

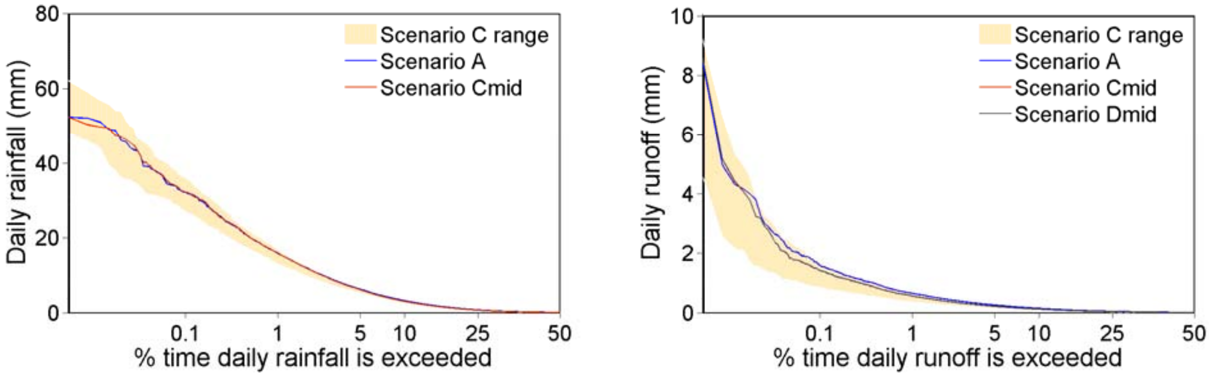

Figure 3-9. Daily flow duration curves under scenarios A, C and D averaged over the region (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

3.4 Discussion of key findings

The mean annual rainfall and modelled runoff averaged over the Loddon-Avoca region are 430 mm and 21 mm respectively. The mean annual rainfall varies from about 800 mm in the south to 300 mm in the north. The modelled mean annual runoff varies from more than 60 mm in the south to less than 5 mm in the north. Rainfall is higher in the winter half of the year and most of the runoff occurs in winter and spring. The Loddon-Avoca region covers about 2.3 percent of the MDB and contributes about 1.7 percent of the total runoff in the MDB.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 11 and 52 percent lower respectively than the long-term (1895 to 2006) mean values. The 1997 to 2006 rainfall is statistically different to the 1895 to 1996 rainfall at a significance level of $\alpha = 0.2$ and the 1997 to 2006 runoff is statistically different to the 1895 to 1996 runoff at a significance level of $\alpha = 0.05$ (with the Student-t and Rank-Sum tests).

Although the rainfall over the ten-year period 1997 to 2006 is 11 percent lower than the long-term (1895 to 2006) mean values, the runoff is 52 percent lower than the long-term (1895 to 2006) mean values. The likely reasons for this include: rainfall-runoff is a nonlinear process and the changes in rainfall are amplified more in runoff in a drier climate; subsurface water storage is low after a long dry period and a significant amount of rainfall is required to fill the storage before runoff can occur; and changes in the daily and seasonal rainfall distribution and sequencing of rainfall events could amplify the reduction in runoff (particularly the observed reduction in autumn and winter rainfall – see Potter et al. (2008)).

The mean annual runoff over the past ten years is lower than the projected decrease in mean annual runoff under Scenario Cdry. However, it is not sufficient evidence that the hydroclimate has shifted to a new regime because it is based on a relatively short ten years of data. Nevertheless, if the hydroclimate has shifted (like in Scenario Cdry), Scenario B conditions will occur more frequently.

The runoff estimates for the Loddon-Avoca region, particularly in the southern parts where most of the runoff occurs, are relatively good because there are many calibration catchments there from which to estimate the parameter values.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Loddon-Avoca will decrease significantly. All the modelling results using climate change projections from different global climate models showing a decrease in runoff. Most of the global climate models show a greater reduction in winter-half rainfall and this translates to an even bigger percent reduction in winter-half runoff, when most of the runoff in the Loddon-Avoca occurs. Although the projections indicate a decrease in mean annual rainfall and runoff, two-thirds of the results also indicate that the extreme rainfall events will be more intense.

The median estimate would a 16 percent reduction in mean annual runoff by ~2030 relative to ~1990. However, there is considerable uncertainty in the modelling results with the extreme estimates ranging from -43 percent to no change in mean annual runoff. These extreme estimates come from the high global warming scenario. The range from the low global warming scenario is -14 to -1 percent change in mean annual runoff. The main sources of uncertainty are in the global warming projections and the global climate modelling of local rainfall response to the global warming. The uncertainty in the rainfall-runoff modelling of climate change impact on runoff is small compared to the climate change projections.

The projected growth in commercial forestry plantations is negligible. The total farm dam storage volume is projected to increase by 3070 ML (3 percent) by ~2030. The median estimate of the combined impact of climate change and farm dam development would be a 17 percent reduction in mean annual runoff. Extreme estimates range from -44 to -1 percent. The modelled reduction in mean annual runoff from the projected increase in farm dams alone is about 1 percent and is relatively small compared to the runoff reduction under Scenario Cmid.

3.5 References

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4 River system modelling

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

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

The information in this chapter is derived from the calibrated Goulburn Simulation Model (GSM) – a REALM representation of the Goulburn, Broken, Loddon and Campaspe river systems provided by the Victorian Department of Sustainability and Environment (DSE). The stand-alone Avoca REALM model was extracted from the Kerang Lakes REALM model provided by DSE.

4.1 Summary

4.1.1 Issues and observations

The Loddon-Avoca region includes the Loddon River and its tributaries, a portion of the Waranga Western Channel, and the Avoca River. The region is connected to the Campaspe, Goulburn-Broken and Wimmera regions via the Waranga Western Channel. River system modelling for the Loddon-Avoca region includes the following modelling scenarios:

- Scenario O
  This scenario represents a GSM system configuration similar to that used by DSE for planning purposes. Run from May 1891 to July 2006, it represents the current level of development. The Avoca model is also run from May 1891 to July 2006. No groundwater behaviour derived from interaction with surrounding groundwater models was applied for this scenario, although the model does include unattributed gains and losses.
- Scenario A – historical climate and current development
  This scenario is based on the Scenario O model with the current level of development but is run for the common historical climate period used in this study (July 1895 to June 2006). Additionally, Scenario A incorporates groundwater behaviour derived from interaction with surrounding groundwater models. No groundwater modelling was undertaken for the Avoca River modelling. This scenario is the baseline scenario against which scenarios B, C and D are compared.
- Scenario P – without-development
  This scenario incorporates the model for Scenario A 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.
- Scenario B – recent climate and current development
  This scenario represents a future climate condition if the climate observed in the region since 1997 is to persist into the future. The level of development is the same as Scenario A. For Scenario B, a without-development model run is also undertaken; this uses Scenario B climate and Scenario P development conditions.
- Scenario C – future climate and current development
  Scenarios Cwet, Cmid and Cdry represent a range of future climate conditions 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. For each Scenario Cwet, Cmid and Cdry, without-development model runs are also undertaken; these use Scenario C climate and Scenario P development conditions.

- Scenario D – future climate and future development
  Scenarios Dwet, Dmid and Ddry use the C scenarios climate inputs with flow inputs adjusted for 2030 development projections (farm dams, commercial forestry plantation and groundwater). The impact of groundwater development on river reaches is also considered. The farm dam and forestry projections are discussed in Chapter 3 while groundwater development is discussed in Chapter 6.

For the Loddon-Avoca river system modelling:

- models are configured to represent the current utilisation of entitlements
- modelled crop areas are fixed and do not reflect any change in irrigated area as a function of available water resources. Crop demands are derived independently based on various factors including rainfall and evaporation. So although crop areas are fixed, demand does vary as a function of climate drivers
- findings are based on current water sharing and management strategies. Adaptive management processes required under Victorian legislation include long-term water resource assessments and sustainable water strategies aimed to ensure the level of equity desired by the broader community is achieved. Thus, water sharing and management arrangements may adapt over time to future water resources conditions.

The Loddon River system is both a gaining and losing stream at different times of the year. Surface water availability in the Loddon River is assessed at the point of maximum average annual flow (without development) which occurs downstream of Laanecoorie Weir (at gauge 407203). The Avoca River is a losing stream in the mid- and lower reaches. Surface water availability in the Avoca River is assessed at the point of maximum average annual flow (without development), that occurs downstream of Coonooer Bridge (at gauge 408200).

4.1.2 Key messages

- Current average surface water availability for the Loddon-Avoca region is 285 GL/year – 201 GL/year generated from runoff in the Loddon catchment and 84 GL/year from runoff generated in the Avoca catchment. On average, 349 GL/year are diverted for use in the Loddon catchment (including channel and pipe losses); there are no surface water diversions in the Avoca catchment. Around 92 GL/year (of the total 349 GL/year diverted for use) are sourced within the region, thus the level of surface water use is 32 percent. This is a high level of development. The other 257 GL/year that is diverted for use is supported by the 264 GL/year transferred from the Goulburn-Broken region via the Campaspe region by means of the Waranga Western Channel. This water use (and the associated water availability) is accounted at the point of diversion (in the Goulburn-Broken region) not at the points of use (in the Loddon-Avoca and other regions).
- Reliability of supply is determined separately for high reliability water shares (HRWS) and low reliability water shares (LRWS) and is reported for final allocations in February. In the regulated Loddon system, a 100 percent HRWS allocation occurs in 92 percent of years and the minimum HRWS allocation is 58 percent. A 100 percent LRWS allocation occurs in 42 percent of years and a zero LRWS allocation occurs in 24 percent of years.
- If the climate of the last ten years were to continue, average surface water availability would be reduced by 50 percent and total end-of-system flows would be reduced by 71 percent. The volume of water diverted for use within the region would be reduced by 28 percent. A 100 percent HRWS allocation would occur in 47 percent of years and the minimum HRWS allocation would be 1 percent. A 100 percent LRWS allocation would occur in 2 percent of years and a zero LRWS allocation would occur in 88 percent of years. Transfers from the Campaspe region via the Waranga Western Channel would be reduced by 24 percent. The relative level of surface water use would rise to a very high 41 percent.
- Under the best estimate (median) 2030 climate, average surface water availability in the region would be reduced by 18 percent and total end-of-system flows would be reduced by 27 percent. The volume of water diverted for use within the region would be reduced by 6 percent. A 100 percent HRWS allocation would occur in 83 percent of years and the minimum HRWS allocation would be 15 percent. A 100 percent LRWS allocation would occur in 21 percent of years and a zero LRWS allocation would occur in 36 percent of years. Transfers from the Waranga Western Channel would be reduced by 4 percent. The relative level of surface water use would increase to 35 percent.
- Under the wet 2030 climate extreme, average surface water availability in the region would be reduced by 5 percent and total end-of-system flows would be reduced by 6 percent. The volume of water diverted for use within the region and the reliability of supply would not be greatly impacted, and there would be no significant

change in Waranga Western Channel transfers. Under the dry 2030 climate extreme, water resources conditions will be broadly equivalent to a continuation of the recent climate.
- Projected future development of small farm dams and increases in groundwater extraction would have minor impacts on streamflow and surface water use.

4.1.3 Robustness

A trial run of the models using inputs representing extremely dry climate conditions was made to assess how robustly they would behave. Allocations to Loddon private diverters during this trial run went down to 1 percent and the combined Loddon system storage and combined Avoca system storage were drawn down to 4.5 GL and 0.3 GL respectively. The models behaved robustly during this extreme test.

The models' responses to inflow increases and decreases were reasonable and the change in diversions and end-of-systems flows was consistent with the change in inflows. Mass balance over the modelling period was maintained within 1 percent for all scenarios.

4.2 Modelling approach

The following section provides a summary of the generic river modelling approach, a description of the GSM and the Avoca River model and how they were developed. Refer to Chapter 1 for more context 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 scenario-related changes in inflows for the reliability of water supply to users. River system models currently employed by state agencies and the Murray-Darling Basin Commission were used in the assessment due to project time constraints and the need to link with state water planning processes. The main models used were IQQM, REALM, MSM-BigMod, WaterCress and a model of the Snowy Mountains Hydro-electric Scheme.

4.2.2 Description of river models for the Loddon-Avoca region

The GSM spans three regions: the Goulburn-Broken, Campaspe and Loddon-Avoca. These three regions are modelled as one because they are hydrologically linked by the Waranga Western Channel which transfers water from the Goulburn-Broken to the Campaspe and on to the Loddon-Avoca (Figure 4-1). The Waranga Western Channel continues on from the Loddon-Avoca through to the Wimmera region. However, this connection is not shown on Figure 4-1 because the GSM is not linked to the river model for the Wimmera. Rather, the Wimmera model is calibrated to observed inflows from the Waranga Western Channel.

The GSM is a REALM (V5.01) representation of the Goulburn, Broken, Campaspe and Loddon river systems. The Broken River flows into the Goulburn River near Shepparton, and the Goulburn, Campaspe and Loddon rivers are all linked via the Waranga Western Channel (DSE, 2005). Therefore, changes in one part of the GSM can affect flows and reliability of supply in other GSM river systems. The GSM was recently updated and covers the period of May 1891 to December 2006 (SKM, 2007a). The common reporting period for this project is July 1895 to June 2006. The GSM is comprised of over 350 nodes and over 780 links, all arranged into the four river systems, the Waranga Western Channel and several water accounting functions.

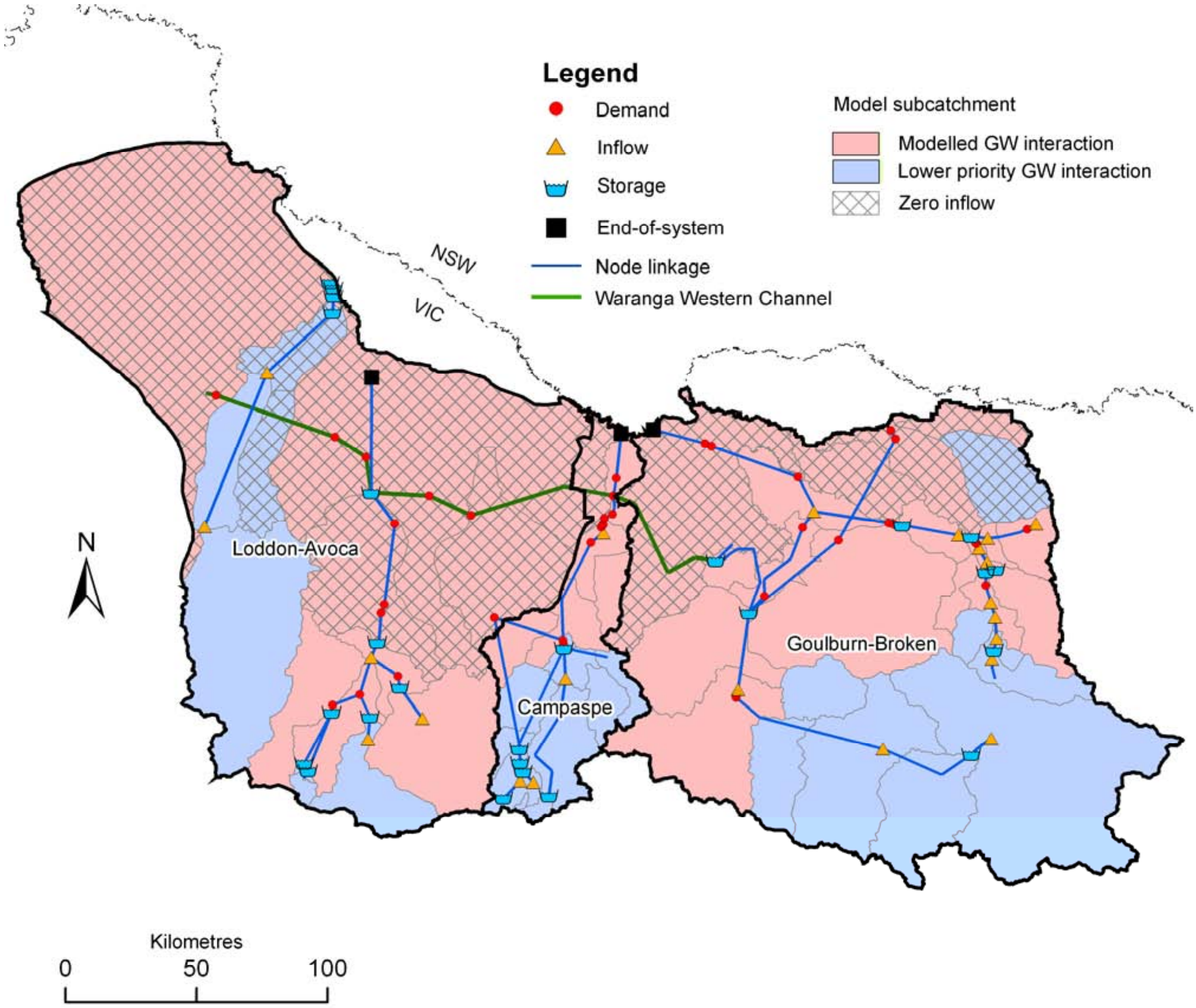

Figure 4-1.The full extent of the Goulburn Simulation Model across the Goulburn-Broken, Campaspe and Loddon-Avoca regions, indicating how the Waranga Western Channel links across the three regions

A schematic of the Loddon-Avoca river system model within the region is shown in Figure 4-2. Components outside of the region are not included. The Loddon river system model is part of the GSM run simultaneously for the Campaspe, Goulburn-Broken and Loddon-Avoca regions.

The Loddon river system is modelled from Cairn Curran Reservoir and upstream Tullaroop Creek to the Laanecoorie Reservoir where these two branches meet, then along the Loddon River to downstream of Appin South. The Loddon River at Appin South is an inflow to the Murray River model and the Murray region.

The Avoca REALM model is a stand-alone model and is not part of the GSM. It consists of 38 nodes and 61 links and represents the Avoca River from Coonooer Bridge to downstream of Third Marsh. The Avoca model uses a daily time step.

The Loddon-Avoca region consists of the Loddon and Avoca river systems, a section of the Waranga Western Channel and the irrigation districts this channel supplies from upstream of the Pyramid Hill Irrigation District to downstream of Boort.

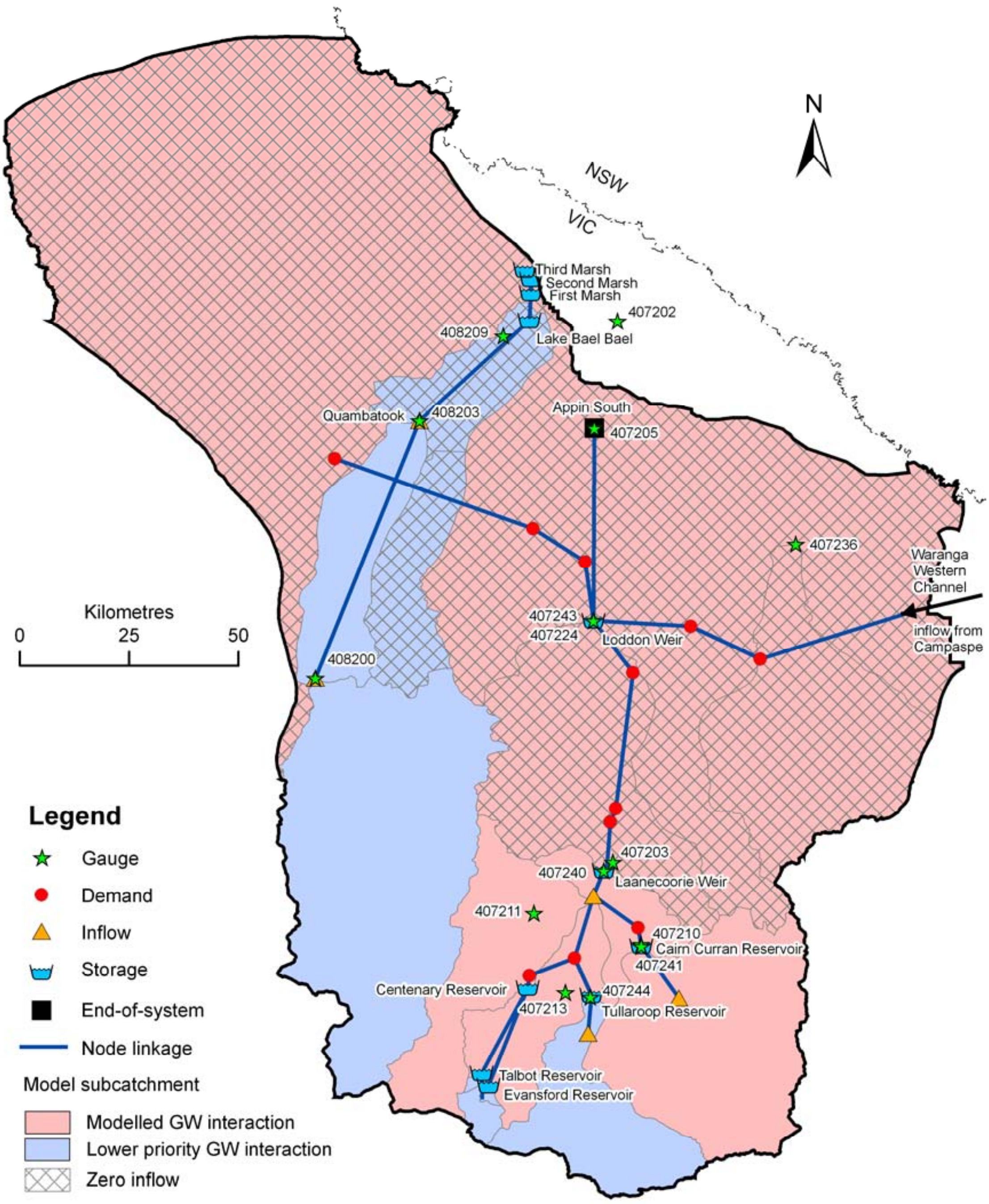

Figure 4-2. River system map showing subcatchments, inflow and demand nodes and gauge locations within the Loddon-Avoca region

The model includes significant losses and the largest is on the offtake channels from the Waranga Western Channel to the irrigation districts. The largest storage is Cairn Curran Reservoir and other storages modelled include Talbot Reservoir, Evansford Reservoir, Centenary Reservoir, Tullaroop Reservoir and Laanacoorie Reservoir. The degree of regulation varies (Table 4-1). First Marsh, Second Marsh, Third Marsh and Lake Bael Bael are natural lakes with no regulation of inflows.

A large portion (66.4 GL/year under Scenario A) of the available water is diverted to the Waranga Western Channel and subsequently used to the west of the Loddon River. A sizeable amount (53.6 GL/year under Scenario A) is lost to flood breakouts, particularly in the lower Loddon and Avoca rivers. A flood breakout occurs when water spills into distributary channels on the floodplain that do not rejoin the main stem of the river (for example, the Loddon River to Wandella Creek flood breakout). Most of the total urban water demand is from Maryborough. Water use is modelled by three stock and domestic demand nodes, three irrigation demand nodes, three private diverter demand nodes and three urban demand nodes (Table 4-2). Water supplied to the environment is delivered in the model by specifying instream demands at particular locations in the river (Table 4-3).

Table 4-1. Storages in the river models in the Loddon-Avoca region

	Active storage	Average annual Inflow	Average annual regulated release	Average annual net evaporation	Degree of regulation
	GL	GL/y			
Headworks					
Talbot Reservoir	0.8	1.0	0.1	0.1	0.2
Evansford Reservoir	1.0	7.4	1.4	0.0	0.2
Tullaroop Reservoir	66.0	46.4	43.1	3.1	1.0
Cairn Curran Reservoir	147.7	107.7	101.3	7.2	1.0
Laanecoorie Reservoir	8.0	187.9	185.9	2.1	1.0
Service basins					
Centenary Reservoir	0.2	2.2	2.1	0.0	1.0
Lakes					
Lake Bael Bael	30.0	41.5	0.0	3.8	0.1
First Marsh	30.0	35.4	0.0	1.3	0.0
Second Marsh	8.0	28.7	0.0	7.2	0.3
Third Marsh	25.0	29.1	0.0	5.7	0.2
Region Total	**316.7**	**487.4**	**334.0**	**30.6**	**0.75**

Table 4-2. Water use configuration in the models

	Number of nodes	Entitlement	Pump constraints	Model notes
		GL/y	ML/day	
Urban	3		various	
Stock and domestic	part of 6 nodes	11.8	various	
High Reliability Water Share	part of 7 nodes	261.0	various	
Low Reliability Water Share				
Irrigation	part of 6 nodes	98.0	various	Includes significant delivery losses
Environment	part of 6 nodes	24.5	various	
Subtotal	part of 6 nodes	122.5	various	

Table 4-3. Water management in the models

Environmental flow requirements	Minimum flows
Loddon River between Cairn Curran Dam and Laanecoorie Reservoir	20 ML/d or natural, Nov-Apr
	20 ML/d or natural from May–Oct if storage in Cairn Curran Dam and Tullaroop Dam <60 GL
	35 ML/d or natural from May–Oct if storage in Cairn Curran Dam and Tullaroop Dam ≥60 GL
	35 ML/d for 7 days, three times from Nov–Apr
Tullaroop Creek between Tullaroop Dam and Laanecoorie Reservoir	10 ML/d or natural, all year
	13.5 ML/d for 7 days, four times from Nov–Apr
Loddon River between Laanecoorie Weir and Serpentine Weir	15 ML/d or natural, Nov–Jul
	15 ML/d or natural from Aug–Oct if storage in Cairn Curran Dam and Tullaroop Dam <60 GL
	52 ML/d or natural from Aug–Oct if storage in Cairn Curran Dam and Tullaroop Dam ≥60 GL
	52 ML/d for 13 days, three times from Nov–Apr
Loddon River between Serpentine Weir and Loddon Weir	19 ML/d or natural, Nov–Apr
	19 ML/d or natural from May–Oct if storage in Cairn Curran Dam and Tullaroop Dam <60 GL
	61 ML/d or natural from May–Oct if storage in Cairn Curran Dam and Tullaroop Dam ≥60 GL
	61 ML/d for 11 days, three times from Nov–Apr
Loddon River between Loddon Weir and Kerang Weir	10 ML/d or natural from May–Oct if storage in Cairn Curran Dam and Tullaroop Dam <60 GL
	61 ML/d or natural from May–Oct if storage in Cairn Curran Dam and Tullaroop Dam ≥60 GL
	50 ML/d for 14 days, Jan–Feb
Avoca	None modelled

4.2.3 Model setup

Model setup involved the following generic steps:

1. The custodians contributed pre-calibrated models to be run for the original modelling period (which in many cases differs from the common modelling period used for scenarios in this project). The results from the model were checked against published results.
2. The modelling period used in the pre-calibrated models was extended to cover the common modelling period used in this project.
3. A without-development version of the model was created by removing all water users and regulated water supplies.
4. The initial state of all storages within the model was determined.
5. The robustness of the model was checked through a trial run using inputs that represent extremely dry climate conditions.

The original GSM and its associated REALM V5.01 code and the Avoca model REALM V5.08 executable code were obtained from DSE. This model was run for the original period of May 1891 to June 2006 and validated against previous results. The model conditions assume post-unbundling of entitlements and a reduction in the capacity of the restored Winton Swamp (formerly Lake Mokoan) from 362 GL to 27 GL. The Avoca model was extracted from the Kerang Lakes daily REALM model, obtained from DSE. The Avoca model is a daily model and it was run for the original period of 1 May 1975 to 30 April 2000 and validated against previous results. The time series rainfall, evaporation and flow inputs to this model were extended to cover the period January 1891 to June 2006.

Without-development versions of these models were created by removing all headworks storages and service basins, consumptive demands and channel systems. There was no difference between without-development and current conditions for the Avoca River.

The Loddon and Avoca rivers contain a significant amount of total storage relative to inflows. The initial state of these storages can influence the results obtained. Each scenario has a one month warm-up period (June 1895) for the storages hence the storage conditions for 31 May 1895 needed to be determined. So Scenario O (which begins on 1 May 1891) was started with all of the storages empty at 30 April 1891 and run up to 31 May 1895, and the final storage volumes recorded. This was repeated with all of the storages initially full. The modelling results (Table 4-4) show that storage traces converge or nearly converge for the two runs by 31 May 1895. An average of the storage volumes starting from empty and full was adopted for storages where complete convergence did not occur.

The models were configured for an extremely dry climate trial run (broadly equivalent to Scenario Cdry) by decreasing or increasing rainfall, evaporation and inflows (Table 4-5). The test model runs appeared to be robust overall with low allocations reached (see bottom of Table 4-4) and no significant changes in model convergence performance. The results of the model setup are summarised in Table 4-4.

Table 4-4. Model setup information

Original models		Version	Start date	End date
Goulburn Simulation Model (GSM)	REALM	5.0	May-1891	Jun-2006
Connection				
Loddon River	Outflow to downstream Appin South			
Waranga Western Channel	Outflow to Wimmera region			
Avoca Model	REALM	5.08	May-1891	Jun-2006
Connection				
Avoca River	Outflow to Kerang Lakes			
Baseline models				
Goulburn Simulation Model (GSM)				
Warm-up period	REALM	5.01	May-1891	Jun-1895
Modelling period	REALM	5.01	Jul-1895	Jun-2006
Loddon River	Outflow to downstream Appin South			
Waranga Western Channel	Outflow to Wimmera region			
Avoca model				
Warm-up period	REALM	5.08	May-1891	Jun-1895
Modelling period	REALM	5.08	Jul-1895	Jun-2006
Avoca River	Outflow to Kerang Lakes			
Modifications				
Data	No adjustment required			
Inflows	No adjustment required			
Groundwater loss nodes	Nodes added to the Loddon component of the GSM			
Initial storage volumes	Scenario O was run to 31 May 1895 with initial storages full and empty. Average of storages at 31 May 1895 taken.			
Warm-up test results				
Setting initial storage volumes	Storages commence empty	Storages commence full	Difference	Percent of full volume
	GL			percent
Talbot Reservoir 31/05/1895	0.7	0.7	0	0
Evansford Reservoir 31/05/1895	0.8	0.8	0	0
Centenary Reservoir 31/05/1895	0.2	0.2	0	0
Tullaroop Reservoir 31/05/1895	34.9	35.1	0.2	0.3
Cairn Curran Reservoir 31/05/1895	85.4	85.9	0.5	0.3
Laanecoorie Weir 31/05/1895	2.2	2.2	0	0
Lake Bael Bael 31/05/1895	7.7	7.6	-0.1	-0.3
First Marsh 31/05/1895	9.1	9.1	0	0
Second Marsh 31/05/1895	0.4	0.4	0	0
Third Marsh 31/05/1895	0.6	0.6	0	0
Original models				
Storage volume end of May (1895-2006)	Mean	Median	Full storage capacity	
	GL			
Talbot Reservoir	0.6	0.7	0.837	
Evansford Reservoir	0.5	0.4	1.35	
Centenary Reservoir	0.2	0.2	0.181	
Tullaroop Reservoir	20.2	16.5	74	
Cairn Curran Reservoir	44.3	39.2	148	
Laanecoorie Weir	2.9	2.2	8	
Lake Bael Bael	4.6	4	30	
First Marsh	4.6	4.1	30	
Second Marsh	0.2	0.1	8	
Third Marsh	0.4	0.1	25	
Robustness test results				
	Original model	Robustness test		
Minimum allocation in February				
Loddon private diverters (%)	58%	1%		
Goulburn private diverters and irrigators	73%	4%		
Minimum combined Loddon system storage (GL)	6.7	4.5		
Minimum combined Avoca system storage (GL)	0.4	0.3		

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

Season	Rainfall	Evaporation	Flow
DJF	0.79	1.05–1.06	0.52–0.66
MAM	0.96	1.06–1.07	0.91–1.08
JJA	0.79	1.05	0.46–0.57
SON	0.75	1.05–1.07	0.37–0.46

4.3 Modelling results

4.3.1 River system water balance

The modelled mass balance for the Loddon-Avoca region is given in Table 4-6. Scenario O and A fluxes are displayed in GL/year and all other scenarios are presented as a percentage change from Scenario A. The averaging period for Scenario O differs from Scenario A.

The directly gauged inflows represent inflows based on river gauges. The indirectly gauged inflows represent the inflows that are derived to achieve mass balance between mainstream gauges. The water supplies were split into four categories: licensed private diverters, irrigation districts, stock and domestic, and urban. End-of-system flows are shown for the three main outflow points: downstream of Appin South on the Loddon River, Waranga Western Channel to the Wimmera-Mallee region, and flows to the Kerang Lakes from the Avoca River downstream of Third Marsh. 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 designated subcatchments in the model. The reach and overall mass balances were checked using the difference between total inflows and outflows of the system. The mass balance error was less than 1 percent in all cases.

The water balance (Table 4-6) shows that catchment inflows decrease under all future climate scenarios. Water supply in the Loddon-Avoca region would be decreased by about 6 percent under Scenario Cmid. Losses would decrease under future climate scenarios as there is less water in the system to be lost. End-of-system flows would be decreased under all future scenarios except for the Avoca River outflow. The Waranga Western Channel has a constant outflow and does not change with different climate scenarios. The Avoca River outflow would increase by 4 percent for scenarios Cwet and Dwet despite causing a 4 percent reduction in inflows. This is due to the different flow pattern affecting the magnitude of the modelled losses that causes higher flow from Quambatook onwards.

A transfer of 66.4 GL/year from the Loddon River to the Waranga Western Channel (as presented in Reach 5 Water Balance, Appendix B) helps service the downstream Waranga Western Channel demands such as Boort, West Loddon, Normanville and the demands in the Wimmera region.

The Avoca and Loddon rivers have a high proportion of flood breakout flows that would be reduced under the drier future climate scenarios.

Table 4-6. River system model average annual water balance in the Loddon-Avoca region under scenarios O, A, B, C and D

	O	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	May-1891	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A						
Storage volume									
Change over period	-1.1	-1.2	-2%	0%	-1%	-2%	0%	-1%	-2%
Inflows									
Subcatchments									
Directly gauged (Avoca system)	87.8	83.8	-48%	-4%	-15%	-44%	-4%	-15%	-44%
Indirectly gauged (Loddon system)	249.0	240.2	-52%	-5%	-19%	-50%	-6%	-19%	-51%
Sub-total	**336.8**	**324.0**	**-51%**	**-5%**	**-18%**	**-49%**	**-6%**	**-18%**	**-49%**
Transfers from other basins	263.9	263.6	-24%	0%	-4%	-30%	0%	-4%	-30%
River groundwater gain*	0.0	0.0	10%	19%	6%	0%	19%	4%	-7%
Sub-total	**600.7**	**587.6**	**-39%**	**-3%**	**-11%**	**-40%**	**-3%**	**-12%**	**-41%**
Diversions									
Water use									
Licensed private diverters	13.6	13.6	-16%	3%	1%	-11%	3%	0%	-11%
Irrigation districts	257.7	256.9	-29%	-1%	-6%	-35%	-1%	-6%	-35%
Stock and domestic	8.8	10.8	-11%	-1%	-2%	-14%	-1%	-2%	-14%
Urban supply	2.4	2.4	-3%	3%	1%	0%	3%	1%	0%
Sub-total	**282.5**	**283.7**	**-27%**	**-1%**	**-6%**	**-33%**	**-1%**	**-6%**	**-33%**
Channel / pipe loss	65.6	65.6	-28%	-1%	-6%	-35%	-1%	-6%	-35%
Sub-total	**348.1**	**349.3**	**-28%**	**-1%**	**-6%**	**-33%**	**-1%**	**-6%**	**-34%**
Outflows									
System outflow									
Loddon River d/s Appin South	56.9	54.0	-60%	-7%	-23%	-55%	-7%	-24%	-55%
Waranga Western Channel to Wimmera-Mallee	6.3	6.3	0%	0%	0%	0%	0%	0%	0%
To flood breakouts	61.0	53.6	-85%	-11%	-35%	-80%	-12%	-38%	-81%
Avoca River d/s Third Marsh	26.4	25.4	-80%	4%	-23%	-59%	4%	-23%	-59%
River groundwater loss**	0.0	0.2	5%	-18%	-2%	15%	-12%	3%	19%
Sub-total	**150.5**	**139.4**	**-71%**	**-6%**	**-27%**	**-63%**	**-7%**	**-28%**	**-63%**
Net evaporation***	31.4	30.6	-27%	4%	-3%	-16%	4%	-3%	-16%
Sub-total	**181.9**	**170.0**	**-63%**	**-4%**	**-22%**	**-54%**	**-5%**	**-23%**	**-55%**
Unattributed fluxes									
River unattributed loss	71.8	69.6	-35%	-9%	-13%	-41%	-9%	-13%	-41%

* Values in the row are those used in the river modelling. The correct value for Scenario A, to be consistent with the groundwater modelling, is 0.4 GL/year. The percentage change values for other scenarios are correct. See the next paragraph for more information.

** Values in the row are those used in the river modelling. The correct value for Scenario A, to be consistent with the groundwater modelling, is 6.0 GL/year. The percentage change values for other scenarios are correct. See the next paragraph for more information.

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

During the report reviewing process, it was discovered that a unit conversion error had been made in translating the groundwater modelling results for input to the river modelling. Rerunning the river modelling was not practical at review stage as the river model (GSM) spans three regions, and is linked to the river models for the Murray and Murrumbidgee regions. The impact on the river modelling results is minor and is footnoted in Table 4-6. The values affected are small compared to other water balance terms, and have only minor impact on other river modelling results presented in this chapter. The main caveat is that the absolute values of end-of-system flows (Section 4.3.5) at low flows should be interpreted with some caution, and the relative level of use values (Table 4-13) would be 2 to 4 percent higher than reported if the groundwater-river fluxes were fully and properly accounted for in the river modelling.

4.3.2 Waranga Western Channel

The outflow from this region into the Waranga Western Channel has been included in the average annual balance table (Table 4-6). The modelled mass balance for the entire Waranga Western Channel is given in (Table 4-7). Scenario A fluxes are displayed as GL/year and all other scenarios are presented as a percentage change from Scenario A.

The inflows from each of the regions into the Waranga Western Channel are presented. The water supply was split by region into three categories: irrigation districts, stock and domestic, and urban. End-of-system flows are shown for Waranga Western Channel to the Wimmera region. The regional outflows are not included in the mass balance but are provided for each region at the end of the table. The change in storage between 30 June 1895 and 30 June 2006 averaged over the 111-year period is also included.

Table 4-7. Average annual water balance for the Waranga Western Channel under scenarios A, B, C and D

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	0.3	-328%	-78%	-344%	-328%	-81%	-344%	-332%
Inflows								
Regions								
Goulburn-Broken								
Indirectly gauged	4.6	-48%	-2%	-15%	-48%	-2%	-15%	-48%
Transfers from Goulburn Weir	1232.8	-24%	-1%	-5%	-28%	-1%	-5%	-28%
Sub-total	**1237.3**	**-24%**	**-1%**	**-5%**	**-28%**	**-1%**	**-6%**	**-29%**
Campaspe								
From Campaspe River to Waranga Western Channel	11.5	-85%	-6%	-25%	-84%	-6%	-28%	-84%
Loddon-Avoca								
Loddon Weir inflows	66.4	-45%	-4%	-15%	-51%	-6%	-15%	-51%
Sub-total	**1315.2**	**-26%**	**-1%**	**-6%**	**-30%**	**-1%**	**-6%**	**-30%**
Diversions								
Water use								
Goulburn-Broken								
Irrigation districts	469.5	-31%	-2%	-8%	-38%	-2%	-8%	-38%
Campaspe								
Irrigation districts	224.7	-30%	-1%	-7%	-36%	-1%	-7%	-37%
Urban diversions	1.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**225.7**	**-30%**	**-1%**	**-7%**	**-36%**	**-1%**	**-7%**	**-36%**
Loddon-Avoca								
Irrigation districts	256.5	-29%	-1%	-6%	-35%	-1%	-6%	-35%
Stock and domestic	1.9	0%	-1%	-1%	0%	-1%	-1%	0%
Sub-total	**258.4**	**-29%**	**-1%**	**-6%**	**-35%**	**-1%**	**-6%**	**-35%**
Channel / pipe loss	307.2	-14%	-1%	-4%	-16%	-1%	-4%	-16%
Sub-total	**1260.9**	**-26%**	**-1%**	**-6%**	**-32%**	**-1%**	**-7%**	**-32%**
Outflows								
System outflow								
To Wimmera	6.3	0%	0%	0%	0%	0%	0%	0%
Net evaporation*	44.4	-12%	8%	5%	14%	8%	5%	14%
Sub-total	**50.6**	**-10%**	**7%**	**4%**	**12%**	**7%**	**4%**	**12%**
Unattributed fluxes								
River unattributed loss	3.4	-3%	0%	-1%	-2%	0%	-1%	-2%
Regional outflows (not included in mass balance)								
Goulburn-Broken to Campaspe	506.9	-25%	0%	-5%	-32%	0%	-5%	-32%
Campaspe to Loddon-Avoca	263.6	-24%	0%	-4%	-30%	0%	-4%	-30%
Loddon-Avoca to Wimmera	6.3	0%	0%	0%	0%	0%	0%	0%

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

4.3.3 Inflows and water availability

Inflows

There are several ways to provide an indication of water availability. The most obvious way is to use the total inflow (the sum of all of the inflows in the model). This is 240 GL/year for the Loddon River and 84 GL/year for the Avoca River prior to accounting of instream losses under Scenario A. A further 264 GL/year is transferred from the Waranga Western Channel into the region.

An alternative is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated as all river models are calibrated to achieve mass balance at mainstream gauges. The without-development conditions remove the influences of upstream extractions and regulation and give a reasonable indication of total inflows without the influence of development.

Figure 4-3 presents a comparison between scenarios under without-development conditions for reaches along the Loddon and Avoca rivers. The maximum average annual mainstream flow on the Loddon River occurs downstream of Laanecoorie Weir (gauge 407203) with a value of 201 GL/year under Scenario A. The maximum average annual mainstream flow on the Avoca River occurs downstream of Coonooer Bridge (gauge 408200) with a value of 84 GL/year under Scenario P. The difference between these values and their corresponding total system inflow are the instream losses and the flood breakouts.

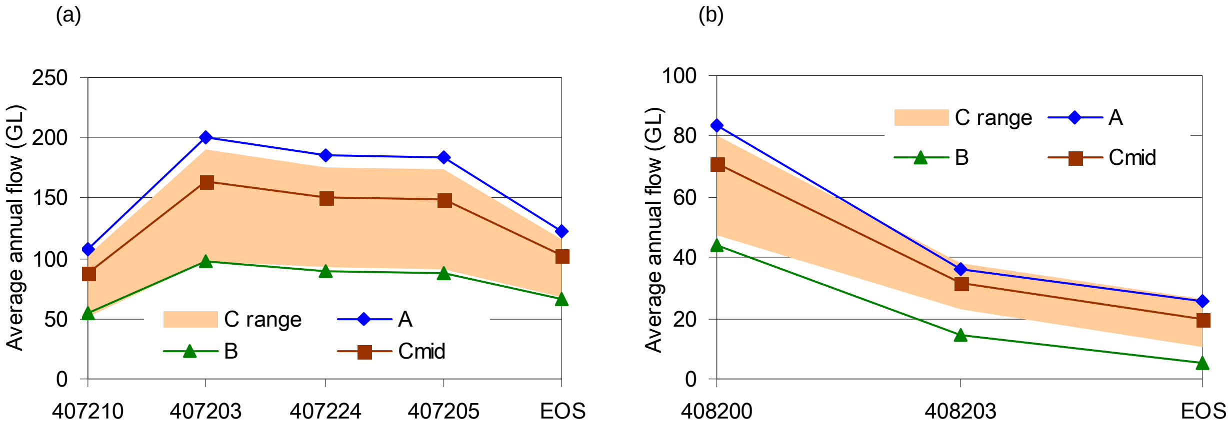

Figure 4-3. Transect of total river flow for without-development conditions under scenarios A, B and C at (a) Loddon River and (b) Avoca River

Water availability

Water availability is a function of climate, and thus is assessed for without-development conditions for scenarios A, B and C. Table 4-8 uses without-development annual mainstream flow at the Laanecoorie Weir and Coonooer Bridge to define water availability (Figure 4-3). It shows the average water availability for the Loddon and Avoca rivers under Scenario A in GL/year and the relative change in water availability under scenarios B and C. The leakage induced by current groundwater use implicit in model calibration is negligible (<0.05 GL/year) and so no adjustment is required for groundwater impacts. There is an estimated 18 percent decrease compared to Scenario A in surface water availability under Scenario Cmid, and a 49 to 50 percent decrease under scenarios B and Cdry.

Table 4-8. Average annual water availability for the Loddon-Avoca region under scenarios A, B and C (assessed for without-development conditions, which for Scenario A is synonymous with Scenario P)

	A	B	Cwet	Cmid	Cdry
	GL/y				
Total surface water availability (modelled without-development maximum average mainstream flow)	284.8	142.0	270.4	234.0	145.5
		percent change from Scenario A			
Change in surface water availability		-50%	-5%	-18%	-49%

A time series of annual water availability under Scenario A is shown in Figure 4-4. Figure 4-5 shows the changes in annual water availability from Scenario A under scenarios B and C.

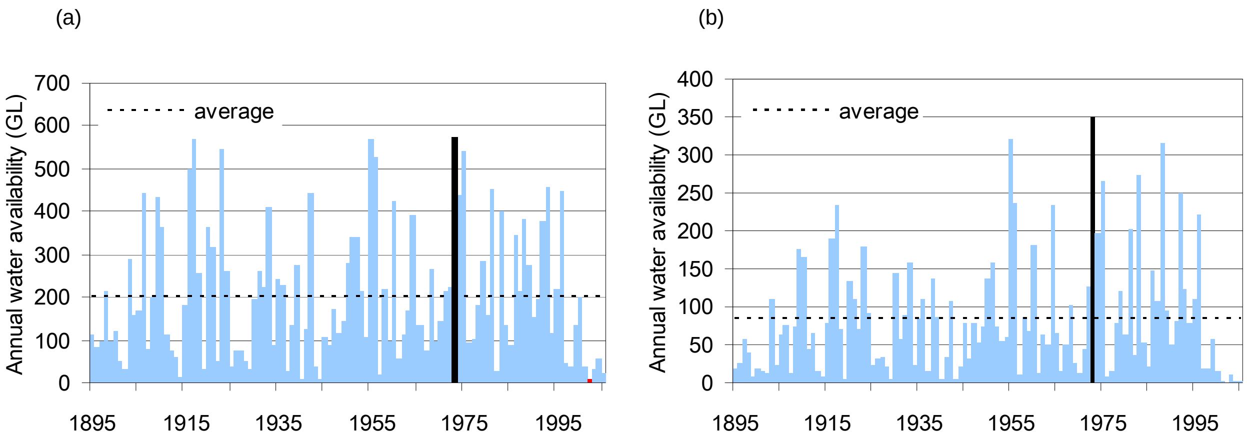

Figure 4-4. Water availability for (a) Loddon River and (b) Avoca River under Scenario A

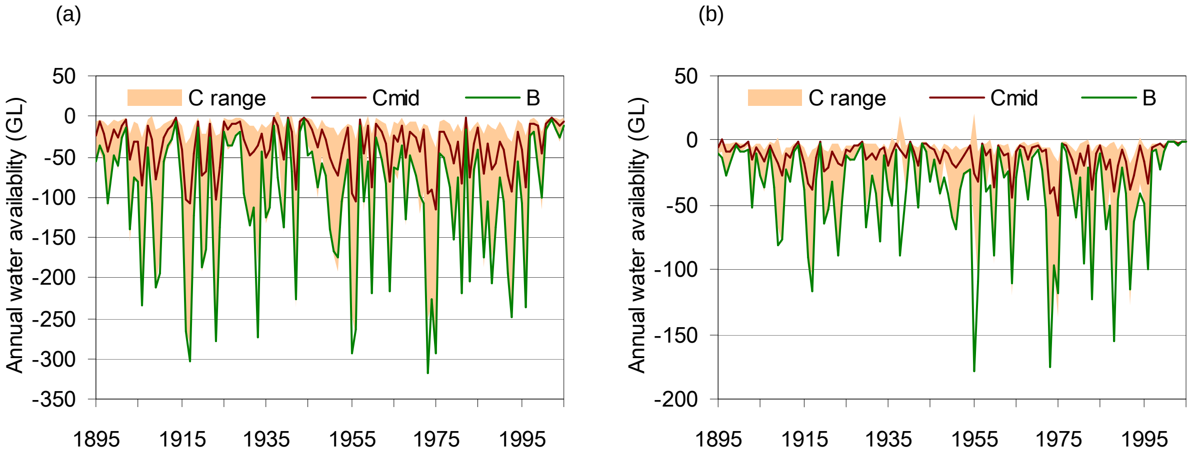

Figure 4-5. Difference in water availability for (a) Loddon River and (b) Avoca River under scenarios B and C relative to Scenario A

4.3.4 Storage behaviour

The modelled behaviour of major public storages in the Loddon-Avoca region gives an indication of the level of regulation of a system as well as how reliable the storages are during extended periods of low or no inflows. Table 4-9 shows the lowest recorded combined storage volume and the corresponding date under each of the scenarios. The average and maximum years between spills is also provided. A spill event commences when the sum of the total system storages exceeds 95 percent of the combined full supply volume and ends when the sum of the total system storages falls below

85 percent of full supply volume. A spill occurs at 95 percent of full supply level because some individual storages will spill at times when total system storage is not at full supply level. The end condition is used to include in a spill event period when the dam is close to full and oscillates between spilling and just below full. The time between spills significantly increases under the dry scenarios.

Table 4-9. Details of storage behaviour for the Loddon system under scenarios A, B, C and D

Total Loddon storages	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Minimum storage volume (ML)	6692	5413	6750	6636	4452	6728	6662	4398
Minimum storage date	04/1968	05/1915	03/1939	03/1939	03/1903	04/1915	04/1915	03/1903
Average years between spills	2.9	36.8	3.3	4.2	36.7	3.3	3.8	36.7
Maximum years between spills	11.2	61.2	14.1	17.8	61.1	14.1	17.8	61.1

The Avoca storages are unregulated. The combined active storage capacity for the Avoca system is 93 GL and the spilling criteria outlined above were not met in any of the scenarios. This is because natural releases are made from the lakes at storage volumes less than 93 GL preventing the lakes from reaching their designated capacity. Table 4-10 shows the lowest recorded combined storage volume and the measurement date for the Avoca system. Scenario D is not included as future development in farm dams, forestry and groundwater is not expected for the Avoca system.

Table 4-10. Details of storage behaviour for the Avoca system under scenarios A, B and C

Total Avoca storages	A	B	Cwet	Cmid	Cdry
Minimum storage volume (ML)	437.5	327.4	390.4	356.5	346.5
Minimum storage date	04/2006	04/2006	04/2006	04/2006	04/2006

The time series of total storage behaviour for the Loddon and Avoca systems during the most severe drought over the last ten years of the project modelling period are shown in Figure 4-6 and Figure 4-7. The plots show that the future dry scenarios (Cdry and Ddry) significantly reduce the combined storage in both the Loddon and Avoca rivers.

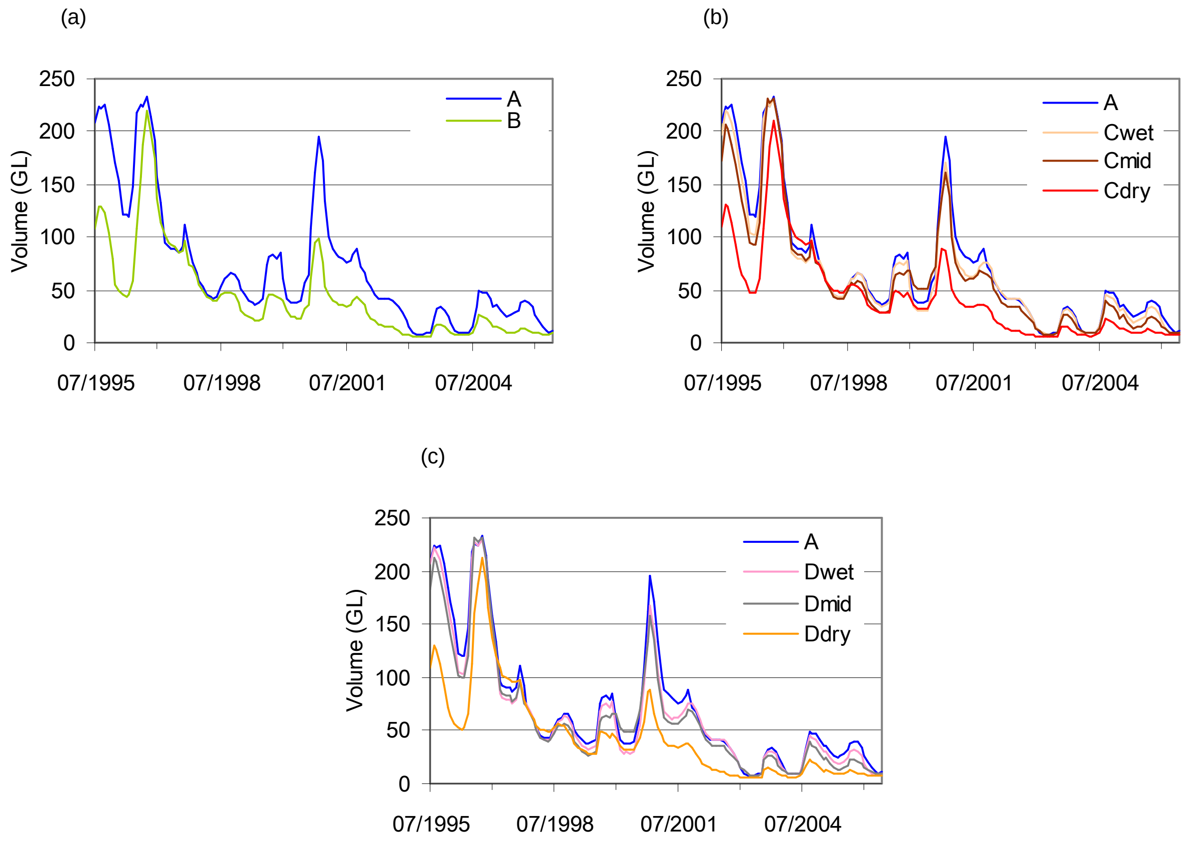

Figure 4-6. Total Loddon storage behaviour over the period of lowest storage volume under (a) scenarios A and B, (b) scenarios Cwet, Cmid and Cdry, and (c) scenarios Dwet, Dmid and Ddry

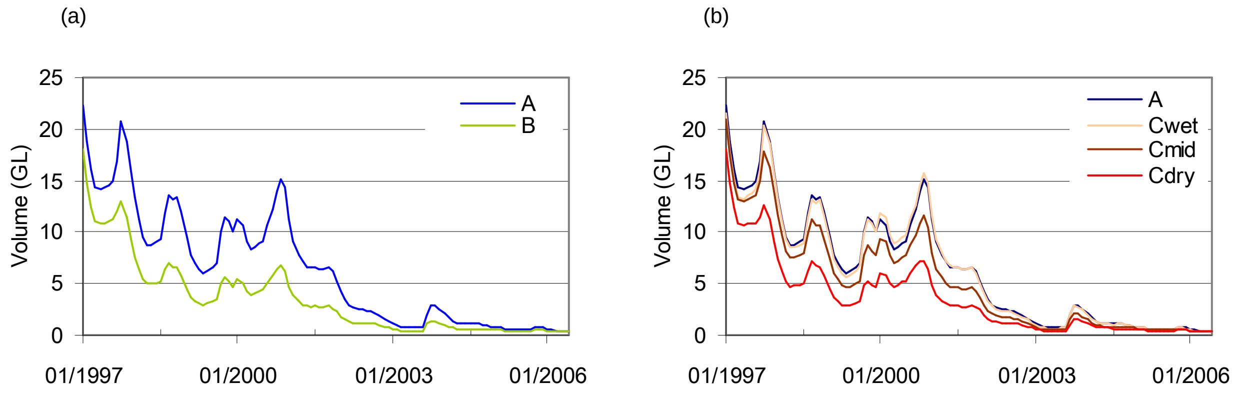

Figure 4-7. Total Avoca storage behaviour over the period of lowest storage volume under (a) scenarios A and B, and (b) scenarios Cwet, Cmid and Cdry

4.3.5 Consumptive water use

Water use

Table 4-11 shows the average annual total water use for different river reaches under Scenario A and the percentage change of all other scenarios compared to Scenario A. Figure 4-8 shows average annual total water use for all scenarios for reaches of the Loddon River from broadly upstream to downstream. This reach-by-reach presentation of water use (and previously inflows in Section 4.3.2) provides a very coarse indication of the changes from upstream to downstream. The Loddon diversions to the Waranga Western Channel are not included in the water use graph (Figure 4-8) because the Waranga Western Channel demands are mainly serviced by the upstream Waranga Western Channel inflows. There is no water use modelled for the Avoca River.

Table 4-11. Change in total surface water use in each subcatchment under scenarios B, C and D relative to Scenario A

Reach	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A						
Tributaries u/s of Cairn Curran Reservoir to Cairn Curran Reservoir outlet	0.0	0%	0%	0%	0%	0%	0%	0%
Tullaroop Creek to d/s Tullaroop Reservoir	2.1	0%	3%	2%	4%	3%	2%	4%
Tullaroop Creek d/s Tullaroop Reservoir plus Loddon River d/s Cairn Curran Reservoir to Loddon River d/s Laanecoorie Weir	2.4	-15%	4%	1%	-7%	3%	1%	-8%
Loddon River d/s Laanecoorie Weir to upstream Loddon Weir (including Serpentine Creek)	18.4	-13%	2%	0%	-11%	1%	0%	-11%
Loddon River from u/s Loddon Weir to d/s Loddon Weir	1.9	-33%	-2%	-7%	-45%	-2%	-7%	-45%
Loddon River from d/s Loddon Weir to d/s Appin South (EOS)	0.0	0%	0%	0%	0%	0%	0%	0%
Waranga Western Channel from d/s Rochester West off-takes to West Loddon, Boort Lake and Normanville	258.8	-29%	-1%	-6%	-35%	-1%	-6%	-35%
Avoca River from d/s Coonooer Bridge to d/s Third Marsh	0.0	0%	0%	0%	0%	0%	0%	0%
Total	**283.7**	**-27%**	**-1%**	**-6%**	**-33%**	**-1%**	**-6%**	**-33%**

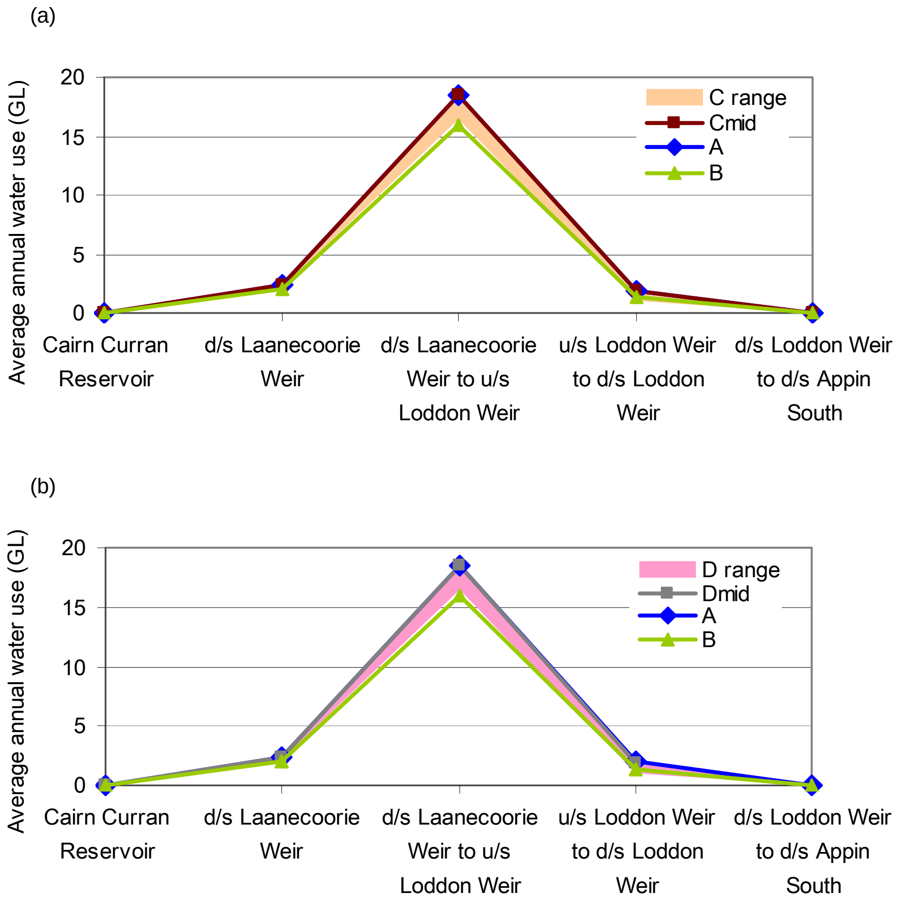

Figure 4-8. Average annual total surface water use from upstream to downstream under (a) scenarios A, B and C, and (b) scenarios A, B and D

Figure 4-9 (a) shows the annual time series of total surface water use under Scenario A and Figure 4-9 (b)–(h) shows the difference in annual volumes for the other scenarios relative to Scenario A. These include all the water supplied in the Loddon-Avoca region. The minimum and maximum annual total water use under Scenario A is 182 GL in 2002 and 332 GL in 1990 respectively.

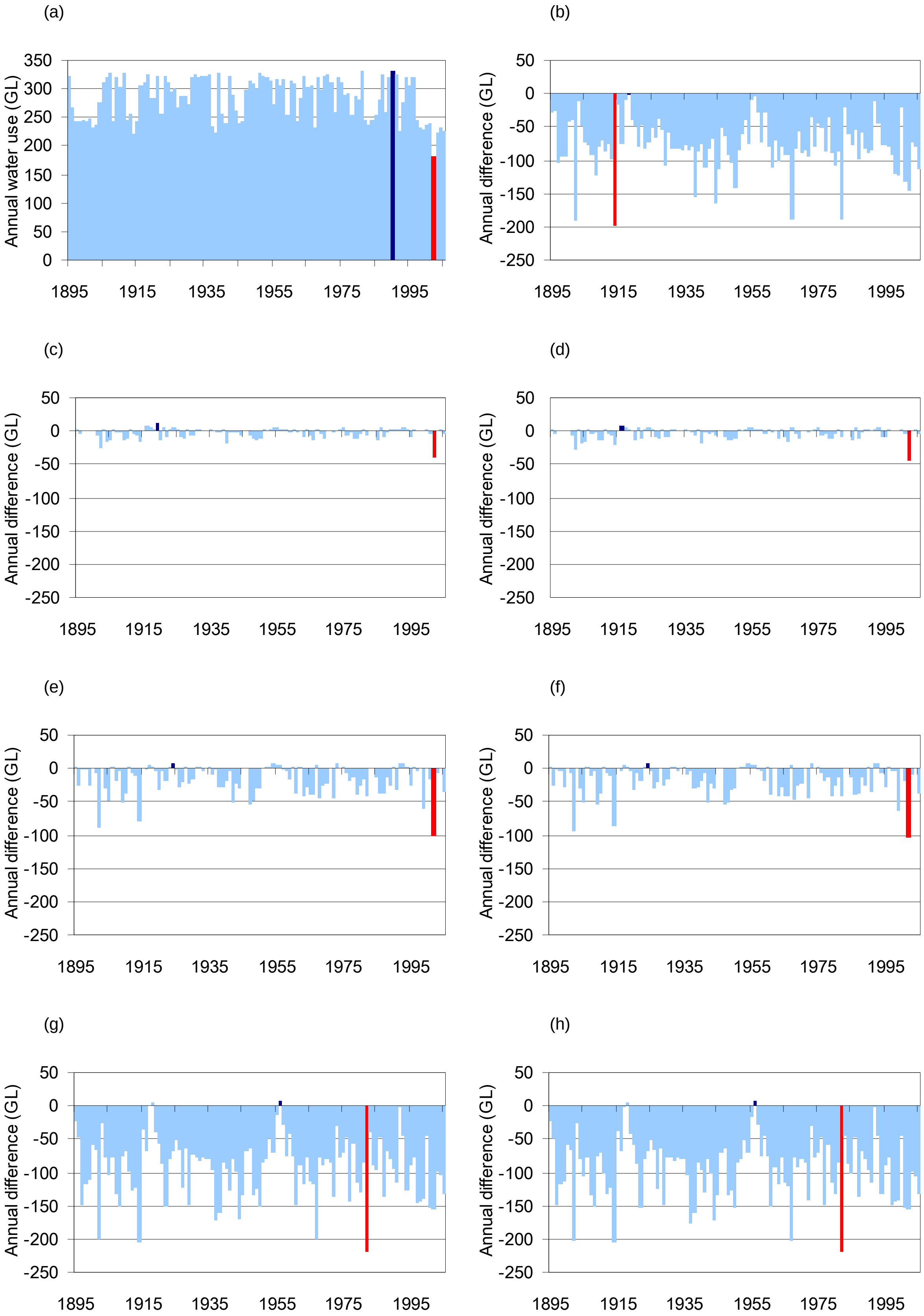

Figure 4-9. Total annual surface water use under (a) Scenario A, and the difference from Scenario A in surface water use under (b) Scenario B, (c) Scenario Cwet, (d) Scenario Dwet, (e) Scenario Cmid, (f) Scenario Dmid, (g) Scenario Cdry and (h) Scenario Ddry

Table 4-12 shows the annual total surface water use for the lowest one-, three- and five-year periods as well as the average annual total water supplied under Scenario A and the percentage change from Scenario A under each other scenario. These figures indicate the average and dry period scenario impacts on water use.

Table 4-12. Annual total surface water use under scenarios A, B, C and D

Annual water use	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A						
Lowest 1-year period	181.8	-88%	-22%	-56%	-92%	-25%	-57%	-91%
Lowest 3-year period	212.3	-54%	-6%	-19%	-63%	-7%	-19%	-63%
Lowest 5-year period	220.4	-49%	-4%	-16%	-58%	-5%	-17%	-59%
Average	283.7	-27%	-1%	-6%	-33%	-1%	-6%	-33%

Level of use

The level of use is defined as the ratio of the total use to water availability. Total use consists of total diversions from the Loddon River and its tributaries (including groundwater usage and future farm dam impacts on streamflow). This includes the supply system losses associated with water use in the region. However, total diversions do not include diversions from the Waranga Western Channel sourced from the Goulburn-Broken region. There are no diversions from the Avoca River. Water availability is defined as in Section 4.3.2. Table 4-13 shows the level of use under each of the scenarios. The relative level of use increases for all future climate scenarios.

Table 4-13. Level of use of water sourced within the region under scenarios A, B, C and D

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y							
Total surface water availability	**284.8**	**142.0**	**270.4**	**234.0**	**145.5**	**270.4**	**234.0**	**145.5**
Subcatchment use								
Groundwater use impacts	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.7
Future farm dam impacts	--	--	--	--	--	1.4	1.4	1.4
Streamflow use								
Total diversions	92.0	57.9	89.6	81.9	54.9	92.0	81.7	54.3
Leakage induced by groundwater use*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total use	**92.2**	**58.1**	**89.7**	**82.1**	**55.1**	**94.3**	**84.0**	**56.7**
	percent							
Relative level of use	**32%**	**41%**	**33%**	**35%**	**38%**	**35%**	**36%**	**39%**

* See footnotes * and ** in Table 4-6

Reliability of supply

The reliability of supply for Loddon private diverters and for irrigation districts off the Waranga Western Channel is shown in Figure 4-10. Reliability of supply is determined separately for low and high reliability water shares. Reliability of supply is reported for allocations in February to represent final allocations. Note the Y-axis is the percentage of the maximum allocation in February. Water users in the regulated Loddon system currently receive the maximum HRWS allocation in 92 percent of years and a minimum allocation of 58 percent. They receive the maximum LRWS allocation in 42 percent of years and a minimum allocation of zero occurring in 24 percent of years. This is similar to the reliability of supply in the Goulburn system. Under Scenario Cmid, Loddon water users would receive the maximum HRWS allocation in 83 percent of years and a minimum February allocation of 15 percent. The maximum LRWS allocation would occur in 21 percent of years and a minimum February allocation of zero would occur in 36 percent of years. The irrigation district and the Loddon system changes in reliability of supply are similar.

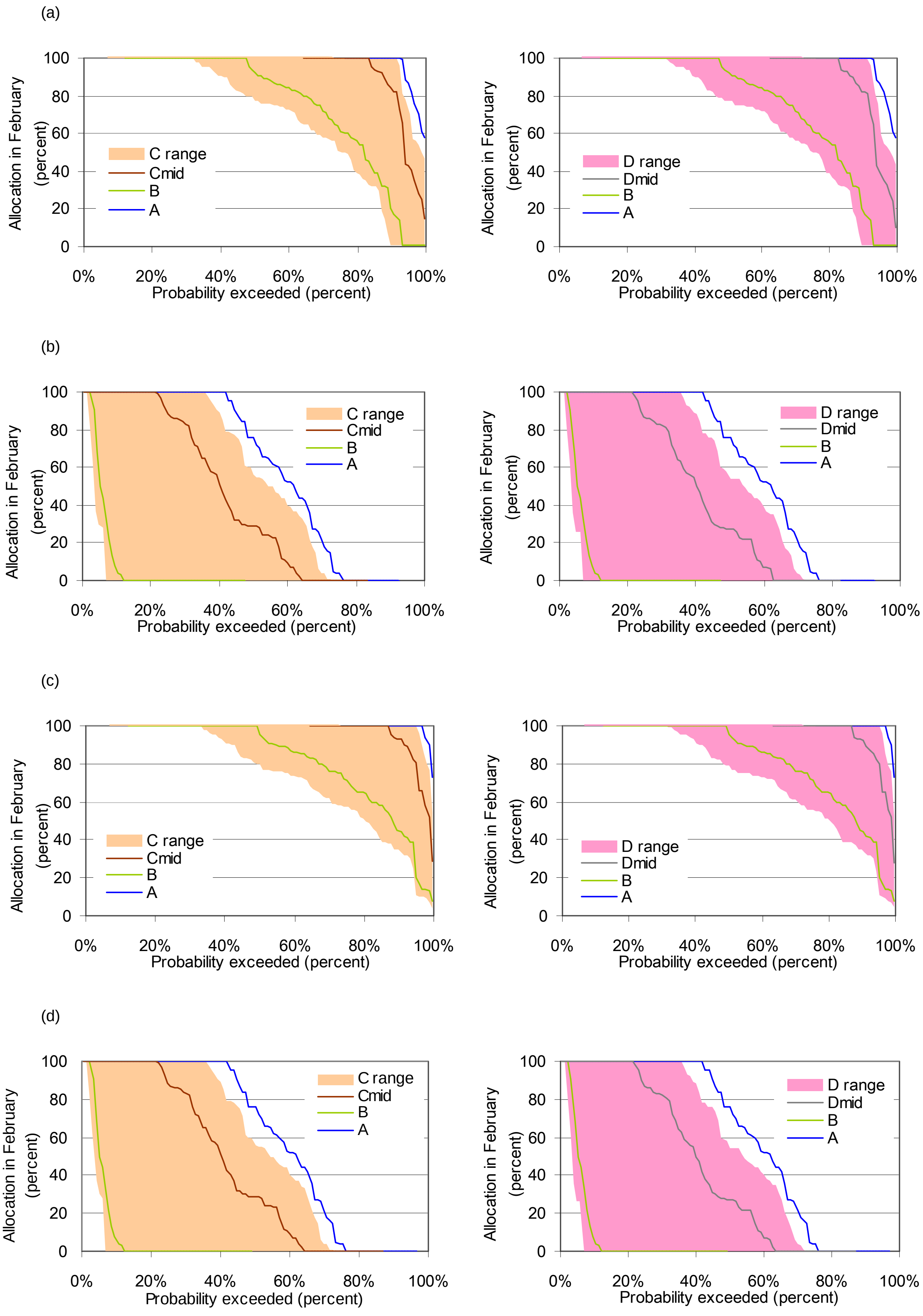

Figure 4-10. Reliability of (a) High Reliability Water Share and (b) Low Reliability Water Share supply in the Loddon-Avoca region for water users in the regulated Loddon River system, and (c) High Reliability Water Share and (d) Low Reliability Water Share supply to private diverters and irrigation districts supplied by the Waranga Western Channel under scenarios A, B, C and D

The reliability of total demand in the Loddon region under each of the scenarios is illustrated in Figure 4-11. The Y-axis represents the percentage of unrestricted demand that is supplied. Unrestricted demand is the amount of water demanded by a consumer that may not be supplied due to water restrictions. All future climate scenarios result in a decrease in the reliability of the supply.

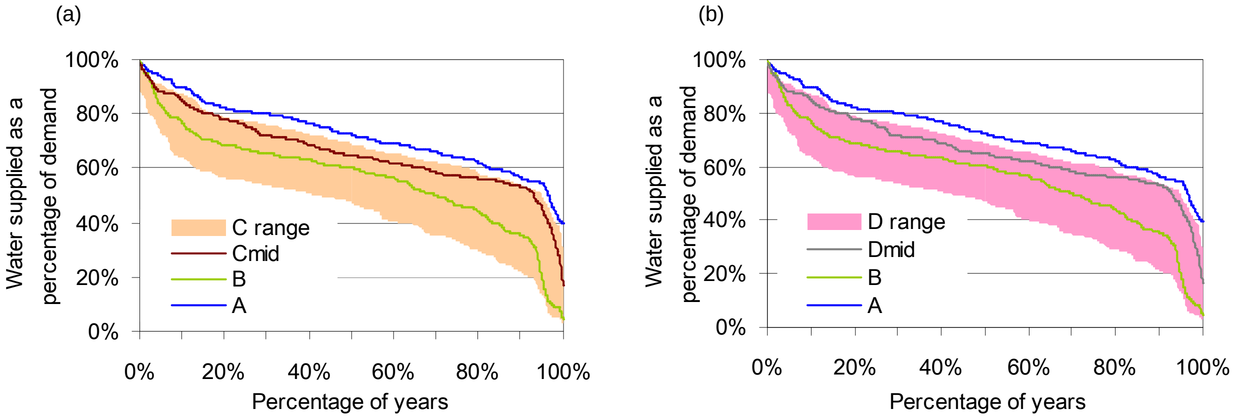

Figure 4-11. Total water supplied as a percentage of unrestricted demand for the Loddon-Avoca region under (a) scenarios A, B and C, and (b) scenarios A, B and D

4.3.6 River flow behaviour

The river flow behaviour in the Loddon-Avoca region is examined at three locations throughout the system: the Loddon River downstream of Laanecoorie Weir (mid-system flow), the Loddon River downstream of Appin South (end-of-system flow) and the Avoca River downstream of Third Marsh (end-of-system flow).

Mid-system flow characteristics

Figure 4-12 shows the flow duration curves for the Loddon River downstream of Laanecoorie Weir. The cease-to-flow percentiles for the scenarios are presented in Table 4-14. Cease-to-flow is considered to occur when model flows are less than 1 ML/month.

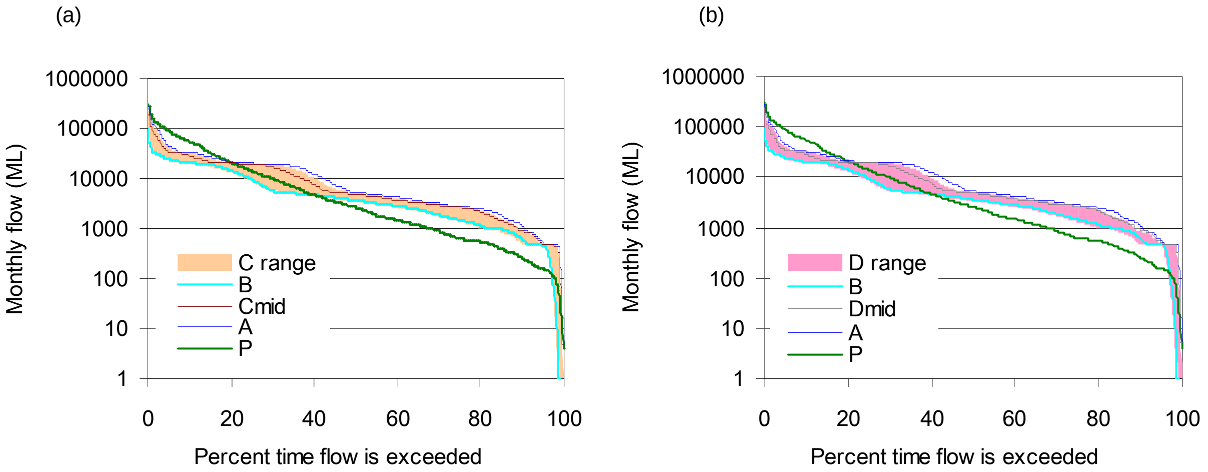

Figure 4-12. Monthly flow duration curves at mid-system Loddon River downstream of Laanecoorie Weir under (a) scenarios P, A, B and C and (b) scenarios P, A, B and D

Table 4-15 shows the size of monthly events with two-, five- and ten-year recurrence intervals under scenarios P, A, B, C and D. This analysis estimates the average peak monthly flow (as the model uses a monthly time step) and not the peak flow for a day, which is considerably higher. The reductions in the size of events for the dry climate scenarios are greater than 50 percent.

Table 4-14. Mid-system cease-to-flow as percentage of time under scenarios P, A, B, C and D

Outflow name	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Loddon River d/s of Laanecoorie Weir	0%	0%	1%	0%	0%	1%	0%	0%	1%

Table 4-15. Monthly flow event frequency at mid-system Loddon River downstream of Laanecoorie Weir under scenarios P, A, B, C and D

Return interval	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
years	ML/month		percent change from Scenario A						
2	62,168	33,182	-33%	0%	-3%	-36%	0%	-3%	-37%
5	132,438	95,273	-68%	-11%	-27%	-66%	-13%	-28%	-68%
10	181,484	135,340	-74%	-5%	-31%	-66%	-4%	-37%	-67%

Figure 4-13 shows the mean monthly flow under scenarios P, A, B, C and D for the mid-system flow location. The flow pattern downstream of Laanecoorie Weir changed compared to the without-development scenario due to the winter storage and summer release of water for Loddon water users downstream of Lake Eppalock.

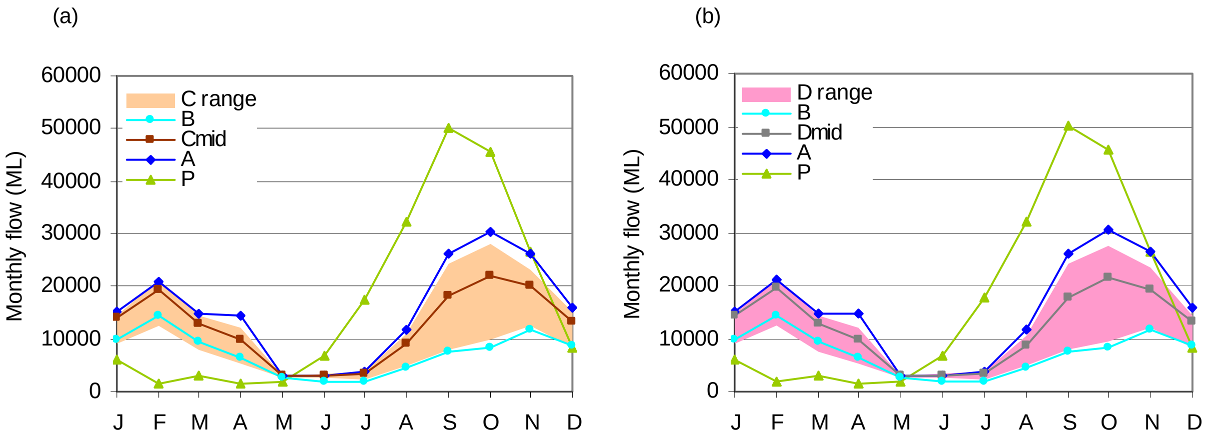

Figure 4-13. Seasonal plots for mid-system Loddon River downstream of Laanecoorie Weir under (a) scenarios P, A, B and C (b) scenarios P, A, B and D

End-of-system flow characteristics

Figure 4-14 shows the flow duration curves for the Loddon downstream of Appin South (end-of-system), and the Avoca River downstream of Third Marsh (end-of-system). The cease-to-flow percentiles for these scenarios are presented in Table 4-16. The Avoca River has no regulation and the cease-to-flow percentage under Scenario A is zero compared to 71 percent for the Loddon River.

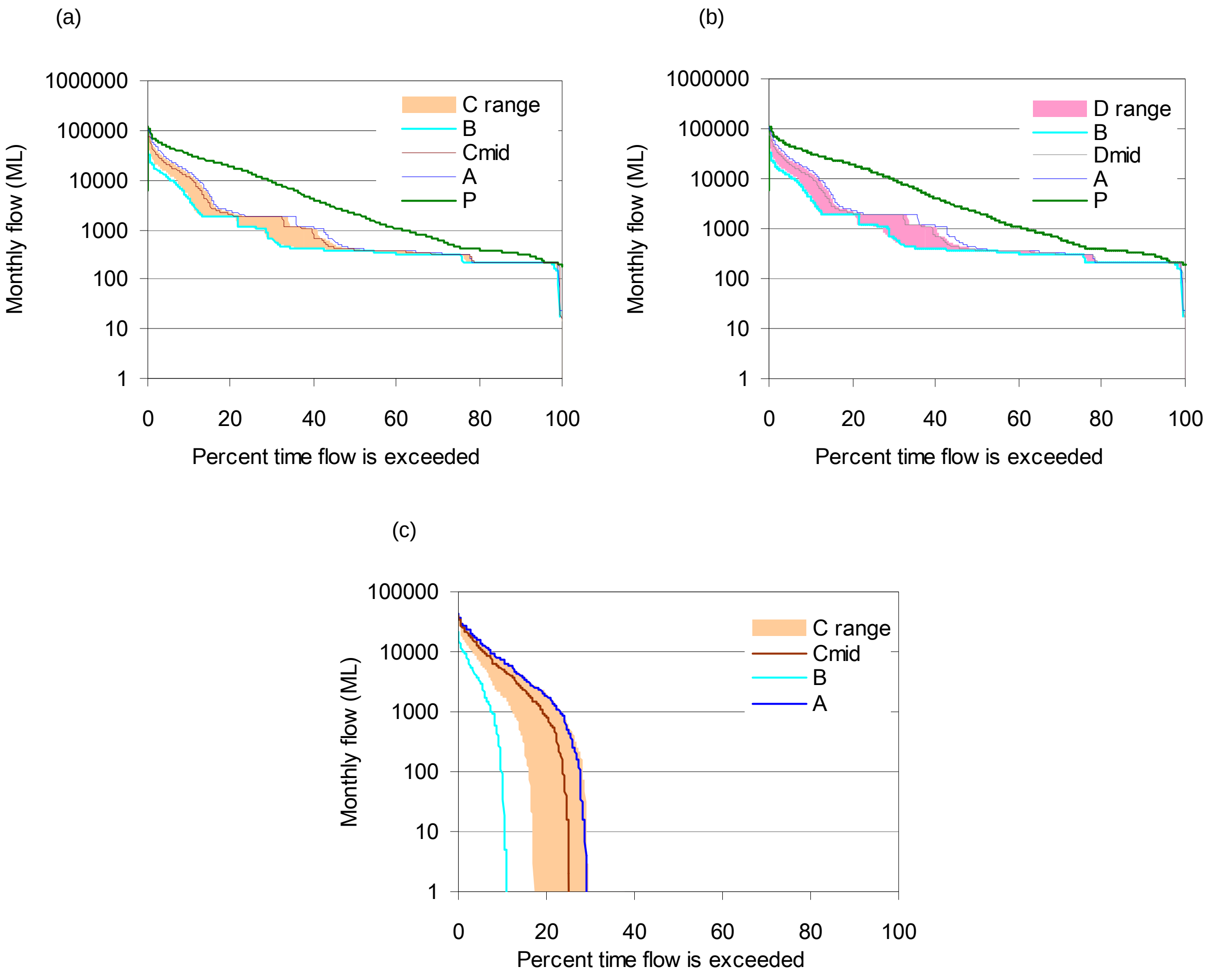

Figure 4-14. Monthly flow duration curves at end-of-system Loddon River downstream of Appin South under (a) scenarios P, A, B and C and (b) scenarios P, A, B and D; and (c) at end-of-system Avoca River downstream of Third Marsh under scenarios A, B and C

Table 4-16. End-of-system Loddon River downstream of Appin South cease-to-flow as percentage of time under scenarios P, A, B, C and D

Outflow Name	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Loddon River downstream Appin South (EOS)	0%	0%	0%	0%	0%	0%	0%	0%	0%
Avoca River downstream Third Marsh (EOS)	-	71%	89%	70%	75%	83%	-	-	-

Table 4-17 shows the size of monthly events with two-, five- and ten-year recurrence intervals under scenarios P, A, B, C and D for the end-of-system flows. There are large reductions in the size of events under scenarios B, Cdry and Ddry.

Table 4-17. Monthly flow event frequency for the end-of-system Loddon River downstream of Appin South, and the end-of-system Avoca River downstream of Third Marsh under scenarios P, A, B, C and D

Return interval	P	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
years	ML/month		percent change from Scenario A						
Loddon River downstream of Appin South									
2	39,919	14,635	-70%	-8%	-20%	-72%	-8%	-17%	-77%
5	63,244	47,233	-66%	-10%	-32%	-59%	-10%	-30%	-60%
10	74,275	63,819	-65%	-11%	-27%	-56%	-10%	-28%	-58%
Avoca River downstream of Third Marsh									
2	2,761	2,761	N/A	5%	-28%	-80%	5%	-28%	-80%
5	19,203	19,203	-81%	5%	-19%	-50%	5%	-19%	-50%
10	27,332	27,332	-65%	5%	-11%	-47%	5%	-11%	-47%

Figure 4-15 shows the mean monthly flow under scenarios P, A, B, C and D for the two end-of-system locations. The post-development flow patterns for the Loddon have seasonality restored compared to the mid-river flow pattern (Figure 4-13). This is likely to be due to the diversion of unseasonal flows to various water users and the addition of new catchment inflows downstream of Laanecoorie Weir. The Avoca end-of-system has no Scenario D results as no future development scenario was modelled.

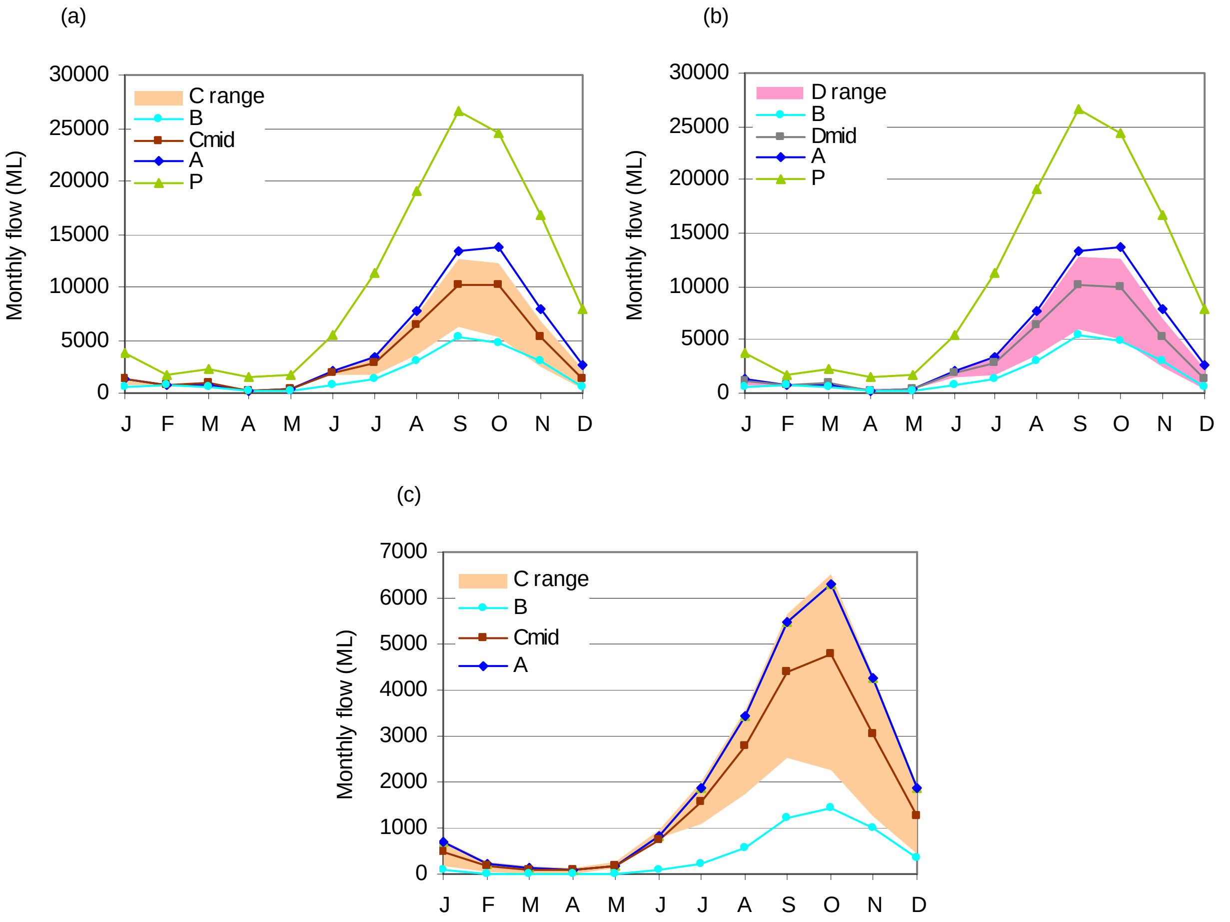

Figure 4-15. Seasonal flow curves at end-of-system Loddon River downstream of Appin South under (a) scenarios P, A, B and C, and (b) scenarios P, A, B and D, and (c) end-of-system Avoca River downstream of Third Marsh under scenarios A, B and C

4.3.7 Share of available resources

Non-diverted water

Table 4-18 presents two indicators for relative impact on non-diverted water: the ratio of average annual non-diverted water to average water availability and the ratio of average annual non-diverted water to Scenario A average annual non-diverted water. Total diversions include consumptive water use (including channel losses and the water diverted to the Waranga Western Channel), groundwater extraction and future farm dam impacts. The irrigation districts supplied by the Waranga Western Channel are not included as these are mainly serviced from upstream inflows from the Waranga Western Channel.

Table 4-18. Relative level of available water not diverted for use under scenarios A, B, C and D

Relative level of non-diverted water	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Non-diverted water as a percentage of total available water	68%	59%	67%	65%	62%	66%	65%	63%
Non-diverted share relative to Scenario A non-diverted share	100%	44%	94%	79%	47%	93%	79%	47%

Combined water shares

Figure 4-16 combines water availability, diversion and non-diverted water. The bar height indicates total water availability and the sub-division indicates the diverted and non-diverted fractions. Diversions are as above. No water in the Avoca River is diverted for consumptive purposes.

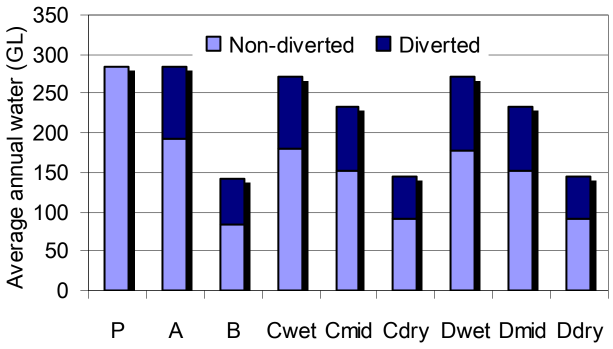

Figure 4-16. Comparison of use and non-diverted shares of water under scenarios P, A, B, C and D

4.3.8 Inter-region water supply reliability comparison

Water users in the Goulburn system are located in the Goulburn-Broken, Campaspe and Loddon-Avoca regions and are connected by the Waranga Western Channel. Separate allocations are also announced for users in areas supplied predominantly or exclusively by the Campaspe and Loddon rivers.

Table 4-19 show the water supply reliability under scenarios A, B and C for each of the Goulburn, Broken, Campaspe and Loddon systems. Water allocations in the different systems are determined on the storage size, inflows, demands and other factors in each supply system. Reliability of the Loddon system is comparable with the Goulburn system and slightly lower than the Campaspe system. Further discussion of the reliability of supply in the Campaspe and Goulburn-Broken systems is in CSIRO (2008a and 2008b).

Table 4-19. Inter-region comparison of water supply reliability in February under scenarios A, B and C

	Percentage of years which receive maximum HRWS allocation	Percentage of years which receive maximum LRWS allocation	Minimum HRWS February allocation	Percentage of years which receive zero LRWS allocation
Scenario A				
Goulburn system	97%	42%	73%	24%
Broken system	88%	84%	1%	11%
Campaspe system	99%	74%	76%	10%
Loddon system	92%	42%	58%	24%
Scenario B				
Goulburn system	49%	2%	8%	88%
Broken system	52%	48%	1%	47%
Campaspe system	77%	24%	8%	46%
Loddon system	47%	2%	1%	88%
Scenario Cwet				
Goulburn system	95%	36%	54%	27%
Broken system	86%	81%	1%	14%
Campaspe system	98%	71%	43%	17%
Loddon system	91%	36%	47%	27%
Scenario Cmid				
Goulburn system	87%	21%	29%	36%
Broken system	83%	79%	1%	17%
Campaspe system	97%	67%	33%	17%
Loddon system	83%	21%	15%	36%
Scenario Cdry				
Goulburn system	33%	1%	4%	93%
Broken system	54%	49%	1%	45%
Campaspe system	83%	37%	13%	33%
Loddon system	32%	1%	1%	93%

4.4 Discussion of key findings

The GSM and the Avoca River system model were recently updated and both cover the period of May 1891 to June 2006 (SKM, 2007a; SKM, 2007b). The common reporting period for this project is July 1895 to June 2006. Table 4-6 shows that the average annual local catchment inflow over the previous modelling period is 337 GL/year and is 324 GL/year for the common modelling period. This difference is due to averaging the inflows over different time periods. Transfers from the Waranga Western Channel are similar over both periods.

The Loddon-Avoca region has a reasonably high degree of regulation (Table 4-1) in the Loddon River and no regulation in the Avoca River. Water use in the Loddon is around 25 GL/year on average and the irrigation districts off the Waranga Western Channel use 259 GL/year on average. Reliability of supply is reported for allocations in February to represent final allocations. Water users in the regulated Loddon system currently receive the maximum HRWS allocation in 92 percent of years and a minimum allocation of 58 percent. The maximum LRWS allocation occurs in 42 percent of years and a minimum allocation of zero occurs in 24 percent of years. Reliability of supply is similar to the Goulburn system.

Under Scenario Cmid, catchment inflows and Waranga Western Channel transfers would be a reduced by 18 and 4 percent respectively. Water use from the Waranga Western Channel would be reduced by 6 percent. End-of-system outflows would be reduced by around 23 percent in both the Loddon and Avoca rivers. Losses would decrease because of less water in the supply system. Loddon users would receive the maximum HRWS allocation in 83 percent of years and a minimum February allocation of 15 percent. The maximum LRWS allocation would occur in 21 percent of years and a minimum allocation of zero would occur in 36 percent of years. Changes in reliability of supply are similar to those for the Goulburn system.

Scenarios Cwet and Dwet would be slightly drier than historical climate conditions. Catchment inflows would be reduced by around 5 percent and there would be no significant changes to Waranga Western Channel transfers. The reduction in water use would only be 1 percent. Loddon end-of-system flows would be reduced by 7 percent but would increase by 4 percent from the Avoca River.

Under the dry scenarios (B, Cdry and Ddry) there would be reductions in catchment inflows of 49 to 51 percent and a 24 to 30 percent reduction in Waranga Western Channel transfers. Total water use would be reduced by 27 to 33 percent and urban water use would be largely unaffected. End-of-system outflows would be reduced by between 55 and 60 percent for the Loddon River and between 59 and 80 percent for the Avoca River. Losses would decrease because of less water in the supply system. The last ten-year drought period (Scenario B) is worse than under Scenario A with a reduction in the total system storage volume over this period.

Scenario D did not differ significantly from the corresponding current level of development scenarios indicating that the predicted effects of future small catchment dam, forestry and groundwater development are minor compared to the impacts of climate change.

4.5 References

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

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

DSE (2005) Goulburn Simulation Model – Calibration for the Murray Darling Basin Cap. Department of Sustainability and Environment, Victoria, Melbourne. Water allocation, Water Sector Group.

SKM (2007a) Goulburn Simulation Model Update of Inputs 2007. Final. 27 August 2007. Prepared for Goulburn-Murray Water and the Department of Sustainability and Environment by Sinclair Knight Merz.

SKM (2007b) River System Modelling – MDB Assessment Project. Victoria – Avoca. Final. 30 July 2007. Prepared for CSIRO by Sinclair Knight Merz.

5 Uncertainty in surface water modelling results

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

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

5.1 Summary

The uncertainty that is internal to the river model (as opposed to that associated with the scenarios), and the implications that this has for confidence in the results and their appropriate use are assessed using multiple lines of evidence. This involves comparing: (i) the river model to historical gauged main stem flows and diversions, which are its main points of reference to actual conditions, and (ii) ungauged inferred inflows and losses in the model to independent data on inflows and losses to ascertain if they can be attributed to known processes. These two aspects of model performance are 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 Loddon-Avoca region has a climate and streamflow gauging network that is denser than the average density of the gauging network across the Murray-Darling Basin (MDB). However, the gauging is concentrated in the Loddon part of the region.
- Water accounts for 1990 to 2006 were developed for three reaches covering most of the Loddon and for one Avoca reach. The accounts included a large part of the total regional runoff generated as well as most of the diversions. The lower Avoca River was not included in accounting due to insufficient data.

5.1.2 Key messages

- The river model of the Loddon-Avoca reproduced observed streamflow patterns very well, and produced estimates of water balance terms that agreed reasonably well with water balance accounts.
- The model provides moderate to very strong evidence that changes in flow pattern will occur under the dry and best estimate 2030 climates. Evidence that changes in flow pattern will occur under the wet 2030 climate was weak to modest.
- The modelling provides strong evidence of changes in flow due to water resource development but the projected changes in flow due to future development are negligible.
- The river model is well suited for the purpose of this project however, caution is required in interpreting predictions of absolute and relative changes in flow and average flows in the Loddon below Loddon Weir.

5.2 Approach

5.2.1 General

A river model is 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.

- *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 historical flow patterns.

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

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

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

The likelihood that 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 is not attempted herein. A possible framework for considering the implications of the assessed uncertainties is shown in Table 5-1.

Table 5-1. Framework for considering implications of assessed uncertainties

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

5.2.2 Information sources

Information on the gauging network was obtained from the Water Resources Station Catalogue (www.bom.gov.au/hydro/wrsc) and the Victorian Water Resources Data Warehouse (www.vicwaterdata.net). Information on the REALM river model was provided for the Loddon River system in SKM (2006) and DSE (2005) and MDBC (2006) and for the Avoca system in SKM (2004). 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

Generic aspects of the water accounting methods are described in Chapter 1. This section includes a description of the basic purpose of the accounts: to inform the uncertainty analysis using an independent set of the different water balance components by reach and by month. The descriptions in Chapter 1 also cover the aspects of the remote sensing analyses used to estimate wetland and irrigation water use and inform calculations for attribution of apparent ungauged gains and losses. Aspects of the methods that are region specific are presented below.

Framework

The available streamflow data for this region was adequate for water accounting for the water years 1990/91 to 2005/06. Water accounts were established for three successive reaches in the Loddon River and a fourth reach in the Avoca. Figure 5-1 shows associated catchment areas, accounting reaches and contributing catchments. Ephemeral waterbodies and floodplain are subject to periodic inundation. Black dots and red lines are nodes and links in the river model respectively. The catchment areas are 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
1	4072132, 4072133, 4072134, 4072135, 4072401, 4072440, 4072112	Loddon at Laanecoorie
2	4072431	Loddon at Loddon Weir
3	4072023	Loddon at Appin South
4	4082031	Avoca at Quambatook
Not assessed		Reason
	4072411	Contributing headwater catchment (to reach 1)
	4082000	Contributing headwater catchment (to reach 4)
	4072360, 4082092	Do not contribute flow to any reach
	4082093, 4082033	Contribute d/s of the last available gauging station

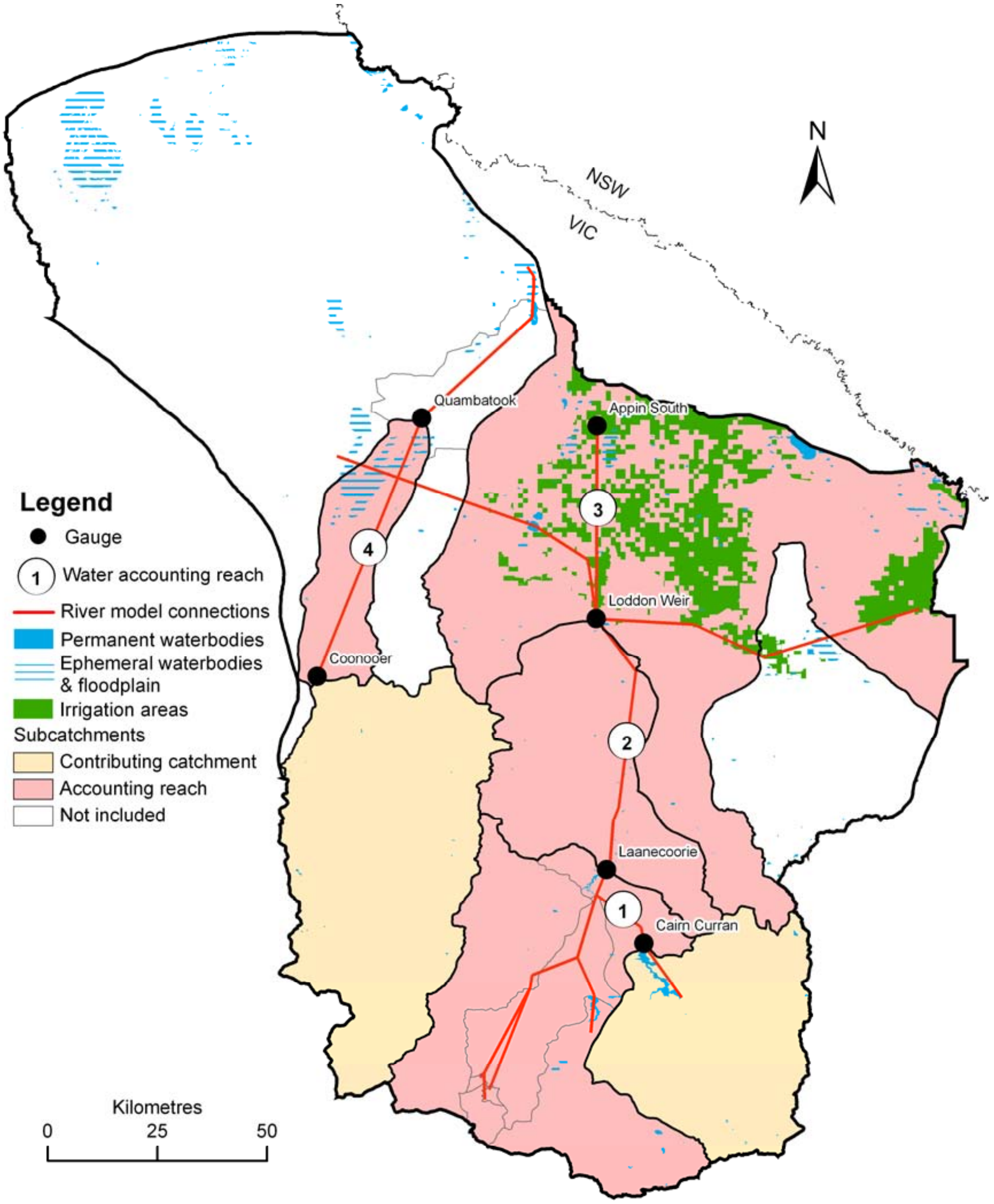

Figure 5-1. Map showing the subcatchments used in modelling and the water accounting reaches

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 and small ephemeral wetlands below Loddon Weir near the Murray River and several ephemeral wetlands in the northern part of the region along the Murray River. Streamflow and diversion data were provided by Sinclair Knight Merz.

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

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

Comparison of modelled and accounted reach water balance

The water balance terms for river reaches were compared for the period of water accounting period as 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 increases the chance that the model will behave in unexpected ways for climate conditions outside the calibration range. The percentage of the overall climate variability range for the 111-year climate sequence that was covered by the extremes in the calibration period was calculated as an indicator.

Performance of the river model in explaining historical flow patterns

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

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

A visual comparison of streamflow patterns at the end-of-reach gauge with the flows predicted by the baseline river model and the outflows that could be accounted was 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 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.

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 Loddon-Avoca region is the fifth most densely gauged region in the MDB. The density of the streamflow, rainfall and evaporation gauging networks is approximately one-and-a-half to two times the average density across the MDB. Streamflow gauging is concentrated in the Loddon valley. The Avoca system has four active gauges and another three near the Murray in the north of the region. Rainfall gauges are distributed evenly across the region, whereas all four active evaporation gauges are concentrated in the Loddon valley.

Table 5-3. Some characteristics of the gauging network of the Loddon-Avoca region (24,918 km^2) compared with the entire Murray-Darling Basin (1,062,443 km^2)

Gauging network characteristics	Loddon-Avoca		MDB	
	Number	per 1000 km^2	Number	per 1000 km^2
Rainfall				
Total stations	269	10.80	6232	5.87
Stations active since 1990	134	5.38	3222	3.03
Average years of record	61		45	
Streamflow				
Total stations	58	2.33	1090	1.03
Stations active since 1990	51	2.05	881	0.83
Average years of record	19		20	
Evaporation				
Total stations	5	0.20	152	0.14
Stations active since 1990	4	0.16	104	0.10
Average years of record	19		27	

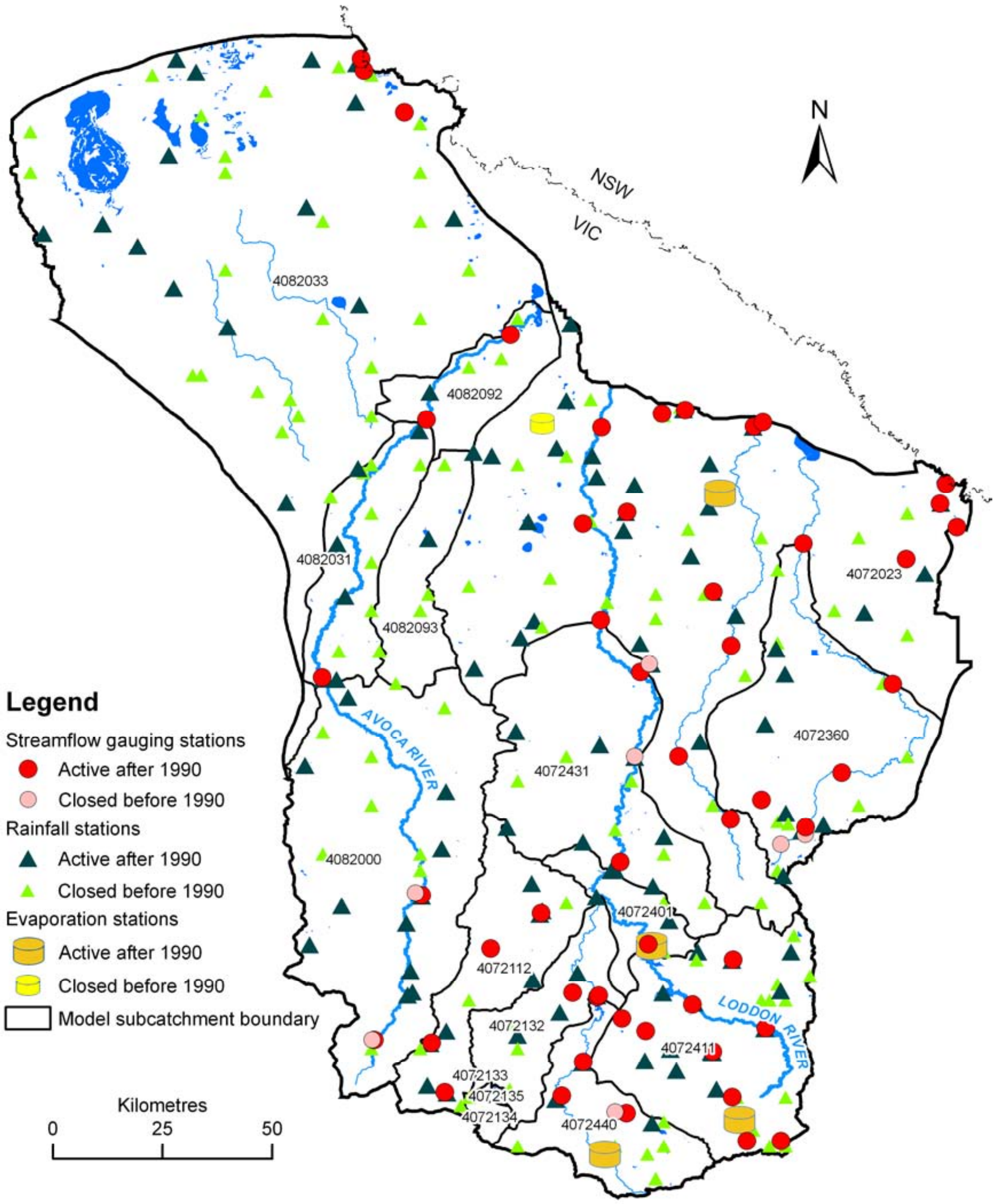

Figure 5-2. Map showing the rainfall, stream flow and evaporation observation network, along with the subcatchments used in modelling

5.3.2 Review of model calibration and evaluation information

Model description

Three river models cover the Loddon River basin. The Goulburn Simulation Model (GSM), a monthly model of the entire system (Chapter 4) covers the upper Loddon River. Outflows from the upper Loddon River are inflows to the Wandella Creek model that, in turn, inputs to the Kerang Lakes model. The lower part of the Avoca River is also modelled as part of the Kerang Lakes model. The original REALM GSM was developed in the 1980s. The GSM has been progressively expanded and refined. There was a major update in 1995.

The GSM simulates the harvesting and supply of water from the major water supply systems and is used extensively by water authorities and the Victorian Government for operational purposes and to develop water policy. The model was the starting point for the recalibration to 1993/94 level of development for MDB Cap auditing. The latest GSM update extends input files to June 2006 (SKM, 2006).The GSM covers the valleys of the Goulburn, Loddon and Campaspe rivers and Broken Creek. These systems form a connected water management system because of the Waranga Western Channel that is used to transfer water between the valleys. The whole system has twenty storages, of which Cairn Curran Dam (148 GL) and Tullaroop Dam (74 GL) are the major ones in the Loddon valley. The whole GSM contains 58 'demand areas' (a localised group of water users). Storages are generally used for resource allocation in their immediate valley, but can also supplement resources in adjacent valleys. The Loddon, Campaspe and Broken systems can supplement the Goulburn system, while Goulburn and Broken can supplement the Murray system with specific allocation and supply rules included in the model.

Water movement within and between the four valleys is simulated by a monthly REALM model. It is used for the implementation of bulk entitlements, although its monthly time step limits its ability to closely simulate some river operations and short-term variability (MDBC, 2006). Irrigation demands are estimated using the PRIDE (PRogram for Irrigation DEmands) model. PRIDE models crop water requirements without considering the management constraints as these are handled by the REALM model. PRIDE simulates rural demands for ten GSM bulk supply irrigation areas: Shepparton, Rodney, Tongala, Deakin, Rochester East, Rochester West, Tandara, Dingee, Campaspe and Boort. Diversions from unregulated tributaries and the upper Loddon water supply system account for the remaining use. It is scattered and too small to be included in the model. Water harvested from farm dams was not included in the model due to uncertainty and because it represents a relatively small volume (DSE, 2005). Diversions simulated by the model represent approximately 98.5 percent of the total diversions from the Goulburn-Broken-Loddon systems.

The Kerang Lakes model is a daily flow and salinity model developed in REALM designed to assess river salinity under the MDBC Basin Salinity Management Strategy (MDBC, 2001). It extends from the National Channel at Torrumbarry Weir through the Kerang Lakes to the Little Murray River. The modelled area includes the Gunbower Creek, the Kerang Lakes, the Avoca River, the Lower Loddon River and Little Murray River, but does not include the River Murray or Barr Creek. The period for this modelling was 1975 to 2000. The Avoca component of the Kerang Lakes model covers the Avoca River from Coonooer Bridge to its outfall from the Third Marsh to Lake Boga or Channel Number 7. The Avoca River flows into the flood plain at Coonooer where the flows diverge into different waterways over the floodplain before flowing to Avoca Marshes. Some of the breakout flows re-emerge into the Avoca River upstream and downstream of Quambatook gauging station so that only a proportion of flood flows actually passes through this station.

Data availability and use

The GSM requires monthly inflows to storages and tributary flows at selected locations, monthly demands, and rainfall and evaporation. The entire model requires 21 inflow, five rainfall, five evaporation and 58 demand values for each month of simulation. Input data were initially provided for the period June 1896 to July 1989, but have since been extended annually, and currently extend until June 2006. Specifics about the streamflow gauging station and climate data were available for the 2006 update (SKM, 2006) but may be different from the data used for initial model development and calibration. Table 5-4 lists the streamflow gauging stations used in the Loddon part of the model and the period of the record. Gaps in streamflow records were filled via regression analysis of data from nearby stations and interpolation.

Table 5-4. Streamflow gauging stations for which data were used in the Loddon REALM model (GSM)

Station	Description	Calibration period	Used for
407210	Loddon River @ Cairn Curran Reservoir	1943 – present	Cairn Curran Dam water balance, Laanecoorie inflow
407211	Bet Bet Creek @ Bet Bet	1943 – present	Laanecoorie Reservoir inflow
407213	McCullum Creek @ Carisbrook	1943 – present	Laanecoorie Reservoir inflow
407215	Loddon River @ Newstead	1946 – present	Cairn Curran Dam sum of inflows
407220	Bet Bet Creek @ Norwood	1954 – present	Ungauged Laanecoorie Reservoir to Loddon Weir inflow
407222	Tullaroop Creek @ Clunes	1954 – present	Tullaroop Dam water balance; Laanecoorie Reservoir inflow
407230	Joyces Creek @ Strathlea	1955 – present	Cairn Curran Dam sum of inflows, Laanecoorie Reservoir inflow
407239	Middle Creek @ Rodborough	1970 – present	Cairn Curran Dam sum of inflows
407244	Tullaroop Reservoir Head Gauge	1958 – present	Tullaroop Dam water balance; Laanecoorie Reservoir inflow
407248	Tullaroop Reservoir Outlet	1960 – present	Tullaroop Dam water balance; Laanecoorie Reservoir inflow

To simulate irrigation demand the PRIDE model required daily evaporation and rainfall data, crop factors and crop areas. Urban demands were generally estimated from regression equations that use evaporation, rainfall and temperature data. Some of the smaller urban and rural demands were assumed constant from year to year with a fixed monthly pattern.

Data from three rainfall stations were used for the Kerang Lakes model: Cohuna, Kerang Post Office and Lake Boga. Temperature and radiation data from the Kerang, Swan Hill and Mildura meteorological stations helped estimate lake evaporation and evapotranspiration. Data gaps were filled either by regression or with long-term averages (SKM, 2004). Flow data for the Avoca River at Coonooer Bridge (station 408200) were available for 1963 to 2000. Empirical relationships were developed to describe flow attenuation and divergence at different flow levels into various anabranches upstream of the marshes. Water level data for the Third Marsh were available from 1980 but the data quality was limited (especially prior to 1993). These data can adequately identify general behaviour but some flood peaks were missed (SKM, 2004).

Model calibration

Demand was a critical aspect of GSM calibration for the Cap model (MDBC, 2006). Initial estimates of irrigation demands were obtained from the PRIDE demand models developed for Bulk Entitlement conversions. These were re-run with daily rainfall and evaporation data from 1992 to 1995 (with estimated 1993/94 crop areas). Monthly demand was simulated 'at the farm gate'. The amount supplied may be less due to shortages or channel capacity constraints. The GSM was first run with unrestricted demands and then with restriction and rationing rules to estimate what could be supplied to each demand zone. Simulated total volumes supplied for the calibration period (1992 to 1995) were compared with recorded volumes. Estimated crop areas were adjusted in the PRIDE model and the process repeated until a good match was obtained if there were differences.

Model verification was done for the two-year period from mid-1995 to mid-1997. In interpreting model performance an allowance was made for measurement and modelling errors and the effect of the capping measures that reduced demands below 1993/94 levels. Simulated cumulative diversions for the combined five years of simulations (calibration and verification periods combined) were compared with recorded diversions at selected sites. Demand calibration was done for offtakes and therefore additional checks were made to ensure that the modelled river diversions (including delivery losses) also matched historical diversions. Comparisons were made on Waranga Basin losses as well as an overall monthly water balance check for each valley (inflow, outflow, demand and storage). Modelled and recorded storage behaviour and end-of-system flows for each river valley were compared for 1992 to 2004.

The Avoca River sub-system in the Kerang Lakes model was calibrated at Lake Bael Bael, First Marsh, Second Marsh and Third Marsh. The calibration period was 1975 to 2000. Model results were compared to historical data on flows and storage levels. Losses from the system were calibrated using calibrated empirical functions.

Model performance assessment

The ability of the GSM to estimate diversions in the combined valleys was very good. The model overestimated diversions by only 0.4 percent per year (39 GL/year) for the five-year period. The seasonal variation of these diversions was reproduced closely. The GSM underestimated total diversions for the Loddon valley by 2.8 percent per year (8.8 GL/year) over the calibration period. The underestimation reduced to 1.3 percent per year (7.5 GL/year) with the two-year verification period added. The model assumed that the Goulburn River and not the Loddon River supplied water to the Waranga Western Channel but the Loddon River actually supplied water in the calibration years. The model closely matched historical diversions over the two years after the calibration period when the model operating rules were being followed more closely (DSE, 2005).

The GSM overestimated storage levels in 1993/94 because Waranga supply from the Loddon River was underestimated. The model matched the 1996/97 drawdown of Cairn Curran and Tullaroop dams quite closely.

Simulated outflows from the Loddon differed from observed flows as there are a number of flood breakouts in the lower Loddon River (upstream and downstream near Loddon Weir). These occurred over short flood periods and were not simulated accurately because of the model's monthly time step.

There was also a lack of accurate gauging of these breakout flows and their return flows. The GSM is capable of representing low flows well but errors occur during floods (DSE, 2005).

Simulations for a 21-year period (1983 to 2005) constrained with observed storage levels and knowledge of growth in diversions were used to calculate statistics for model errors to assess the uncertainty in model estimates of the diversion targets. A 'standard error of estimate' of 4.2 percent was reported for the combined Goulburn, Broken and Loddon systems (DSE, 2005).

The Avoca component of the Kerang Lakes model simulated recorded storage volumes and outflows quite well. The timing of intermittent outflows from Third Marsh, in particular, was simulated well (SKM, 2004). Modelled end-of-system flows at Quambatook were reasonably similar to recorded data. The Kerang Lakes model was considered suitable for use in regional studies of the river salinity for the Basin Salinity Management Strategy (SKM, 2004). However, the model was not suitable for accurate prediction of flow and salinity at a given point and time, and particularly not for extreme events. The limited ability of REALM to represent time lag and attenuation contributes to uncertainties (SKM, 2004).

Model improvements and uncertainties

Model representation of some system components and processes was insufficient. Those relevant to the Loddon-Avoca region include:

- Loddon supplements to the Waranga Western Channel: the model assumes all these to be sourced from the Goulburn River which is not always the case
- lower Loddon River flood breakouts: flood breakout flows and subsequent return flows are poorly gauged and also could not be represented well in a monthly time step model.

The MDBC (2006) identified uncertainty about modelling transmission losses as fixed percentages of flows and that variation of these losses with flow was not considered. This assumption may lead to uncertainty, particularly under future climate scenarios, where losses may become greater or smaller than assumed by the model.

Some refinements for the Avoca component of the Kerang Lakes model including better measurement and monitoring of flow and salinity, and improvement in data management were recommended by SKM (2004).

5.3.3 Model uncertainty analysis

The river model results and water accounts were used to derive measures of model uncertainty. The different analyses are described below. In the interest or brevity, 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

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

- Gains in the reaches with water accounts are generally well gauged (87 to 91 percent; Figure 5-3a), except in Reach 1 where only 43 percent of gains appear to be gauged. This may partly be because this reach includes Laanecoorie Reservoir. Storage change data for the reservoir were not used in accounting and could not be well simulated.

- Outflows and losses are reasonably well gauged in the three Loddon River reaches (66 to 76 percent) but less well gauged in the Avoca reach (Reach 4, 37 percent gauged).
- Overall, 59 to 81 percent of the total water balance for each reach is gauged.
- Attribution of gains and losses using SIMHYD estimates of local runoff, diversion data and remote sensing helps to explain 70 to 83 percent of the combined reach gains and losses. Water accounting in the Avoca River did not attribute a large fraction of the ungauged losses (Reach 4, 70 percent attributed). These ungauged losses may result from other processes such as bank seepage and distributary flows.
- Overall, most gains and losses were gauged or could be attributed. Therefore the water balance of the Loddon River is well understood. The Avoca River is slightly less well understood.

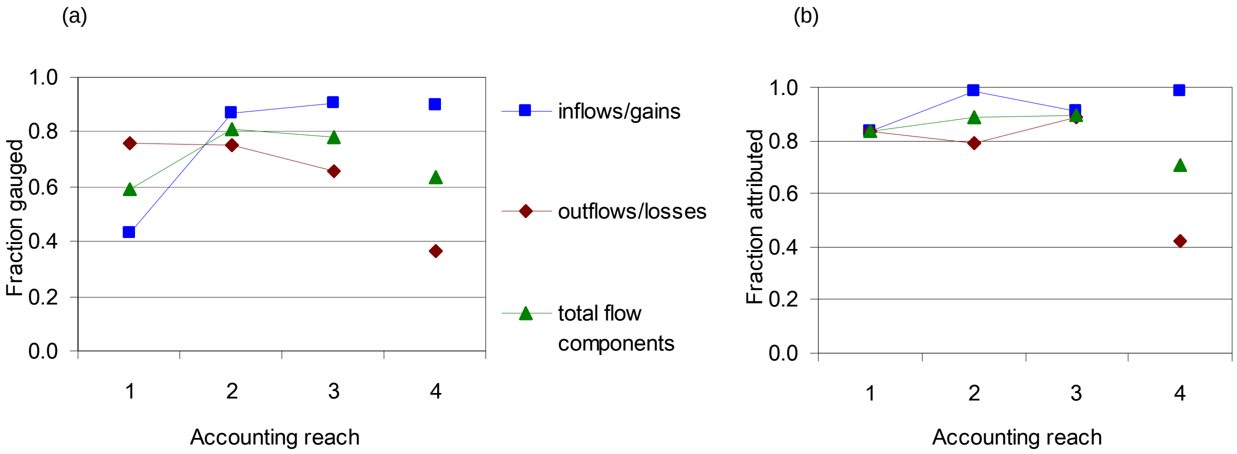

Figure 5-3. The fraction of inflows/gains, outflows/losses and the total of water balance components along the length of the river that is (a) gauged or (b) could be attributed in the water accounts

Comparison of modelled and accounted reach water balance

A summary of reach-by-reach water balances simulated by the river model and derived by water accounting can be found in Appendix C. This is summarised into a water balance for all accounted reaches in Table 5-5. Numbers are averaged for the period 1990 to 2006.

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

Water balance (Jul 1990 – Jun 2006)	Model (A)	Accounts	Difference	Difference
		GL/y		percent
Inflows (gains)				
Main stem inflows	155	147	8	5%
Tributary inflows	0	1	-1	-100%
Local inflows	84	104	-20	-19%
Subtotal gains	**239**	**251**	**-13**	**-5%**
Unattributed gains and noise	1	43	-42	-98%
Outflows (losses)				
End of system outflows	97	78	19	24%
Distributary outflows	30	0	30	n/a
Net diversions	70	55	15	26%
River flux to groundwater	0	0	0	n/a
River and floodplain losses	2	42	-40	-96%
Unspecified losses	40	–	40	n/a
Subtotal losses	**240**	**176**	**64**	**36%**
Unattributed losses and noise	0	118	-118	-100%

The regional water balance can be interpreted as follows:

- Reach 1 (Loddon River ending below Laanecoorie Reservoir) is strongly gaining. The three other reaches all lose more water than they gain.
- The distinction between tributary and local inflows differs between the model and the water accounting and therefore only the sum of inflows can be compared.
- No attempt was made to estimate groundwater exchanges in the water accounting due to the lack of direct data.
- Simulated combined main stem inflows into the Loddon above Cairn Curran Dam and into the Avoca River above Coonooer (90 and 65 GL/year respectively) are 8 GL/year or 5 percent higher than accounted inflows (82 and 65 GL/year). This is due to a 10 percent overestimate of Loddon inflows (Appendix C).
- Simulated combined main stem outflows from the Loddon River below Appin South and the Avoca River at Quambatook (69 and 28 GL/year respectively) are 19 GL/year or 24 percent higher than accounted (52 and 27 GL/year). This is mainly due to 33 percent overestimation of Loddon outflows (Appendix C).
- The sum of simulated local and tributary inflows (84 GL/year) is 20 GL/year (19 percent) lower than the sum of accounted equivalent terms (gauged tributary inflows and SIMHYD estimates: 104 GL/year). Some of this difference may be due to 43 GL/year of apparent gains that could not be attributed in the accounts.
- Simulated diversions for the water accounting period (70 GL/year) are 15 GL/year (26 percent) greater than those recorded (55 GL/year).
- Simulated combined river and floodplain losses and unspecified losses are equal to accounted river and floodplain losses (42 GL/year).
- Gauged water balance terms including diversions represent 48 percent of the total water balance but not all gauging data can used in accounting. Another 25 percent could be attributed using SIMHYD local runoff estimates (104 GL/year) and estimates of river and floodplain losses (42 GL/year).
- Unattributed gains are smaller than unattributed losses. Unattributed gains (including measurement noise) for the entire accounted system combined represent 43 GL/year or 15 percent of total apparent gains. Unattributed losses (including measurement noise) represent 118 GL/year or 40 percent of total apparent losses. The sum of the unattributed gains and losses represents 27 percent of the total water balance. The river model simulates 30 GL/year of distributary losses in the Avoca River (Reach 4) that are unattributed losses in the accounts.
- Overall, the system is reasonably well gauged and understood. End-of-system flows and net diversions differ between simulations and accounts and suggest uncertainty in these components. The greatest uncertainty is associated with a large volume of unattributed losses that appear to occur in reaches 1, 2 and 4, in particular.

Climate range

Calibration covered the five-year period 1992 to 1997. Nine years in the entire 111-year record used in modelling were drier than those included in this calibration period. Three years were wetter. The average rainfall for the calibration period was 6 percent higher than the long-term average (431 mm/year). The historical 111-year rainfall record had seven years that were drier and four years that were wetter than the extremes during the period of water accounting (1990 to 2006). Overall, although the period of calibration was short, it provides a good representation of the longer climate record, due to a dry 1994 (258 mm) and a wet 1992 (641 mm). 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 that it represents the response of river flows to changed climate, land use and regulation changes (notwithstanding the possibility that the model is right for the wrong reasons through compensating errors). Appendix C lists indicators reach by reach of the model's performance in reproducing different aspects of the patterns in historically measured monthly and annual flows (all are variants of Nash-Sutcliffe model efficiency).

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

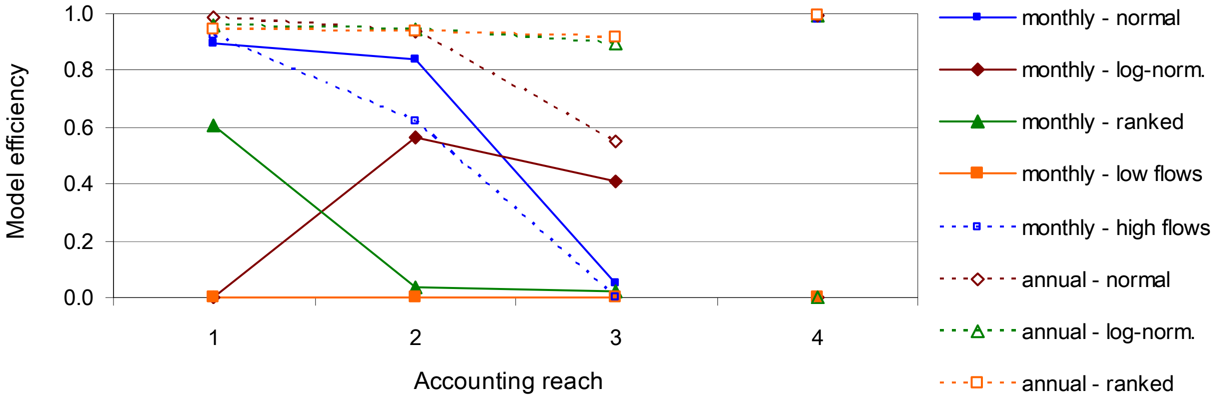

Figure 5-4. Changes in the model efficiency (the performance of the river model in explaining observed streamflow patterns) along the length of the river (numbers refer to reach)

- Model performance for total annual flow is very good to excellent (NSME of 0.94 to 0.99) in all reaches except Reach 3 (NSME of 0.55). Model performance for monthly totals is very good in all reaches (NSME of 0.84 to 0.99) except Reach 3, where performance is very poor (NSME of 0.05). Some of the high flows in this reach appear to be considerably overestimated by the model (Figure 5-5).
- Model performance for the 10 percent highest flows is very good to excellent and better than overall performance in reaches 1 and 4 (NSME of 0.92 to 0.98). It is less good but still fair in Reach 2 (NSME of 0.62). High flows are simulated poorly in Reach 3 (NSME less than 0).
- Model performance for the 10 percent lowest flows is not calculated for the Avoca (Reach 4) as it is an ephemeral river. Performance in reproducing low flow is poor in the three Loddon River reaches (NSME less than 0). A comparison of monthly time series and flow duration curves suggests that low flow patterns are generally reasonably well reproduced and in the right order of magnitude (Appendix C). Low flows in Reach are consistently overestimated by the model after 2001 (Appendix C).
- The simulated and observed flow duration curves agree rather well for all reaches (Appendix C).
  A comparison of monthly patterns () suggests that the model simulates river flows at the end-of system well.

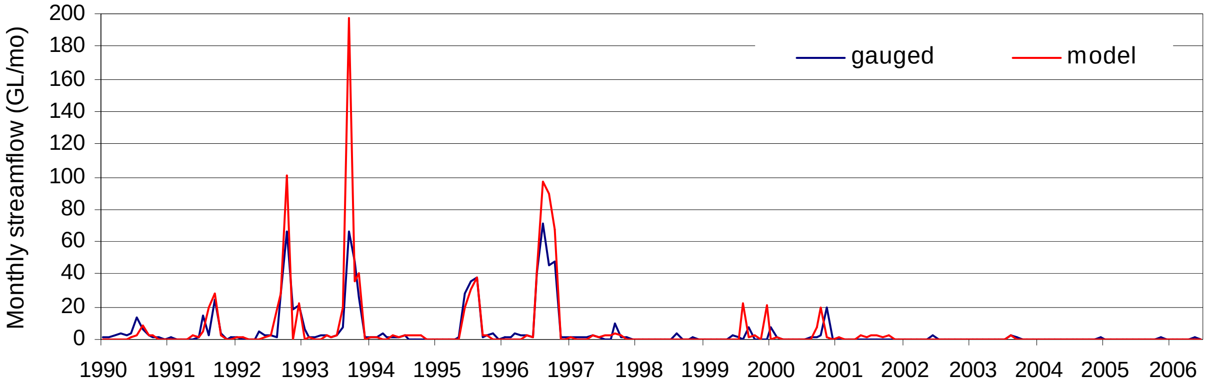

Figure 5-5. Observed (gauged) and simulated (model) monthly streamflow in the lower Loddon River at Appin South for the accounting period

Scenario change-uncertainty ratio

A high change-uncertainty ratio (CUR) corresponds to a change in scenario related flows that is likely to be significant given the uncertainty, or noise, in the model. A CUR of around 1.0 means that the modelled change has a similar magnitude as the uncertainty in the model. The CUR is shown for each reach for changes in monthly and annual flows in Figure 5-6.

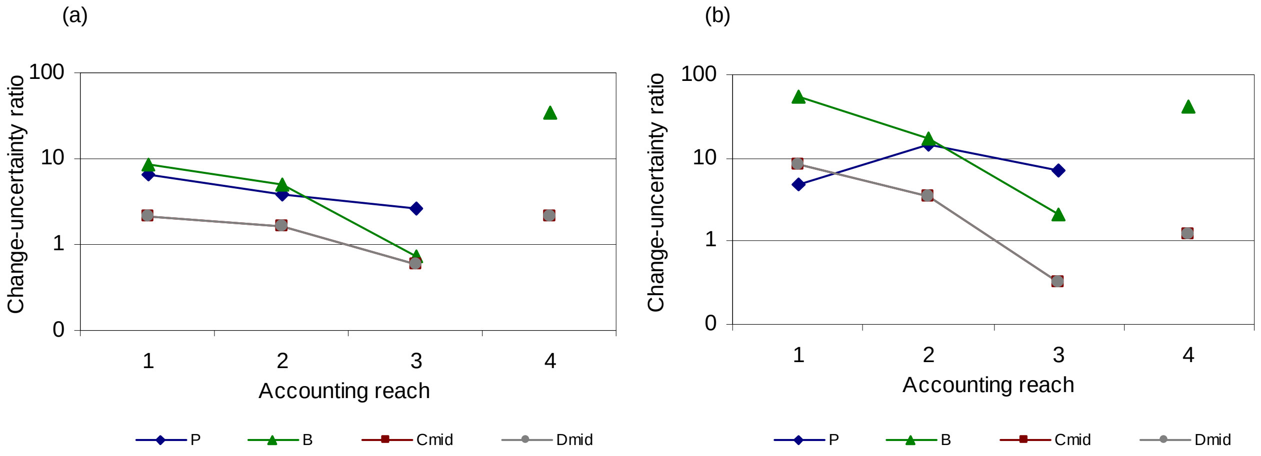

Figure 5-6. Pattern along the river (numbers refer to reach) of the ratio of the projected change over the river model uncertainty for (a) monthly and (b) annual flows under scenarios P, B, C and D

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 significance of the simulated change from without-development to current flow pattern is reasonable to strong in the three Loddon River reaches when compared to model performance (CUR of 2.7 to 15). Modelled flows have reduced across the flow range due to water resource development (Appendix C). Without-development flow scenarios were not available for the Avoca River.
- The projected changes under Scenario Cdry are almost identical to those under Scenario B and Scenario Ddry (Appendix C). In all three cases the projected change is much greater than model uncertainty (CUR of 15 to 59) except for the lower Loddon (Reach 3). This is because the Scenario A model overestimates historical flows.
- The projected changes under scenarios Cmid and Dmid are of moderate to fair significance when compared to model uncertainty (CUR of 1 to 8) whereas scenarios Cwet and Dwet are modestly significant (CUR of 0.5 to 3.5). All these scenarios are within model uncertainty for the lower Loddon River (Reach 3).
- The projected changes due to scenarios C and D have almost identical CUR values. Differences between scenarios C and D are less than 2 percent of average flows in all cases.

Conclusions follow:

- The projected changes in flow pattern due to water resource development are significant compared to internal model uncertainty.
- The dry and median climate change scenarios lead to changes in flow that are moderate to very significant when compared with internal model uncertainty. Changes under the wet scenarios are close to model noise.
- The impact from projected future development is very small when compared to the impact from climate change.
- The model uncertainty for Reach 3 is large when compared to projected changes due to the bias in the model for this reach.

5.4 Discussion of key findings

Gauging and understanding of the hydrology of the Loddon-Avoca region

The hydrology of the Loddon-Avoca surface water system is well gauged (with the exception of the lack of attribution of losses in Reach 4). The density of gauging is greater than the average network density for the MDB, but the gauging in the region is concentrated in the Loddon valley. Water accounts could be established for three reaches in the Loddon valley and for one reach in the Avoca valley.

The upper reach of the Loddon above Lake Laanecoorie is gaining and the other three reaches are losing. Overall, the region appears to be sufficiently well gauged and understood for reliable river modelling.

The conceptual understanding of the current hydrology of the Loddon and Avoca rivers system appears reasonable. Groundwater interactions appear to play a minor role in the Loddon-Avoca surface water system and were not simulated by the river model. Surface water diversions are a significant component of total inflows (around 19 percent). Uncertainty associated with unanticipated changes in river regulation, irrigation and development are possible. Prior model assessment suggested that the supplemental flows from the Loddon system into the Waranga Western Channel are not always predicted well (Section 5.3.2).

The uncertainty analysis confirmed prior work that found measurement and modelling of flood breakouts and subsequent return flows in the lower Loddon River are uncertain. These flows and losses are poorly gauged and could not be represented well in the monthly time step model. There are also uncertainties associated with assumptions about river transmission losses (Section 5.3.2). The sum of unspecified and river and floodplain losses for the accounted reaches represented 42 GL/year or about 7 to 9 percent of the total water balance. Uncertainty is within this range.

There may be more internal model uncertainty in assumptions about runoff generation that are implicit in the river modelling methodology. Uncertainty associated with development (future farm dam increases in particular) was less than 1.5 GL/year or 2 percent of average annual flow in the Loddon and negligible in the Avoca valley, and therefore small compared to other uncertainties.

Model performance in explaining observations and comparison to water accounts

Overall model performance appears to be very good to excellent for the accounted part of the system except for the lower Loddon where flows are not simulated well. This confirmed prior model evaluation. Although the calibrated climate range was short it provides a good mix of wet and dry years which further increases confidence in the reliability of the model under climate change scenarios.

The accounted and simulated water balance terms generally agree reasonably well, although differences greater than 20 percent occur in total diversions, lower Loddon outflows, and total inflows.

Implications for use of these results

Based on the model assessment it was concluded that:

- the model reproduces observed streamflow patterns very well, and produces estimates of water balance terms that agreed reasonably well with water balance accounts
- the projected changes in flows due to climate change are greater than model internal uncertainty under the dry and medium scenarios, but similar to model noise under the wet scenarios
- the model provides strong evidence of changes in flow pattern due to prior water resource development, but the projected changes due to future development are negligible.

While the model is well suited for the purpose of this project, caution is required in interpreting predictions of absolute and relative changes in flow patterns and average flows in the lower Loddon below Loddon Weir.

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6 Groundwater assessment

This chapter describes the groundwater assessments for the Loddon-Avoca region. It has nine sections:

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

6.1 Summary

6.1.1 Issues and observations

There are three groundwater management units (GMUs) and a proposed GMU that cover part of the Loddon-Avoca region. The three GMUs are Water Supply Protection Areas (WSPAs). The rest of the region is an unincorporated area.

A numerical groundwater model developed for this project underpins the assessment for the Mid-Loddon GMU. Simpler water balance analyses were conducted for the remaining GMUs and the part of the unincorporated area in the upper catchment. Management intervention in response to water table drawdown under future scenarios has not been included in the groundwater modelling.

6.1.2 Key messages

- Groundwater extraction in the Loddon-Avoca Region for 2004/05 is estimated to be 29 GL. This represents 1.7 percent of groundwater use in the Murray-Darling Basin (MDB). About 64 percent of this extraction came from the Mid-Loddon GMU. Groundwater use represents 9 percent of total current water use on average, and 14 percent of total water use in years of lowest flow. Extraction is currently at a medium level of development (30 to 70 percent of recharge) for all GMUs.
- The Loddon River switches between gaining and losing along its length. The Avoca River is losing along most of its length apart from a short upstream reach.
- Modelling suggests that historical groundwater extraction has and will continue to impact on streamflow in the region. The total eventual impact on streamflow will be a loss to groundwater of 5.4 GL/year.
- Mid-Loddon GMU water levels in the confined Calivil Formation and Renmark Formations have fallen between 1 and 5 m since the mid-1990s. Similar falls in the Shepparton Formation are attributed to downward leakage caused by pumping in the underlying Calivil Formation. Falls of up to 10 m have occurred since the mid-1990s in the fractured basalt aquifers of Spring Hill GMU.
- Groundwater extraction in the region is expected to approximately double by 2030 to 59 GL/year. The total eventual impact of this groundwater extraction would be an average streamflow reduction of 17 GL/year. Projected extraction under the best estimate (median) 2030 climate would remain at a medium level of development for the Mid-Loddon GMU and the proposed Avoca GMU, but would be high for the Spring Hill GMU and very high for the Upper Loddon GMU where extraction would exceed recharge.

6.1.3 Uncertainty

The priority of each GMU in the context of the overall project and the analysis method were ranked. Ideally the ranking of each match so GMUs likely to influence MDB-wide outcomes have reliable information on groundwater availability and the level of development. The analysis method ranking criteria are: hydrogeological description – minimal; simple water balance – simple; and numerical modelling – medium to very thorough. The ranking of the 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 and (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 been previously been calibrated under steady state conditions or (ii) have small model extent can become less than fit for this purpose. If the first of these conditions are not met, the modelled water table levels may show drifts that are more associated with the calibration process than hydrological processes. If the second 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 or 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 for 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 Southern Riverine Plains groundwater model used for assessment of higher priority GMUs in the region was assessed as thorough. The model is based on a grid of 1000 m. It was run in a without-development mode. The model was constructed for this project and has been internally reviewed. However, only as it is used more widely, will it receive more thorough external peer review. Flows across boundaries represent about 12 percent of the modelled groundwater balance. The model is adequate for providing information on water availability in the context of this project, but less reliable for local management requirements. The model reached a dynamic equilibrium under both current and future extraction rates. The level of reliability of predictions could be improved to very thorough by recognising the importance of the Calivil Formation as a groundwater resource.

6.2 Groundwater management units

6.2.1 Location

The aquifers within the region are divided into a number of GMUs for management purposes as shown in Figure 6-1. These units are three-dimensional in nature. The GMUs relevant to the region are:

- Mid-Loddon Water Supply Protection Area (WSPA) (V45, referred to as the Mid-Loddon GMU). This is a relatively new WSPA which replaced the Ascot and Moolort WSPAs in April 2004.
- Upper Loddon WSPA (V55, referred to as the Upper Loddon GMU)
- Spring Hill WSPA (V56, referred to as the Spring Hill GMU)
- proposed Avoca GMU
- Ellesmere GMA (V44, referred to as the Ellesmere GMU)
- Campaspe Deep Lead WSPA (V42, referred to as the Campaspe Deep Lead GMU)
- Shepparton WSPA (V43, referred to as the Shepparton GMU)
- Bungaree GMA (V57, referred to as the Bungaree GMU).

Only the first four GMUs are assessed in this report. The Ellesmere and Campaspe Deep Lead GMUs are assessed in the Campaspe region (CSIRO, 2008a) and the Shepparton GMU is assessed in the Broken-Goulburn region (CSIRO, 2008b). The Bungaree GMU is not assessed as it has no recorded groundwater extraction. The GMUs do not cover the entire region. Those areas not covered are referred to as 'unincorporated areas'. When used in the body of this report the term WSPA refers to regulatory matters not the groundwater assessment.

6.2.2 Priority ranking

Available groundwater extraction, entitlement and recharge data are itemised for each GMU in the region in Table 6-1. The Upper Loddon GMU has a low priority and the Spring Hill GMU has a very low priority in the context of this project due to the comparatively low level of groundwater use and limited potential for groundwater to impact on streamflow. The Mid-Loddon GMU has a medium priority.

The groundwater assessments vary for different GMUs by the availability of data and analysis tools as well as the priority of the GMU. They range from minimal to very thorough. A simple ranking for the GMUs in the Loddon-Avoca region denotes a simple water balance approach including mapping of the surface–groundwater connectivity. A thorough ranking denotes the use of a numerical groundwater model. The analysis method is consistent with the respective priority rankings for all Loddon-Avoca GMUs. While these assessments are appropriate given the constraints and terms of reference of this project, further analysis would be required for local management of groundwater resources.

The Mid-Loddon GMU has been assessed using the Southern Riverine Plains groundwater model, which provides for a relatively high level of assessment. The assessments for the: Upper Loddon and Spring Hill GMUs, proposed Avoca GMU and unincorporated areas of the upper catchment were limited to a simple analysis. This involved an overview of the hydrogeological setting, a surface–groundwater connectivity assessment and an evaluation of the impact of changing rainfall recharge and extraction under each of the scenarios.

The main groundwater indicator used is the ratio of extraction to rainfall recharge (E/R). 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.

Table 6-1. Groundwater management units of the Loddon-Avoca region, together with entitlement and extraction data

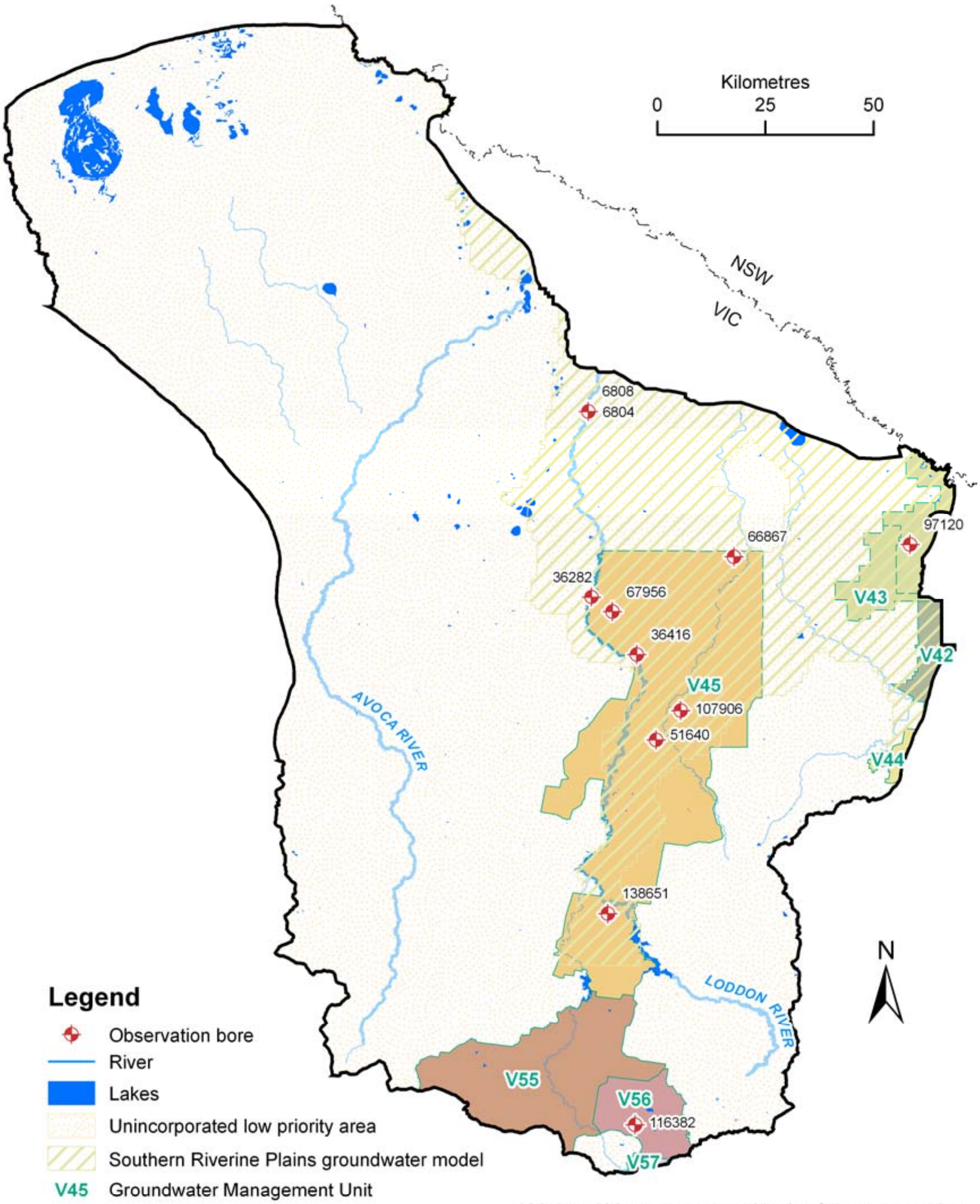
Code	Name	Priority	Assessment	Total entitlement	Current extraction[1] (2004/05)	Permissible consumptive volume[2]	Estimated use (2030)
				GL/y			
V45	Mid-Loddon WSPA	medium	thorough	34.05	18.1	37.2 (proposed)	37.2
V55	Upper Loddon WSPA	low	simple	13.04	6.67	13.6 (proposed)	13.23
V56	Spring Hill WSPA	very low	simple	4.91	1.64	5.1 (proposed)	3.44
-	Proposed Avoca GMU	-	simple	1.34	0.98	none as yet	1.52
-	Unincorporated Areas[3]	-	na	2.84	1.94	none	3.18

[1] Source: Department of Sustainability and Environment Victoria (DSE, 2006). These volumes include estimated stock and domestic use of: 0.47 GL/year for the Mid-Loddon WSPA, 0.46 GL/year for the Upper Loddon WSPA, 0.27 GL/year for the Spring Hill WSPA, 0.20 GL/year for the proposed Avoca GMU and 0.67 GL/year for unincorporated areas.
The installation of bore meters has not been completed in the Mid-Loddon WSPA or the Upper Loddon WSPA, where 2 and 4 GL/year respectively of licensed extractions have been estimated.

[2] Source: DSE, 2006.

[3] The unincorporated portion of the region represents those water resources outside of the GMUs where groundwater salinity is less than 1500mg/L Total Dissolved Solids (TDS), and covers an area of 1450 km^2.

na: not applicable



* V42 and V44 are assessed in the Campaspe region
** V43 is assessed in the Goulburn-Broken region
*** V57 is not assessed

Figure 6-1. Location of groundwater management units within the Loddon-Avoca region

6.2.3 Hydrogeology

The Loddon-Avoca region is divided into two zones: the upper catchment – dominated by the fractured rock aquifers (including basalts) of the North Central Highlands – and the lower catchment which is dominated by sedimentary deposits of the MDB.

Ordovician bedrocks underlie the region and are locally overlain and deeply dissected by Newer Volcanic basalts. The broad, low volcanic plateau forms the main divide in the Ballarat region and narrows to tongues of basalt that extend along the Loddon Valley and its upper tributaries. The fractured basalt aquifer is recharged both directly through numerous volcanic cones via infiltration through fractures.

However, lava vents are the main recharge source for the aquifer system. Groundwater flow typically radiates outward from the elevated recharge sources into the plains and groundwater flows from south to north. Groundwater quality of the Newer Volcanic basalt aquifers is highly variable depending on proximity to the recharge area. Groundwater is of good quality (<560 mg/L TDS) around volcanic vents and increases to over 3360 mg/L TDS in low recharge areas. Groundwater quality of the basalt in the Daylesford area is good, averaging around 200 mg/L TDS (Heislers, 1993).

Weathered Ordovician bedrock is an important source of mineral water in the Daylesford area. The Ordovician bedrock is intruded by granite (Harcourt Batholith) and fresh springs (100 to 300 micro Siemens per cm electrical conductivity (µS/cm EC)) and saline discharge (5,000 to 10,000 µS/cm EC) occur in close proximity (Kevin, 1992). High recharge areas in the granitic landscape typically match areas of shallow sands of high hydraulic conductivity and good quality groundwater.

The Avoca Deep Lead is a confined to semi-confined aquifer incised within Ordovician bedrock and the basalts. Tertiary-aged White Hills Gravels follow generally the present course of the Avoca River and associated tributaries. A higher energy environment caused streams to erode through the White Hills Gravels and Ordovician bedrock and subsequently deposit reworked gravels and bedrock at the base of the palaeovalleys. These sediments comprise the Calivil Formation which is associated with the Avoca Deep Lead. Overlying the deep leads within the palaeovalleys are the Quaternary aged Shepparton Formation alluvial sediments that make up the surface geology in most of the area. Quaternary aged Newer Volcanic basalt up to 50 m thick overlies the bedrock and deep leads but it’s limited to the eastern margin of the area. Regional groundwater flows north and there are some flows to the east and west that the main aquifer flow path. The hydraulic connection between the shallow aquifers and the Avoca Deep Lead aquifer is significant (SKM, 2005b).

The deep leads are generally thin in the highland reaches and tend to broaden to the north. Recharge to the deep lead aquifer occurs from two main sources: periodic leakages from overlying formations and direct rainfall recharge where the Calivil Formation outcrops in the highland tracts of the catchment. Yields of good quality (<1500 mg/L TDS) groundwater exist in the Calivil-Renmark aquifer along the tract of the Loddon Deep Lead. Salinities within the Calivil Formation range from 900 to 1200 mg/L TDS in the upland areas to 2000 mg/L TDS in the mid-catchment and then deteriorate to 9000 mg/L TDS within the discharge zone on the lower Loddon Plain (URS, 2006). The proposed Avoca GMU is defined by the inferred extent of the Avoca Deep Lead.

Trends in water levels

Groundwater levels rose in the Calivil Formation during the wetter years of 1973 to 1975, 1984 and 1993. There has been a general groundwater level decline of between 1 and 3.5 m in the Calivil Formation around the middle of the region since 1996. Groundwater extraction may be affecting the groundwater levels in this area. Falls of 1 to 5 m in the groundwater level of the Renmark Group have been recorded in intensively pumped areas of the Calivil Formation in the Upper-Loddon (SKM, 2007).

Groundwater levels in the fractured basalt aquifers of Spring Hill GMU have declined in the more intensively pumped zones by approximately ten metres in ten years (Figure 6-2). Water levels have also declined in response to below average rainfall conditions (GMW, 2006).

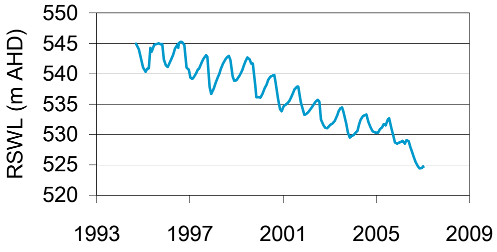


Figure 6-2. Hydrograph for Bore 116382 completed in the Fractured Rock aquifer showing a declining trend. Ground level is 250.74 m AHD.

Groundwater levels within the Shepparton system have fluctuated with recharge from river leakage. This was disrupted significantly after 1996 to a strong falling trend associated with downward leakage induced by declining levels in the underlying Calivil Formation (Figure 6-3).

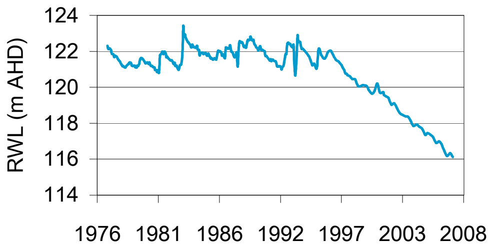


Figure 6-3. Hydrograph for Bore 107906 completed in the Shepparton Formation of the Upper Loddon GMU displaying a strong downward trend since 1996. Ground level is 125.53 m AHD.

6.3 Surface–groundwater connectivity

Objectives of the surface–groundwater connectivity mapping are to: (i) provide a catchment context for surface–groundwater interactions, (ii) constrain surface water balances and (iii) 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 groundwater flux to the stream as the product of the aquifer hydraulic conductivity, aquifer thickness and groundwater gradient adjacent to the stream. The method is dependent on the availability of appropriate groundwater monitoring and on previous work estimating hydraulic conductivity.

River levels and groundwater levels were compared at a single point in time to provide a snapshot of the direction and magnitude of the flow between surface water and groundwater. The date selected for production of the flux map and associated calculations was January 2006, as this was the most recent date with both a large quantity of available bore and river elevation data. This date represents a low flow period in the context of historical flows in the Loddon River with an average depth of 0.1 m at Appin South (stream gauge 407205).

An average aquifer thickness of 20 m was used for all river reaches. The adopted hydraulic conductivity value varied across the region between 0.5 and 5 m/day. A horizontal hydraulic conductivity of 5 m/day has been assigned to the upper Shepparton Formation downstream of Loddon Weir. The watertable aquifer upstream of Loddon Weir was assigned a horizontal hydraulic conductivity of 0.5 m/day.

Figure 6-4 shows the surface–groundwater connectivity results from the flux assessment. The Avoca and Loddon Rivers are assumed to be gaining in their upper reaches but the bore data in these areas is limited.

The assessment found that:

- The Avoca River is losing over most of its length.
- The Loddon River is gaining at a low rate for approximately 85 km, between Newstead and Bridgewater.
- The Loddon River changes from gaining to losing for approximately 40km downstream of Bridgewater. This change is likely due to the groundwater development in the region.
- The Loddon River is gaining at a low rate or hydraulically neutral (that is, neither gaining nor losing) for the 81 km reach to Appin South (stream gauge 407205). The river is losing at low to moderate rates between Appin South and the junction with the Murray River.

This result is generally consistent with previous hydrogeological interpretations of the region.

River levels at two gauging stations and adjacent groundwater levels were compared to obtain information on how fluxes change with time. This showed an increase in rate of loss over time for losing sections, and a decrease in the rate of gain for gaining sections of the river. Gaining conditions have been reversed In some cases due to groundwater level declines. The relationship between groundwater level and river stage for a gaining section of the Loddon River is shown in Figure 6-4. The ongoing drawdown from groundwater extraction decreases the gradient from the aquifer to the stream over time.

Figure 6-5 and Figure 6-6 are examples of a losing section of the Loddon River. River levels are recorded at the Appin South (Stream Gauge 407205) and groundwater levels taken from bores 6804 and 6808, situated approximately 50 m from the river. The hydrograph shows that prior to 2002 the Loddon River here was gaining and, due to a consistent decline in groundwater levels over the last ten years, this section of river is now losing.

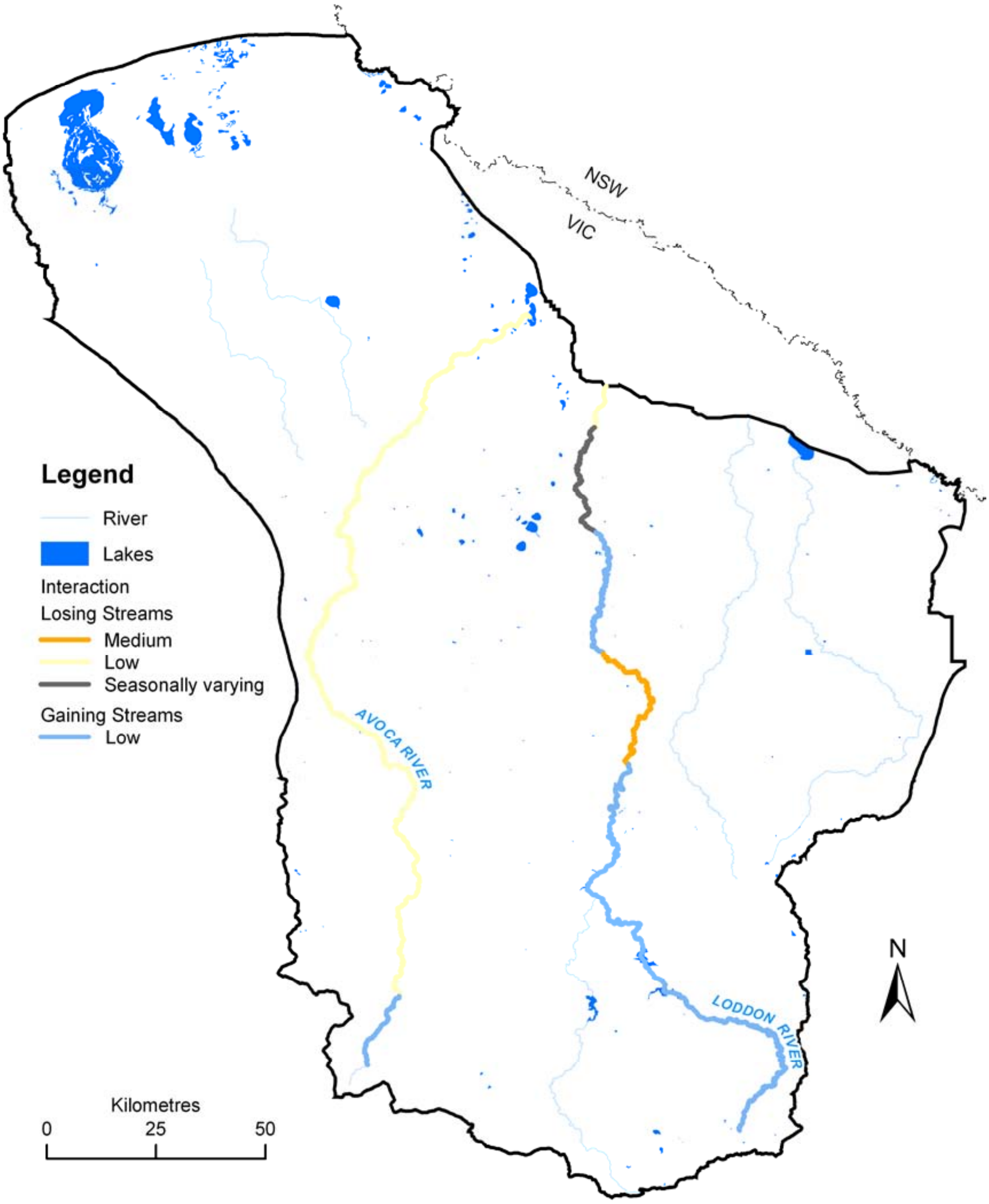


Figure 6-4. Map of surface–groundwater connectivity

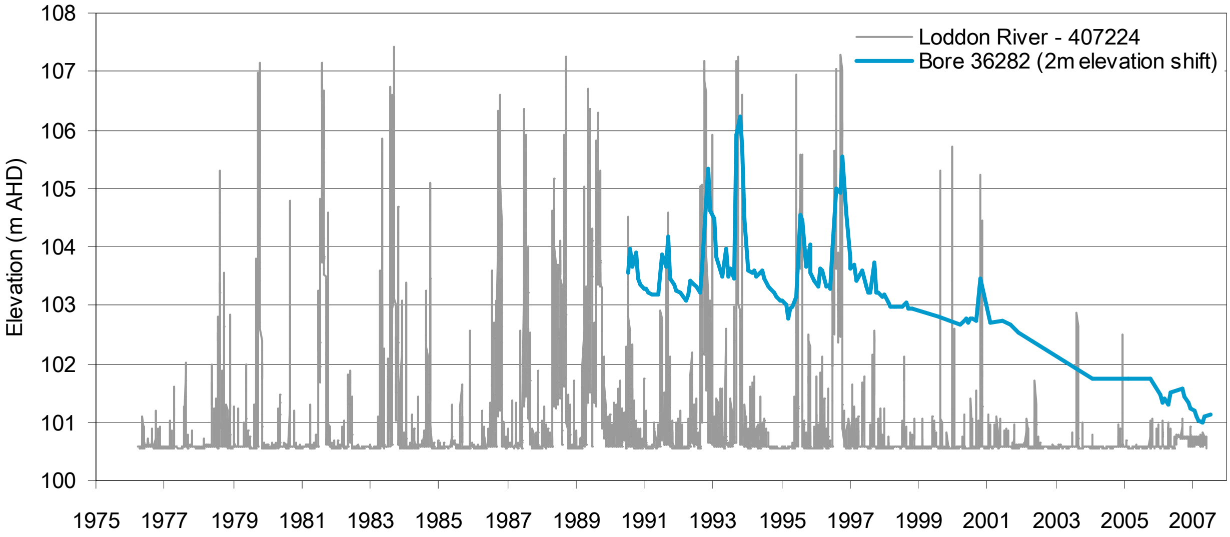


Figure 6-5. Comparison of Loddon River level at Loddon Weir with groundwater levels in a nearby bore

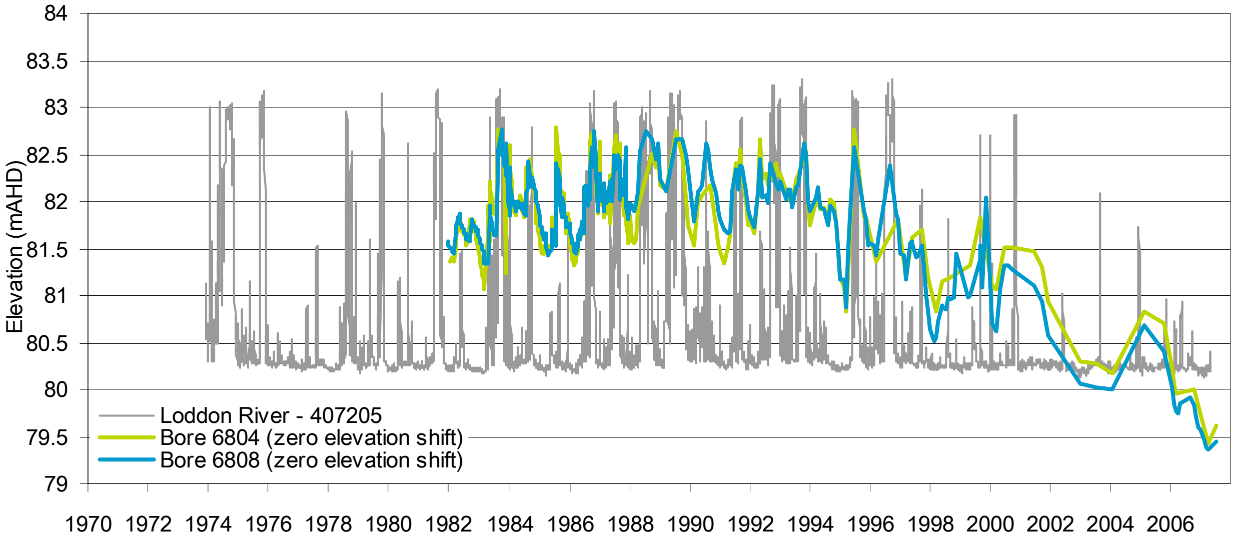


Figure 6-6. Comparison of Loddon River level at Appin South with groundwater levels in a nearby bore

6.4 Recharge modelling

Recharge Scaling Factors (RSFs) are applied in the groundwater modelling and the simple water balance analyses. Values of diffuse dryland recharge are used to calibrate the original implementation of the groundwater model and for management of the other GMUs within the region. The RSFs are used to multiply these values to provide estimates of dryland recharge under different climate scenarios to be used in further analyses. The RSF is 1.0 by definition for Scenario A and close to 1.0 for other climate scenarios. The impacts of climate change on recharge are reported as percentage changes from Scenario A. The RSFs are obtained by dividing the percentage change by 100 and adding to 1.0.

Scenarios Cdry, Cmid and Cwet represent a range of global climate model (GCM) output, and rank mean annual runoff to reflect the range of predictions (Chapter 3). Groundwater recharge is not perfectly correlated with mean annual rainfall or runoff. Apart from mean rainfall, diffuse dryland recharge is sensitive to seasonal rainfall and potential evaporation and to the extreme events or years that lead to episodic recharge.

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, which is more dependent on average and seasonal rainfall.

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

Figure 6-7 shows the percentage change in the modelled mean annual recharge averaged over the region under Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual recharge and the percentage change in mean annual rainfall from the corresponding GCMs are tabulated in Table 6-2. The plots show that there is a wide range in results across GCMs and scenarios for the Loddon-Avoca with just over half the scenarios predicting less recharge and the remainder predicting more recharge, although predictions for reduced recharge are greater in magnitude that those which indicate increased recharge. The high global warming scenario predicts both the highest and lowest change in recharge for the region.

Only an extreme dry (Scenario Cdry), a median (Scenario Cmid) and an extreme wet (Scenario Cwet) variant are shown in subsequent modelling and reporting of modelling results. Results from the second lowest and second highest modelled recharge rates were used for scenarios Cdry and Cwet and the most appropriate was chosen for Scenario Cmid. This approach is slightly different to that used for surface water modelling in the region (where the median is used for Cmid) but the effect is negligible. The selected scenarios are indicated in bold type in Table 6-2. 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, despite a reduction in mean rainfall. The groundwater model used for analysis of the Mid-Loddon GMU covers many regions and the RSF used is an average of those for the relevant regions.

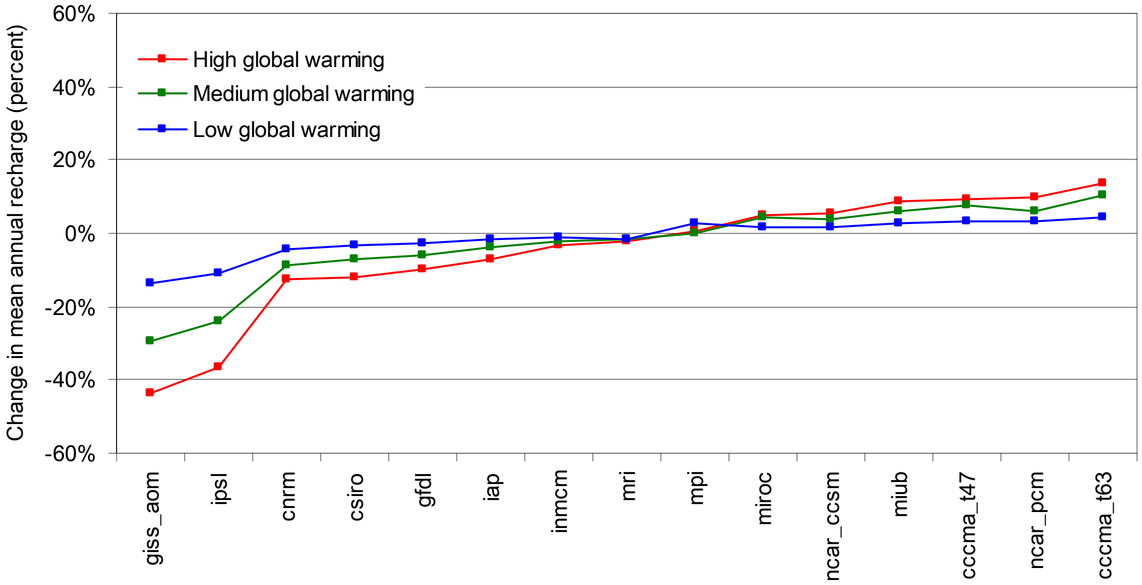


Figure 6-7. Percentage change in mean annual recharge from the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A recharge

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

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Recharge	GCM	Rainfall	Recharge	GCM	Rainfall	Recharge
giss_aom	-23%	-44%	giss_aom	-15%	-29%	giss_aom	-7%	-14%
ipsl	**-20%**	**-36%**	ipsl	-13%	-24%	ipsl	-6%	-11%
cnrm	-15%	-13%	cnrm	-10%	-9%	cnrm	-4%	-5%
csiro	-10%	-12%	csiro	-7%	-7%	csiro	-3%	-3%
gfdl	-12%	-10%	gfdl	-8%	-6%	gfdl	-3%	-3%
iap	-3%	-7%	iap	-2%	-4%	iap	-1%	-2%
inmcm	-6%	-3%	**inmcm**	**-4%**	**-2%**	inmcm	-2%	-1%
mri	-8%	-2%	mri	-5%	-1%	mri	-2%	-2%
mpi	-6%	1%	mpi	-4%	0%	mpi	-2%	3%
miroc	-4%	5%	miroc	-3%	4%	miroc	-1%	2%
ncar_ccsm	0%	6%	ncar_ccsm	0%	4%	ncar_ccsm	0%	2%
miub	0%	8%	miub	0%	6%	miub	0%	3%
ncar_pcm	**3%**	**10%**	ncar_pcm	2%	6%	ncar_pcm	1%	3%
cccma_t47	-1%	9%	cccma_t47	-1%	7%	Cccma_t47	0%	3%
cccma_t63	3%	14%	cccma_t63	2%	10%	Cccma_t63	1%	4%

6.5 Groundwater modelling

Groundwater extraction in the Mid-Loddon GMU was analysed using the Southern Riverine Plains groundwater model. It was developed specifically for this project, and covers a 292 x 250 km area spanning either 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 Modelling approach

The groundwater model covers an area of 34,285 km^2 and utilises a 1 km^2 grid cell resolution. Outcropping bedrock forms the southern boundary of the active model domain and the northern boundary is defined by Billabong Creek. The groundwater model is divided into five layers based on the area's hydrogeology: Upper Shepparton Formation, Lower Shepparton Formation, Calivil Formation, Renmark Group and bedrock (inactivated in the model). The distinction between the Upper and Lower Shepparton is arbitrary as the formation is extremely variable in character. Inclusion of two model layers to represent the Shepparton Formation allows additional flexibility in modelling vertical fluxes from the surface to the deep lead aquifers and enables the inclusion of aquitards if necessary above the Calivil Formation. Importantly the Southern Riverine Plains groundwater model combines the Lower Murray, Katunga and Campaspe models and attempts 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 were included in the model to help account for tributaries and drainage channels that cannot be explicitly modelled. Drainage cells were only 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 NSW.

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 (ET) package is used to simulate ET from shallow water tables. Groundwater pumping is simulated from a total of 2400 extraction bores. The model was calibrated from the period January 1990 to December 2005. The mass balance for the modelled area is shown in Figure 6-8.

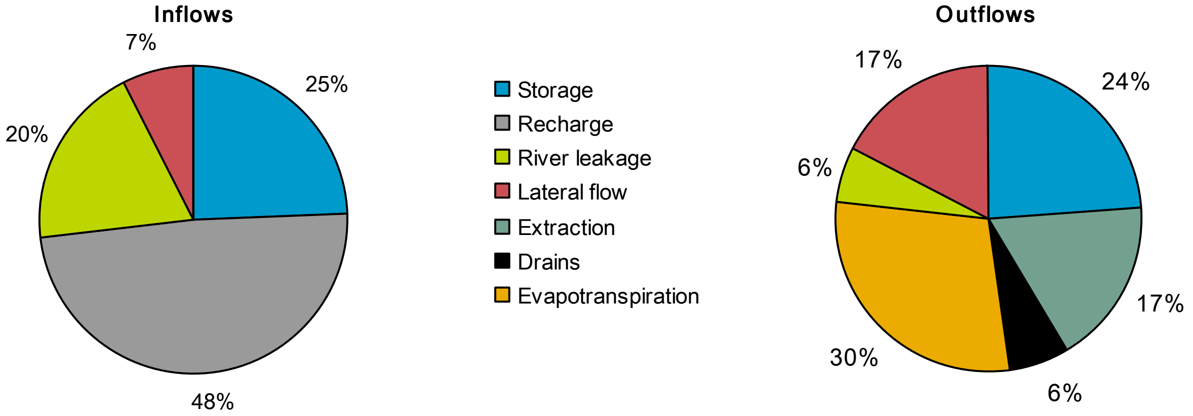


Figure 6-8. Mass balance for the calibration model for the model area (Jan 1990 – Dec 2005; Inflows = Outflows)

6.5.2 Scenario implementation

The objective of the numerical modelling is to assess groundwater and surface water impacts under a range of groundwater extraction scenarios. 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 19 GL/year for the portion of the model contained within the region, and 245 GL/year across the model area.

Climate can change dryland recharge, the area of irrigation or river flows. The impact of climate on diffuse dryland recharge is assessed through the application of a RSF (Section 6.4). However, RSFs were not varied spatially across the model area, which includes four reporting regions. Constant scaling factors were used across the entire model for each of the scenarios, instead.

Table 6-3 shows the percentage changes in recharge rate applied to the model under scenarios B and C. Scenario B represents a continuation of current drought conditions and Scenario C represents the climate as predicted for 2030 by the GCMs. Scenario D also represents the climate as predicted for 2030 by the GCMs, it has the same three variants as Scenario C, and the same dryland recharge rates.

Scenario D introduces changes in surface and groundwater use, commercial forestry plantations and farm dams. River stage (which is calculated from outputs of the river model) may vary from Scenario C because of changes to water management. Under Scenario D, groundwater pumping was increased to a total of 23 GL/year in the Goulburn-Broken section of the model and 300 GL/year across the model domain. This level of pumping is consistent with the likely future maximum pumping as defined by New South Wales and Victorian jurisdictions.

Table 6-3. 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 were 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 would implicitly include surface–groundwater exchanges within the unattributed losses and gains. The calibration periods for the groundwater and surface water models broadly coincide so the change in surface–groundwater exchange fluxes in the MODFLOW calibration outputs is assumed to be the same as the change in groundwater gains and losses included in the REALM unattributed gains and losses. In all cases, extraction rates were assumed to be constant.

Model results are expressed as water levels, changes to the groundwater balance, and a number of groundwater indicators (Table 6-4). The environmental groundwater indicator was calculated using annual total recharge from all sources and may include diffuse rainfall and irrigation recharge, river leakage, leakage from overlying aquifers and lateral flow from outside GMU boundaries.

Table 6-4. Definition of groundwater indicators

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

Only the eastern half of the region is covered by the groundwater model (Figure 6-1). This includes the Loddon but not the Avoca River.

The dry scenarios cause significant reductions in total diffuse recharge (Table 6-5 and Figure 6-9). This has significant follow-on impacts for surface–groundwater interactions and evapotranspiration and there are increases in net river loss and decreases in evapotranspiration in response (Figure 6-10). Evapotranspiration is particularly important in the Loddon due to large areas of shallow watertables and a number of saline lakes. Differences in groundwater pumping between scenarios A, B and C, and between the different D scenarios are due to some model cells running dry, with consequent loss of pumping. Scenario Ddry has slightly less extraction than Scenario Dwet, because the reduction in recharge in the former case causes some additional model cells to dry up.

Flow through head dependent boundaries represents flow into or out of the catchment across the north-eastern corner of the model. This flow increases in scenarios with increased pumping and decreased recharge. The head dependent boundary condition can introduce modelling artefacts that could lead to underestimation of drawdown and stream impacts.

Table 6-5. Groundwater balance the part of the Loddon-Avoca region covered by the Southern Riverine Plains groundwater model under scenarios without-development, A, B, C and D

Groundwater balance	Without-development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	78.8	78.8	61.6	55.5	76.7	88.4	55.5	76.7	88.4
Head dependent boundary	15.3	19.7	22.1	23.1	20.2	19	23.4	20.5	19.3
River recharge	10.9	14.4	14.6	15.3	14.2	13.2	15.5	14.4	13.6
Lateral flow	21.2	18.7	17.9	17.7	18.4	18.9	18	18.6	19
Total	**126.2**	**131.6**	**116.2**	**111.6**	**129.5**	**139.5**	**112.4**	**130.2**	**140.3**
Outflows									
Extraction	0	19.1	17.8	17.8	19	19.1	20.9	22.6	23.1
Head dependent boundaries	6.9	5.2	4.2	3.9	5	5.6	3.8	4.9	5.4
Lateral flow	64.8	69	67.9	67.2	69.1	70	66.7	68.9	69.9
Evapotranspiration	46.6	32.7	22.5	19.7	31.1	38.3	18.2	28.8	35.7
To drains	4	3.5	2.3	1.8	3.3	4.1	1.8	3.3	4
To rivers	3.9	2	1.4	1.2	2	2.3	1	1.8	2.2
Total	**126.2**	**131.5**	**116.1**	**111.6**	**129.5**	**139.4**	**112.4**	**130.3**	**140.3**
Net river losses to groundwater	**7**	**12.4**	**13.2**	**14.1**	**12.2**	**10.9**	**14.5**	**12.6**	**11.4**

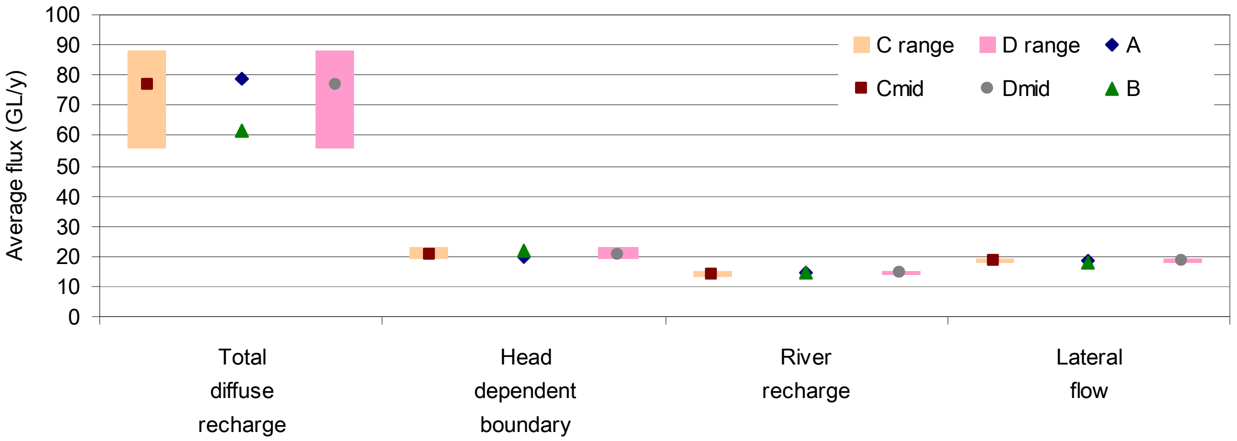


Figure 6-9. Groundwater inflows into the Loddon-Avoca region under scenarios A, B, C D

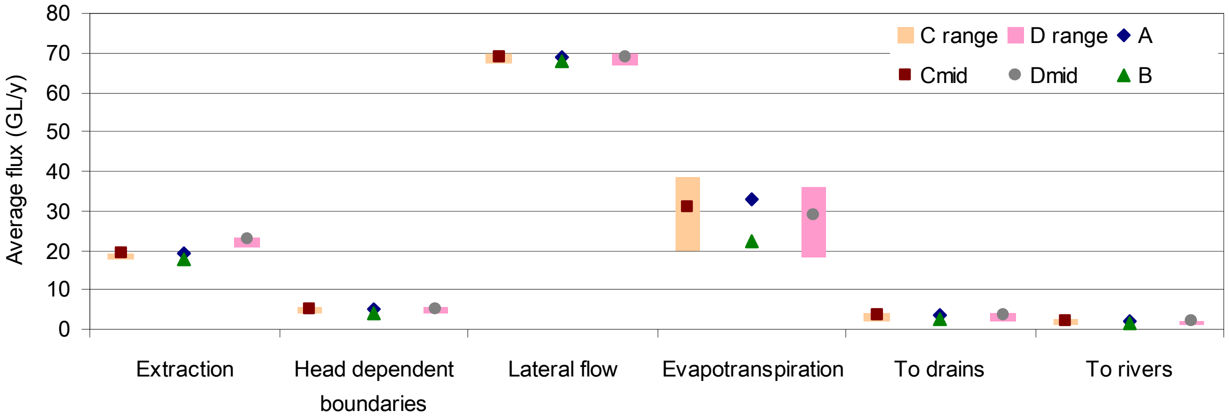


Figure 6-10. Groundwater outflows from the Loddon-Avoca region under scenarios A, B, C and D

6.6.1 Mid-Loddon GMU

Table 6-6 shows the affect of the various scenarios on the mean groundwater water levels in the Mid-Loddon GMU. They vary from 1.6 m higher to 4.6 m lower than under Scenario A. Drawdown is greater in the Calivil Formation and least within the Upper Shepparton Formation aquifer. Drawdowns in indicator bores are shown in Table 6-7.

Table 6-6. Median groundwater in the Mid-Loddon GMU under levels 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)						
Upper Shepparton Formation	122.7	-1.3	-1.9	-0.2	0.5	-2.2	-0.4	0.3
Lower Shepparton Formation	120.5	-2.2	-3.5	-0.4	1.3	-3.7	-1.0	0.8
Calivil Formation	102.7	-2.7	-4.4	-0.5	1.6	-4.6	-1.2	0.8
Average	**115.7**	**-2.1**	**-3.3**	**-0.3**	**1.2**	**-3.5**	**-0.9**	**0.6**

Table 6-7. Groundwater levels in key observation bores under Scenario A, and changes from this level under scenarios B, C and D

Bore	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	change from Scenario A (m)						
36416_1	109.2	-1.3	-1.8	-0.2	0.7	-2.0	-0.4	0.4
66867_1	95.3	-2.3	-3.6	-0.3	0.8	-4.2	-0.6	0.6
67956_1	104.4	-1.4	-2.1	-0.2	0.6	-2.5	-0.5	0.3
138651_1	181.8	-0.1	-0.1	0.0	0.1	-0.1	0.0	0.1
36416_2	107.9	-1.5	-2.1	-0.2	0.8	-2.4	-0.5	0.4
66867_2	94.0	-2.4	-3.7	-0.3	0.9	-4.3	-0.7	0.6
67956_2	103.8	-1.4	-2.0	-0.2	0.6	-2.5	-0.6	0.2
138651_2	184.8	-0.8	-1.0	-0.1	0.4	-1.0	-0.1	0.4
51640_2	112.2	-5.1	-8.9	-1.1	3.7	-8.3	-2.9	2.2
36416_3	103.3	-2.1	-3.2	-0.3	1.1	-3.7	-0.7	0.6
66867_3	92.7	-2.5	-3.8	-0.3	1.1	-4.5	-0.8	0.6
67956_3	103.3	-1.3	-1.9	-0.2	0.6	-2.4	-0.7	0.1
51640_3	111.3	-4.7	-8.5	-1.1	3.8	-7.9	-2.8	2.1

The water balance for the Mid-Loddon GMU is presented in Table 6-8, Figure 6-11 and Figure 6-12, and refers to all aquifers including the Shepparton Formation. Rainfall recharge is the dominant recharge mechanism and consequently the impacts of climate variability are quite pronounced. A comparison of the without-development scenario and Scenario A indicates that groundwater pumped from the GMU is accounted for by increased river losses (32 percent), decreased evapotranspiration (34 percent) and decreased groundwater flows out of the GMU (34 percent).

Table 6-8. Groundwater balance for the Mid-Loddon GMU

Groundwater balance	Without development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflows									
Total diffuse recharge	25.1	25.1	19.2	17.1	24.3	28.3	17.1	24.3	28.3
Head dependent boundary	0	0	0	0	0	0	0	0	0
River recharge	3.4	6.2	6.9	7.4	6.2	5.4	7.5	6.5	5.7
Lateral flow	2.3	3.3	3.3	3.4	3.3	3.2	3.5	3.4	3.4
Total	**30.8**	**34.6**	**29.4**	**27.9**	**33.8**	**36.9**	**28.1**	**34.2**	**37.4**
Outflows									
Extraction	0	14.3	13.1	13	14.2	14.4	13.5	15.1	15.6
Head dependent boundaries	0	0	0	0	0	0	0	0	0
Lateral flow	16.7	12.9	11.2	10.2	12.6	13.9	10.2	12.4	13.5
Evapotranspiration	10.4	5.5	3.9	3.5	5.2	6.6	3.5	5.1	6.4
To rivers	3.6	1.8	1.3	1.1	1.8	2.1	0.9	1.7	2
Total	**30.7**	**34.5**	**29.5**	**27.8**	**33.8**	**37**	**28.1**	**34.3**	**37.5**

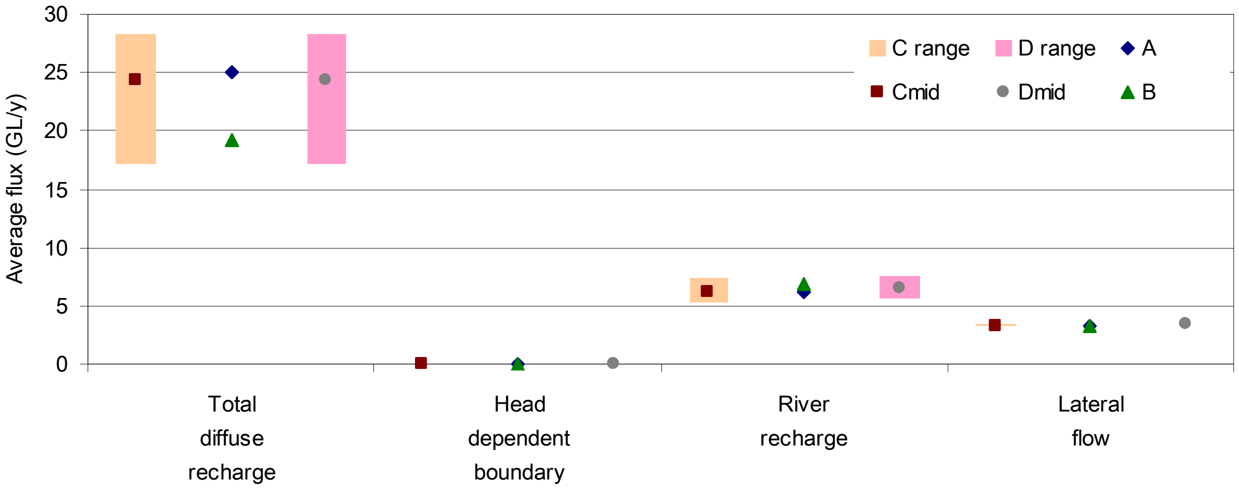


Figure 6-11 Groundwater inflows into the Mid-Loddon GMU under scenarios A, B C and D

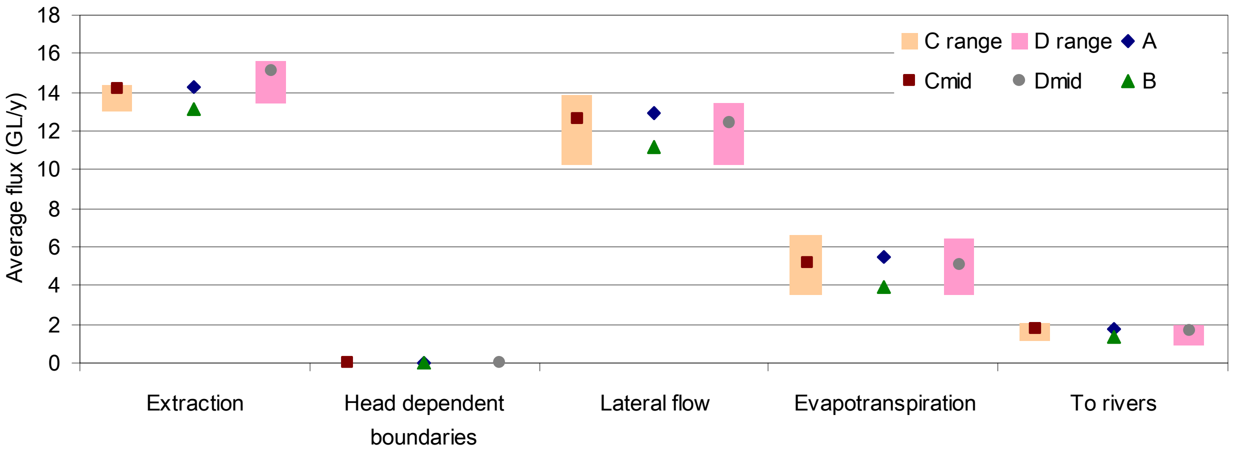


Figure 6-12 Groundwater outflows from the Mid-Loddon GMU under scenarios A, B C and D

The groundwater indicators for the Mid-Loddon GMU are listed in Table 6-9. Groundwater security is high under all scenarios. The Environmental indicator is 0.33 under Scenario A, and ranges between 0.31 and 0.39 under the various scenarios. An increase in this value towards 1 represents a decrease of water for environmental purposes.

The Drought Indicator shows large drawdown values in some of the indicator bores in the area of major groundwater extraction with falls of up to 6.6 m under Scenario Ddry.

Figure 6-13 shows the annual net river loss for the Mid-Loddon GMU under Scenario A over the 111 years of simulation. The average river loss to groundwater is 4.4 GL/year. There was an average flow of groundwater to the rivers of 0.2 GL/year under without-development conditions.

Table 6-9. Groundwater indicators for the Mid-Loddon 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							
	0.33	0.36	0.38	0.33	0.31	0.39	0.35	0.33
Drought indicator	change (m) from Baseline							
36416_1	-2.0	-2.4	-1.2	-0.5	-2.6	-1.4	-0.8	-1.0
66867_1	-3.8	-4.9	-1.8	-0.7	-5.6	-2.3	-1.1	-1.6
67956_1	-2.4	-2.9	-1.4	-0.7	-3.4	-1.8	-1.1	-1.2
138651_1	-0.4	-0.4	-0.3	-0.3	-0.4	-0.3	-0.3	-0.3
36416_2	-2.4	-2.9	-1.4	-0.6	-3.2	-1.7	-0.9	-1.2
66867_2	-4.1	-5.2	-2.1	-0.8	-5.9	-2.6	-1.3	-1.8
67956_2	-2.4	-2.9	-1.4	-0.7	-3.5	-1.9	-1.2	-1.2
138651_2	-2.3	-2.4	-2.0	-1.8	-2.4	-2.0	-1.8	-2.0
51640_2	-7.7	-11.4	-4.4	-0.3	-10.8	-6.1	-2.4	-3.7
36416_3	-3.8	-4.7	-2.3	-1.1	-5.3	-2.8	-1.7	-2.0
66867_3	-4.4	-5.5	-2.5	-1.1	-6.2	-3.1	-1.7	-2.2
67956_3	-2.4	-2.9	-1.5	-0.8	-3.6	-2.1	-1.4	-1.3
51640_3	-7.9	-11.4	-4.8	-0.4	-10.9	-6.6	-2.4	-3.8

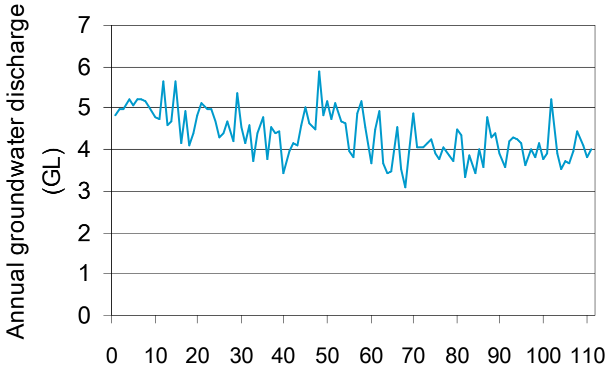


Figure 6-13. Annual net river loss for the Mid-Loddon GMU in the A scenario over 111 years

6.7 Water balances for groundwater management units not modelled and unincorporated ares

The Upper Loddon, Spring Hill and the proposed Avoca GMUs are not covered by the Southern Riverine Plains groundwater model and were analysed using a simple water balance approach. These GMUs contain a relatively small proportion of regional groundwater extraction. The water balance covers an area of approximately 2300 km^2. It covers the proposed Avoca GMU in the Avoca catchment (670 km^2) and the upper part of the Loddon catchment (encompassing approximately 2300 km^2), upstream of the Mid-Loddon GMU. The water balance covers the Spring Hill GMU and part of the Upper Loddon GMU in the Loddon catchment.

6.7.1 Groundwater extraction

Estimated groundwater extraction from the proposed Avoca GMU, and from the southern portion of the Loddon catchment (including the Upper Loddon and Spring Hill GMUs) is shown in Table 6-10. The estimates cover groundwater use from unmetered bores and include a nominal usage of 2 ML/year for stock and domestic bores. The proposed Avoca GMU is sourced principally from the Avoca Deep Lead aquifer.

The Newer Volcanic basalts support most of the groundwater development within the southern parts of the Loddon catchment. Some extraction comes from the Ordovician sediments and granite (hillside colluvium or granitic sandy detritus). Total 2004/05 groundwater use in the region outside of the Mid-Loddon GMU is estimated to be 11.2 GL/year.

Table 6-10. Estimated groundwater extraction for southern parts of the Loddon-Avoca region

Code	Name	Licenced extraction (2004/05)	Stock and domestic (2004/2005)	Current extraction (2004/05)	Total entitlement	Future extraction (2030)
				GL/y		
V55	Upper Loddon WSPA	6.21	0.46	6.67	13.04	13.23
V56	Spring Hill WSPA	1.37	0.27	1.64	4.91	3.44
–	Proposed Avoca GMA	0.78	0.20	0.98	1.34	1.52
	Unincorporated Areas	1.27	0.67	1.94	2.84	3.18
	TOTAL	**9.63**	**1.60**	**11.23**	**22.13**	**21.37**

Note: Unincorporated areas include a small part of the Bungaree WSPA, which mostly lies outside the MDB

6.7.2 Future groundwater extraction

Table 6-10 also include estimates of projected (2030) groundwater extraction. Urban and stock and domestic use were assumed not increase above current levels. All other use (principally irrigation) is assumed to increase by 3.65 percent per year until it reached the current entitlement volume. The rate of increase is equal to the mean annual increase in water usage across Australia between 1983/84 and 1996/97 (Land & Water, 2000). Therefore all other use would be equal to the current entitlement volume by 2030. Total 2030 groundwater use (outside of the Mid-Loddon GMU) is estimated to be 21.3 GL/year.

6.7.3 Estimates of rainfall recharge

Rainfall recharge is the largest factor within the water balance and is the focus of this assessment.

Recharge to the Avoca Deep Lead occurs via vertical leakage from overlying aquifers, the direct infiltration of rainfall (where the Deep Lead is exposed in the highland areas) and groundwater inflows from outside the GMU. Recharge to the Deep Lead aquifer was estimated to range from 2 to 3 GL/year (SKM, 2005) and is assumed to be 2.5 GL/year for the purpose of this assessment.

Recharge to the Spring Hill GMU was estimated by SKM (1998) to be 2 percent annual rainfall recharge as there is an extensive deeply weathered soil profile that restricts infiltration of rainwater over much of the area. Recharge areas that incorporated volcanic vents were assigned a 7 percent annual rainfall recharge rate. Total recharge to the Spring Hill GMU was thus estimated at 5.1 GL/year.

The Upper Loddon GMU was formed by amalgamation of Zone 2 of the Moolort GMU, and the Ascot GMU. Zone 2 of the Moolort GMU had previously been assigned a recharge rate of 3.8 GL/year (SKM, 1998b). A recharge rate of

8.2 GL/year had been estimated for the Ascot GMU using the hydrograph fluctuation method (SKM, 1998c). Recharge to the Upper Loddon GMU is thus estimated to be 11.9 GL/year.

The unincorporated area of the Loddon catchment mainly comprises forested Ordovician bedrock and cleared unconsolidated alluvial sediments. Recharge to the forested bedrock area is estimated to be 1 percent of annual rainfall, and recharge to the unconsolidated alluvial sediments is estimated to be 5 percent of annual rainfall. Total recharge to the unincorporated area is therefore estimated to be 46 GL/year. The total recharge to the region is estimated to be 65 GL/year (Table 6-11).

The impact of each scenario on total annual recharge (Table 6-11) was determined via RSFs (Section 6.4) applied to the Scenario A volume of recharge to the system. The main groundwater indicator used is the ratio of extraction to rainfall recharge (E/R). This is used an indication of the potential level of stress within an aquifer under each scenario under the following level of development classifications: low (0.0–0.3), medium (0.3–0.7), high (0.7–1.0) and very high (>1.0).

Table 6-12 shows that the E/R ratio for current (2004/05) groundwater extraction (Scenario A) for the low priority GMUs (including the unincorporated area) is ‘low’ (0.17 percent)).

Scenario B would result only in a 5 percent increase in the total E/R ratio due to a decline in the annual recharge and the development classification would also remain low under Scenario Cmid and Cdry (E/R ratio increase of 1 and 10 percent respectively). Scenario Cwet would result in a 1 percent decrease in the total E/R ratio due to higher rainfall. Scenario D incorporates reduced recharge and increased groundwater extraction and the Dwet, Dmid and Ddry scenarios lead to increases of 13, 16 and 34 percent respectively. The development classification would therefore move to medium under Scenario D.

The Spring Hill GMU is currently classified medium (E/R ratio 0.32) and would move to high under Scenario Dmid (E/R 0.7) and very high (E/R ratio 1.07) under Scenario Ddry. Groundwater levels are already declining in the Spring Hill GMU and the rate of decline will increase with increased extraction. The level of development in the Upper Loddon GMU would move from medium (E/R ratio 0.56) under Scenario A to very high (E/R 1.13) under Scenario Dmid. The level of development in the proposed Avoca GMU would move from medium to high under Scenarios Dmid and Ddry.

Extraction to recharge ratios of more than 1.0 are possible within small areas as pumping can be sustained by groundwater inflows from adjacent areas. The ratios are not sustainable across larger regions.

Table 6-11. Recharge under Scenario A, and scaled recharge under scenarios B, C and D

Code	Name	Recharge	Scaled Recharge						
		A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
		GL/y							
V55	Upper Loddon WSPA	12	9	8	12	13	8	12	13
V56	Spring Hill WSPA	5	4	3	5	6	3	5	6
-	Proposed Avoca GMU	3	2	2	2	3	2	2	3
-	Unincorporated Areas	46	36	29	45	50	29	45	50
	Total	**65**	**51**	**42**	**64**	**72**	**42**	**64**	**72**
	Recharge Scaling Factor	-	0.22	0.36	0.02	-0.10	0.36	0.02	-0.10

Table 6-12. Extraction to recharge ratios for groundwater management units not modelled under scenarios A, B, C and D

Code	Name	E/R							
		A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
V55	Upper Loddon WSPA	0.56	0.72	0.87	0.57	0.51	1.73	1.13	1.01
V56	Spring Hill WSPA	0.32	0.41	0.51	0.33	0.29	1.07	0.7	0.62
	Proposed Avoca GMU	0.39	0.5	0.61	0.4	0.35	0.95	0.62	0.55
	Unincorporated Areas	0.04	0.05	0.07	0.04	0.04	0.11	0.07	0.06
	Total	**0.17**	**0.22**	**0.27**	**0.18**	**0.16**	**0.51**	**0.33**	**0.30**

Note: Groundwater extraction includes both licensed extraction and stock and domestic use.

6.7.4 Impact of extraction on streamflow

The Avoca River is ephemeral and is losing over most of its length. Although partly confined, the Deep Lead aquifer is highly connected to the overlying aquifers. A reduction in pressure in the Deep Lead aquifer as a result of groundwater pumping may increase leakage from the shallower aquifers and increase the hydraulic gradient between the river and the groundwater. This will increase the rate of loss from the Avoca River and may cause the river to remain dry for longer periods of time. The length of river that is ephemeral is also likely to increase with increased groundwater extraction.

The Loddon River is a gaining stream within the upper part of the catchment. The Loddon River was perennial historically but over the last decade it tended to run dry during the low rainfall summer months. This is likely the result of lower than average rainfall over the last decade and increased groundwater extraction.

The impact of 2030 groundwater extraction on Loddon River average annual and low flows was analysed at Newstead. The average river flow over the last decade is 29 GL/year and the average flow during the low-flow period (that is, average flow for the period March to May over the last decade) is around 176 ML/month. The analysis relates to the increase in groundwater extraction of approximately 10 GL/year under Scenario D.

Not all of the increase in groundwater extraction under Scenario D is likely to impact the Loddon River since a large portion of extraction increase would occur on the basalt plateau to the south of the catchment and in other highland areas, a distance away from the Loddon River. Around 20 percent of the extraction increase (2 GL) could influence flow of the Loddon River at Newstead as this extraction will occur within 1 to 5 km of the river. Streamflow of the Loddon River is approximately 528 ML over the three-month low-flow period and groundwater extraction over this same period is approximately 500 ML.

The portion of groundwater extraction derived from streamflow has been estimated based on an analytical model developed by Glover and Balmer (1954). The results are shown in Figure 6-14. An average aquifer transmissivity of 100 m^2/day and storage coefficient of 0.05 was assumed. The impact of groundwater pumping on average annual flow is minor (less than 10 percent streamflow depleted after more than 100 years of pumping), although the effect on summer low streamflow conditions is much more significant. Groundwater extraction after 100 years may lead to the depletion of around 85 percent of summer streamflow at Newstead. This analysis is simplistic and based on a number of assumptions but it indicates that additional pumping close to the river will have a significant impact on summer streamflow within a relatively short timeframe. If additional developments are not permitted close to the river, then the time scale for groundwater extraction to impact the river would be much longer.

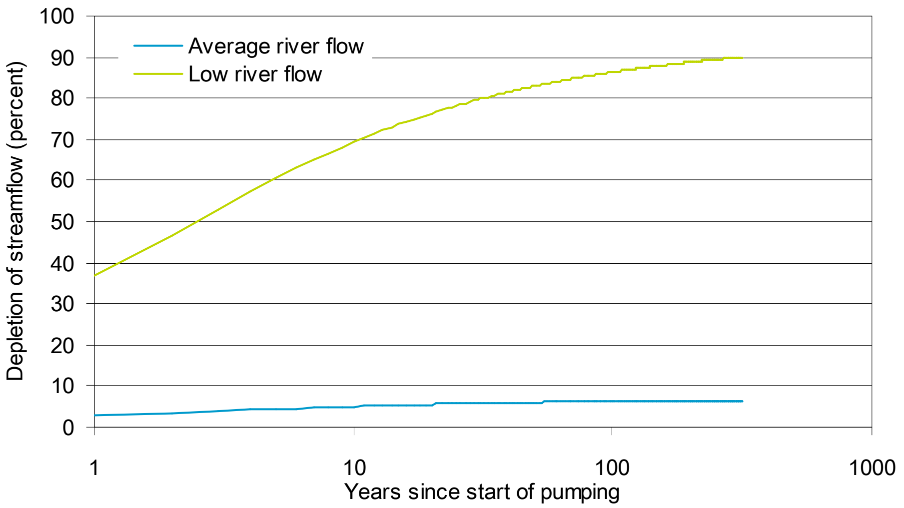


Figure 6-14. Impact of increased groundwater extraction on flow of the Loddon River at Newstead under Scenario D

6.8 Conjunctive water use indicators

Groundwater can provide a secure water source during drier periods. Irrigators may elect to change from surface water to groundwater during years of low flow where such 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 6-13 shows ratios of groundwater use to total water use for years of lowest surface water diversions up to a year with average flow. Groundwater can be from 9 to 14 percent of total diversions under current conditions. This increases to 13 to 66 percent under Scenario Cdry and to 9 to 17 percent under Scenario Cwet. There is expected to be a doubling in groundwater extractions under Scenario D with an 18 percent increase in the average use and a 43 percent increase in the lowest 1-year period under Scenario Dmid. Groundwater thus forms a minor source of water for the region under average flow years but is more important in drier years but not the dominant source of water.

Table 6-13. Groundwater use as a percentage of total water use in the Loddon-Avoca region in 1-year, 3-year and 5-year periods of lowest surface water diversions and the average year under scenarios A, B, C and D

	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Lowest 1-year period	14%	57%	66%	27%	17%	78%	43%	30%
Lowest 3-year period	12%	23%	27%	15%	13%	42%	25%	23%
Lowest 5-year period	12%	21%	24%	14%	12%	39%	24%	22%
Average	9%	12%	13%	10%	9%	24%	18%	17%

6.9 Discussion of key findings

Groundwater provides 9 percent of the total water diverted with this increasing to 14 percent in drier years. This percentage is likely to increase under future scenarios. Most groundwater extraction occurs from the Mid-Loddon and Upper-Loddon GMUs. Groundwater modelling suggests that most of the extraction from the Mid-Loddon GMU has been sourced equally from: a reduction in river flow, decreased evapotranspiration, and decreased groundwater flows to adjacent areas. In the Upper Loddon GMU, groundwater use is currently 56 percent of recharge, and this is predicted to increase to over 100 percent by 2030. This high rate of extraction will draw water into the GMU from adjacent areas.

6.10 References

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7 Environment

This chapter presents the environmental assessments undertaken for the Loddon-Avoca region. It has four sections:

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

7.1 Summary

7.1.1 Issues and observations

- Assessment of the environmental implications of changes in water availability is largely beyond the terms of reference (Chapter 1) of this project. The exception is reporting against environmental water allocations and quantified environmental flow rules specified in water sharing plans. Otherwise, environmental assessments form a very small part of the project.
- The Loddon system is highly regulated with large volumes of water extracted and large volumes transferred from other regions.
- Environmental flows in the Loddon-Avoca region are provided via a number of regulatory provisions.
- Changes in winter–spring low flows that maintain native fish habitat in the lower Loddon River and small winter floods that are important for riparian and floodplain ecosystems along the lower Loddon River are assessed.

7.1.2 Key messages

- Water resources development has decreased the frequency and magnitude of small winter floods that benefit riparian and floodplain ecosystems along the lower Loddon River. The average period between small winter floods has increased from around 10 months to 18 months and the average annual flooding volume of medium winter floods has halved. These changes are likely to have had significant ecological impacts. Additionally, the percentage of months with undesirably low flows in the lower Loddon River during the winter–spring period has increased from 21 to 31 percent. This has degraded native fish habitat with consequences for native fish populations.
- Under a long-term continuation of the recent (1997 to 2006) climate the average period between small winter floods would increase by 43 percent and the average volume of these floods would decrease by 65 percent. The total flooding volume would be thus 75 percent lower or 13 percent of the without-development value. This climate would lead to undesirably low flow conditions in 58 percent of winter–spring months. These changes would be highly likely to degrade the ecology of the lower Loddon River.
- Under the best estimate 2030 climate the average period between small winter floods would not change greatly. However, floods would be smaller such that the average annual volume would be reduced by 32 percent. This climate would lead to undesirably low flow conditions in 37 percent of winter–spring months.
- The dry extreme 2030 climate would lead to conditions similar to a continuation of the recent climate, while the wet extreme 2030 climate would lead to conditions reasonably similar to those under the historical climate and current development.
- The small projected increases in farm dam capacity and groundwater extraction by 2030 would have a minimal additional impact on environmentally important aspects of the flow regime of the lower Loddon River.

7.1.3 Uncertainty

The main uncertainties involving analysis and reporting include:

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

7.2 Approach

This chapter focuses on the specific rules that apply to the provision of environmental water in the Loddon-Avoca region and on the assessment of hydrological indicators defined by prior studies for key environmental assets. A broader description of the catchment, water resources and important environmental assets is provided in Chapter 2.

7.2.1 Summary of environmental flow rules

Formal rights to water for environmental use were established under the Victorian Water (Resources Management) Act 2005 that provides for water to be delivered under Environmental Water Reserves (the environment's legally protected share of water in both rivers and groundwater systems) for designated river basins across the state. This includes the Loddon River Environmental Reserve held by the Minister for the Environment and passing flows released as a condition of consumptive bulk entitlements held by Central Highlands Water and Goulburn-Murray Water and all other water in the catchment not allocated for consumptive use. The Environmental Water Reserve for the Avoca Basin simply includes passing flows released as a condition of consumptive bulk entitlements held by Central Highlands Water and all other water in the catchment not allocated for consumptive use. No basic rights are quantified in water management plans, but diversions are allowed under the Water Act 1989. There is also harvesting of runoff water in farm dams (DSE, 2007).

There are many passing flow requirements in the Loddon-Avoca region including those described in Bulk Entitlement (Loddon River Environmental Reserve) Order 2005 (Victorian Government 2005) and listed in Table 7-1.

Table 7-1. Passing flow requirements in the Loddon-Avoca region

Timing	Passing flow
Loddon River, between Serpentine Weir (Cairn Curran Dam) and Loddon Weir	
November to April, inclusive	the lesser of 19 ML/day or the natural flow, and three freshes of 61 ML/day for seven consecutive days
May to October, inclusive	if the combined storage volume in Cairn Curran and Tullaroop reservoirs is • > 60,000 ML, the authority must pass 61 ML/day • ≤ 60,000 ML, the authority must pass 19 ML/day.
Loddon River, between Loddon Weir and Kerang Weir	
January and February	one fresh of 50 ML/day (plus flow equal to loss) for 14 consecutive days
November to April, inclusive	cyclical over two weeks, a rise from 7 to 12 ML/day in one week followed by fall from 12 to 7 ML/day in the next week
May to October, inclusive	if the combined storage volume in Cairn Curran and Tullaroop reservoirs is • greater than 60,000 ML, the authority must pass 61 ML/day (plus flow equal to loss) • less than or equal to 60,000 ML, the authority must pass 10 ML/day (plus flow equal to loss)

7.2.2 Environmental assets and indicators

The Kerang Wetlands – associated with the Loddon River – are recognised nationally and internationally as important wetlands. The hydrology of the lakes is complex due to many factors including diversions, levee banks, localised drainage, use in the regional water supply system, and Murray River influences (LREFSP, 2002a). Only some of the lakes are directly affected by Loddon River flows, but the contributions have not been identified (LREFSP, 2002a). Consequently, hydrological indicators for assessing the water regime of the Kerang Wetlands are not available and the wetlands were not assessed in this project.

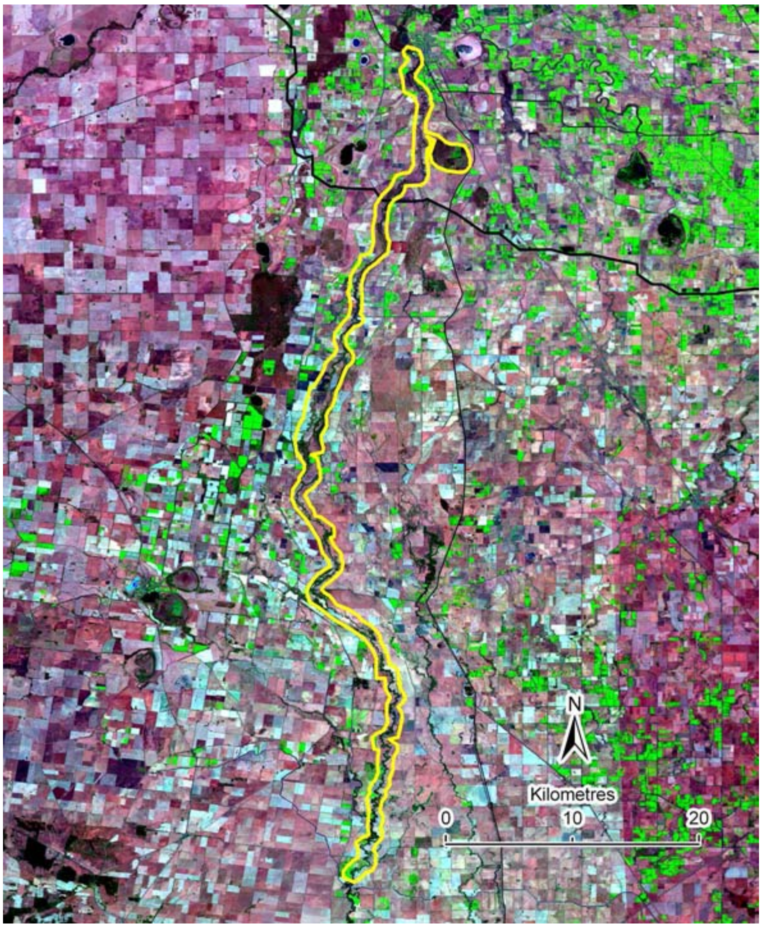


Figure 7-1. Satellite image of the lower Loddon River.
The yellow polygon indicates the extent of Reach 4 as defined in LREFSP (2002b)

The Victorian Department of Sustainability and Environment (DSE) recommended assessment of summer low flows in 'Reach 4' of the lower Loddon River based on the advice in LREFSP (2002b). The lower Loddon River extends from Loddon Weir to Kerang Weir (Figure 7-1). The capacity of the Loddon River channel decreases as it progresses downstream (LREFSP, 2002a). The channel capacity of Reach 4 is approximately 400 ML/day (compared with up to 7300 ML/day for reaches upstream (LREFSP, 2002a). Irrigation flows are diverted from the river at Loddon Weir. Consequently the flow regime in Reach 4 is considerably altered from natural conditions (LREFSP, 2002a).

According to LREFSP (2002a, b) Reach 4 has:

- increased summer low flows (compared to natural)
- reduced median flows year round (compared to natural)
- variable water quality, with some parameters such as total phosphorus, elevated turbidity and salinity
- river bed siltation and artificial channelisation
- potentially high fish diversity.

At least eight species of native fish are expected to be found in this reach – Silver Perch (*Bidyanus bidyanus*), Western Carp Gudgeon *(Hypseleotris klunzingeri)*, Murray Cod (*Maccullochella peelii peelii*), Golden Perch (*Macquaria ambigua*), Murray Rainbowfish (*Melanotanenia fluviatilis*), Bony Bream (*Nematolosa erebi*), Flat-headed Gudgeon (*Philypnodon grandiceps*) and Australian Smelt (*Retropinna semoni*) (LREFSP, 2002b).

The summer low flow indicator recommended by DSE was intended to assess how often flows fall too low to provide the cues for fish movement in the lower Loddon River. However, analyses of modelled flows suggest that flow regulation has in fact increased summer low flows above the levels of without-development conditions and that the flow cues for fish movement occur more frequently under with-development conditions. It is noted in this context that the ability of the river model to model low flows is assessed as poor (Chapter 5). An alternative low flow indicator from LREFSP (2002b) to assess winter–spring low flows (which have been reduced by water resource development) was therefore used. LREFSP (2002b) indicates that during May to October (inclusive) a minimum flow level of 61 ML/day is required to maintain native fish habitat. Additionally, LREFSP (2002b) recommended that a small flood of more than 400 ML/day (channel capacity flow) for 7 days, and for 2 periods, July to October (inclusive) is required to maintain riparian and floodplain ecosystems and geomorphic processes.

The selected flow measures were converted to equivalent monthly flows to determine flow regime changes under different scenarios as the river model used for this region (Chapter 4) uses a monthly time step. Determination of the monthly equivalent flow to achieve an event which exceeds 400 ML/day for at least seven days is complicated. Daily streamflow data (1946 to 2006) for the Appin South gauge were used to first identify months in which an event (400 ML/day for seven days) occurred. These daily data were then aggregated to monthly totals and a monthly equivalent threshold was determined by minimising the average error between counting the correct number of event months. This predicted an event month from monthly data when none occurred based on daily data and did not predict an event month from monthly data when one did occur according to daily data. The average error for a threshold of 8100 ML/month across these three criteria was 4.6 percent. No criteria had an error greater than 7 percent. A monthly threshold of 8100 ML/day was adopted as an equivalent threshold to 400 ML/day for seven days. The adopted threshold (8100 ML/month) is much greater than simply multiplying 400 ML/day by seven days. This is because, for those months where a medium sized event occurs, the flow is likely to peak much higher than 400 ML/day and the high flow recession may extend for several days at a level below 400 ML/day but still be high. The minimum daily flow threshold (61 ML/day) was simply multiplied by 30 to provide a minimum monthly flow threshold of 1830 ML/month. The indicators are defined in Table 7-2.

Table 7-2. Definition of Loddon River environmental indicators

Loddon River Indicators	Description
Average period between small winter flood events	Average period (years) between events of 8100 ML/month during Jul–Oct at Appin South
Maximum period between small winter flood events	Maximum period (years) between events of 8100 ML/month during Jul–Oct at Appin South
Average volume of small winter floods per event	Average volume (GL) per event above 8100 ML/month during Jul–Oct at Appin South
Average volume of small winter floods per year	Average volume (GL) per year above 8100 ML/month during Jul–Oct at Appin South
Percentage of months (Oct–May) with undesirably low flow events	Percentage of months (Oct–May) where the flow at Appin South during May–October (inclusive) falls below 1830 ML/month

7.3 Results

The projected changes in the environmental indicators are listed for the various scenarios in Table 7-3 using the outputs of the REALM river model for the Loddon-Avoca region which is described in Chapter 4.

Table 7-3. Environmental indicator values under scenarios P and A, and percentage change (from Scenario A) in indicator values under scenarios B, C and D

	P	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	years		percent change from Scenario A						
Average period between small winter flood events	0.84	1.53	43%	38%	5%	4%	44%	9%	6%
Maximum period between small winter flood events	2.7	6.7	30%	30%	0%	0%	30%	0%	0%
	GL								
Average volume of small winter floods per event	150	126	-65%	-62%	-30%	-7%	-61%	-29%	-6%
Average volume of small winter floods per year	136	69	-75%	-71%	-32%	-10%	-72%	-34%	-10%
	percent								
Percentage of months (May-Oct) with undesirably low flows	21%	31%	58%	59%	37%	34%	60%	38%	36%

7.4 Discussion of key findings

Small winter floods

Water resources development has increased the average period between small winter floods by about 8 months and has increased the maximum period between events by 4 years. The average event volume has decreased substantially by 24 GL and the average annual event volume is about half of what it would have been under without-development conditions. LREFSP (2002b) demonstrated flows of 400 ML/day occurred on nearly 30 percent of days under without-development conditions but reduced to about 13 percent of days under current conditions. These changes are likely to adversely affect a range of aquatic ecosystem and river geomorphic processes.

Scenario B would increase the average period between events by 43 percent and the maximum period between events by 30 percent. The average event volume of these less frequent events would be decreased by 65 percent and the average annual event volumes would be decreased by 75 percent. Such changes are likely to have major impacts on the ecology of the lower Loddon River.

Under Scenario Cmid there would be a 5 percent increase in the average period between events but no increase in the maximum period between events. However the average flood volume of these events and average annual volume would be reduced by 30 and 32 percent respectively. It is likely these changes would have substantial adverse ecological consequences. Scenario Cdry would be similar to Scenario B and would lead to a 38 percent increase in the average period between events and increase the maximum period between events by 30 percent. The average and annual volumes of these events would also be reduced substantially. Such changes are likely to have major impacts on the ecology of the lower Loddon River. Under Scenario Cwet, the average period and maximum period between events would not change signifcantly. The excess event and excess annual volumes would be reduced slightly. It is likely that these changes would have some adverse ecological consequences.

The small projected increases in farm dam capacity and groundwater extraction under Scenario D would have a minimal additional impact on the frequencies and volumes of small Winter floods.

Winter–spring low flows

Water resource development has increase the percentage of months during October to May in which flow falls to undesirably low levels by 10 percent. Under Scenario B, the percentage of months during October to May in which undesirably low flows occur would increase from 31 percent to 58 percent. Such a change would be likely to have significant impacts on the fish populations of the lower Loddon River as habitat conditions would be seriously affected.

Under Scenario Cmid, 37 percent of the October–May months would experience undesirably low flows, while conditions under Scenario Cdry would be similar those under Scenario B. Under Scenario Cwet, the percentage of months with undesirably low flow would only increase slightly.

The small projected increases in farm dam capacity and groundwater development under Scenario D would have a very small additional impact on the percentage of months with undesirably low flow.

7.5 References

DSE (2007) State Water Report 2005/06. A statement of Victorian water resources. Department of Sustainability and Environment, Victoria. Melbourne.

LREFSP (2002a) Environmental Flow Determination of the Loddon River Catchment: Issues paper. Unpublished report to the North Central Catchment Management Authority and Department of Natural Resources and Environment by the Loddon River Environmental Flows Scientific Panel.

LREFSP (2002b) Environmental Flow Determination of the Loddon River Catchment: Final Report. Unpublished report to the North Central Catchment Management Authority and Department of Natural Resources and Environment by the Loddon River Environmental Flows Scientific Panel.

Victorian Government (2005) Bulk Entitlement (Loddon River Environmental Reserve) Order 2005, Gazette No. S42, page 2663. Available at: http://www.gazette.vic.gov.au/Gazettes2005/GG2005G046.pdf

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					
4072023	5710	392	1274	13	3%	14%	-15%	-36%	-4%	-13%	3%	7%
4072112	918	519	1182	28	5%	5%	-18%	-44%	-4%	-15%	-1%	-5%
4072132	576	545	1164	31	6%	3%	-18%	-53%	-4%	-19%	-1%	-5%
4072133	8	672	1107	63	9%	0%	-18%	-55%	-4%	-21%	-1%	-6%
4072134	68	672	1107	63	9%	1%	-18%	-55%	-4%	-21%	-1%	-6%
4072135	10	672	1107	63	9%	0%	-18%	-55%	-4%	-21%	-1%	-6%
4072360	1654	449	1244	14	3%	5%	-18%	-42%	-4%	-13%	-1%	-3%
4072401	319	486	1201	22	4%	1%	-18%	-44%	-4%	-14%	-1%	-5%
4072411	1629	665	1141	61	9%	19%	-18%	-52%	-4%	-19%	-1%	-5%
4072431	1629	453	1232	15	3%	5%	-18%	-47%	-4%	-17%	-1%	-5%
4072440	718	664	1115	67	10%	9%	-18%	-52%	-4%	-20%	-1%	-6%
4082000	2688	508	1199	45	9%	23%	-18%	-44%	-4%	-15%	-1%	-4%
4082031	745	384	1267	12	3%	2%	-15%	-35%	-4%	-13%	4%	7%
4082033	7134	330	1310	7	2%	10%	-12%	-27%	-4%	-12%	7%	18%
4082092	531	346	1300	8	2%	1%	-12%	-28%	-4%	-13%	7%	17%
4082093	582	400	1265	14	3%	2%	-15%	-37%	-4%	-14%	3%	5%
	24918	**430**	**1251**	**21**	**5%**	**100%**	**-16%**	**-43%%**	**-4%**	**-16%**	**2%**	**0%**

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

Modelling catchment	A runoff	Plantations increase	Farm dam increase		Ddry runoff	Dmid runoff	Dwet runoff
	mm	ha	ML	ML/km^2	percent change from scenario A		
4072023	13	0	441	0.1	-36%	-14%	6%
4072112	28	0	152	0.2	-45%	-16%	-5%
4072132	31	0	148	0.3	-53%	-20%	-6%
4072133	63	0	1	0.1	-55%	-22%	-6%
4072134	63	0	7	0.1	-55%	-22%	-6%
4072135	63	0	4	0.4	-55%	-22%	-6%
4072360	14	0	976	0.6	-44%	-17%	-7%
4072401	22	0	77	0.2	-45%	-16%	-6%
4072411	61	0	683	0.4	-52%	-20%	-6%
4072431	15	0	97	0.1	-48%	-17%	-5%
4072440	67	0	337	0.5	-53%	-21%	-7%
4082000	45	0	149	0.1	-44%	-16%	-5%
4082031	12	0	0	0.0	-35%	-13%	7%
4082033	7	0	0	0.0	-27%	-12%	18%
4082092	8	0	0	0.0	-28%	-13%	17%
4082093	14	0	0	0.0	-37%	-14%	5%
	21	**0**	**3071**	**0.1**	**-44%**	**-17%**	**-1%**

Appendix B River modelling reach mass balances

Reach 1 – Tributaries upstream of Cairn Curran Reservoir to Cairn Curran Reservoir Outlet

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	-0.8	-3%	0%	-1%	-3%	0%	-1%	-3%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	107.7	-50%	-5%	-19%	-52%	-6%	-20%	-52%
Transfers from other subcatchments	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**107.7**	**-50%**	**-5%**	**-19%**	**-52%**	**-6%**	**-20%**	**-52%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**107.7**	**-50%**	**-5%**	**-19%**	**-52%**	**-6%**	**-20%**	**-52%**
Diversions								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	0.0	0%	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%	0%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Channel / pipe loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End-of-system outflow								
To d/s Loddon (Reach 3)	101.3	-50%	-6%	-20%	-53%	-7%	-21%	-53%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**101.3**	**-50%**	**-6%**	**-20%**	**-53%**	**-7%**	**-21%**	**-53%**
Net evaporation*	7.2	-38%	3%	-5%	-30%	2%	-5%	-33%
Sub-total	**108.5**	**-50%**	**-5%**	**-19%**	**-51%**	**-6%**	**-20%**	**-52%**
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

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

Reach 2 - Tullaroop Creek to downstream Tullaroop Reservoir

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	-0.3	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	54.8	-51%	-6%	-20%	-52%	-7%	-21%	-53%
Transfers from other subcatchments	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**54.8**	**-51%**	**-6%**	**-20%**	**-52%**	**-7%**	**-21%**	**-53%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**54.8**	**-51%**	**-6%**	**-20%**	**-52%**	**-7%**	**-21%**	**-53%**
Diversion								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	2.1	0%	3%	2%	4%	3%	2%	4%
Stock and domestic	2.1	0%	3%	2%	4%	3%	2%	4%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**2.1**	**0%**	**3%**	**2%**	**4%**	**3%**	**2%**	**4%**
Channel / pipe loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**2.1**	**0%**	**3%**	**2%**	**4%**	**3%**	**2%**	**4%**
Outflows								
End-of-system outflow								
To d/s Loddon (Reach 3)	43.0	-53%	-7%	-21%	-56%	-8%	-22%	-57%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**43.0**	**-53%**	**-7%**	**-21%**	**-56%**	**-8%**	**-22%**	**-57%**
Net evaporation*	3.3	-23%	5%	-1%	-9%	5%	-1%	-10%
Sub-total	**46.2**	**-51%**	**-6%**	**-20%**	**-53%**	**-7%**	**-21%**	**-54%**
Unattributed fluxes								
River unattributed loss	6.7	-68%	-7%	-26%	-65%	-8%	-27%	-65%

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

Reach 3 - Tullaroop Creek downstream Tullaroop Reservoir plus Loddon River downstream Cairn Curran Reservoir to Loddon River downstream Laanecoorie Weir

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	0.0	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	50.9	-53%	-5%	-17%	-47%	-6%	-18%	-48%
From upstream Loddon (Reaches 1 and 2)	144.3	-51%	-6%	-20%	-54%	-7%	-21%	-54%
Sub-total	**195.1**	**-52%**	**-6%**	**-19%**	**-52%**	**-7%**	**-20%**	**-53%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**195.1**	**-52%**	**-6%**	**-19%**	**-52%**	**-7%**	**-20%**	**-53%**
Wdiversions								
Water use								
Licenced private diverters	2.4	-15%	4%	1%	-7%	3%	1%	-8%
Irrigation districts	0.0	0%	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%	0%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**2.4**	**-15%**	**4%**	**1%**	**-7%**	**3%**	**1%**	**-8%**
Channel / pipe loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**2.4**	**-15%**	**4%**	**1%**	**-7%**	**3%**	**1%**	**-8%**
Outflows								
End-of-system outflow								
To downstream Loddon (Reach 4)	185.9	-53%	-6%	-20%	-54%	-7%	-21%	-55%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub total	**185.9**	**-53%**	**-6%**	**-20%**	**-54%**	**-7%**	**-21%**	**-55%**
Net evaporation*	2.1	-15%	6%	3%	2%	5%	3%	1%
Sub-total	**188.0**	**-53%**	**-6%**	**-20%**	**-53%**	**-7%**	**-21%**	**-54%**
Unattributed fluxes								
River unattributed loss	4.8	-24%	-2%	-8%	-25%	-3%	-8%	-26%

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

Reach 4 - Loddon River downstream Laanecoorie Weir to upstream Loddon Weir (including Serpentine Creek)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	0.0	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	26.9	-60%	-5%	-17%	-47%	-5%	-17%	-48%
From u/s Loddon (Reach 3)	185.9	-53%	-6%	-20%	-54%	-7%	-21%	-55%
Sub-total	**212.7**	**-54%**	**-6%**	**-20%**	**-53%**	**-7%**	**-21%**	**-54%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**212.7**	**-54%**	**-6%**	**-20%**	**-53%**	**-7%**	**-21%**	**-54%**
Water supplied								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	11.2	-16%	3%	1%	-11%	3%	0%	-12%
Stock and domestic	6.9	-7%	-1%	-1%	-9%	-1%	-1%	-9%
Urban supply	0.3	-21%	0%	-3%	-24%	0%	-3%	-25%
Sub-total	**18.4**	**-13%**	**2%**	**0%**	**-11%**	**1%**	**0%**	**-11%**
Channel / pipe loss	0.1	-86%	-8%	-39%	-94%	-9%	-34%	-94%
Sub-total	**18.5**	**-13%**	**1%**	**0%**	**-11%**	**1%**	**0%**	**-11%**
Outflows								
End-of-system outflow								
To Serpentine floodbreaks	17.8	-88%	-11%	-37%	-83%	-13%	-40%	-84%
To d/s Loddon (Reach 5)	160.3	-58%	-7%	-22%	-58%	-8%	-23%	-58%
To Dingee	0.4	-86%	-8%	-39%	-94%	-9%	-34%	-94%
River groundwater loss*	0.1	10%	-19%	2%	18%	-11%	6%	17%
Sub-total	**178.6**	**-61%**	**-7%**	**-23%**	**-60%**	**-8%**	**-24%**	**-61%**
Net evaporation**	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**178.6**	**-61%**	**-7%**	**-23%**	**-60%**	**-8%**	**-24%**	**-61%**
Unattributed fluxes								
River unattributed loss	15.6	-21%	-2%	-5%	-22%	-3%	-5%	-23%

* Values in the row are those that were used in the river modelling. The correct value for Scenario A, to be consistent with the groundwater modelling, is 2.7 GL/year. The percentage change values for other scenarios are correct.

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

Reach 5 - Loddon River from upstream Loddon Weir to downstream Loddon Weir

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	0.0	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
From u/s Loddon (Reach 4)	160.3	-58%	-7%	-22%	-58%	-8%	-23%	-58%
Sub-total	**160.3**	**-58%**	**-7%**	**-22%**	**-58%**	**-8%**	**-23%**	**-58%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**160.3**	**-58%**	**-7%**	**-22%**	**-58%**	**-8%**	**-23%**	**-58%**
Diversions								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	0.0	0%	0%	0%	0%	0%	0%	0%
Stock and domestic	1.9	-33%	-2%	-7%	-45%	-2%	-7%	-45%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**1.9**	**-33%**	**-2%**	**-7%**	**-45%**	**-2%**	**-7%**	**-45%**
Channel / pipe loss	0.3	-33%	-2%	-7%	-45%	-2%	-7%	-45%
Sub-total	**2.2**	**-33%**	**-2%**	**-7%**	**-45%**	**-2%**	**-7%**	**-45%**
Outflows								
End-of-system outflow								
To Waranga Western Channel	66.4	-45%	-4%	-15%	-51%	-6%	-15%	-51%
To d/s Loddon (Reach 6)	91.7	-68%	-8%	-27%	-63%	-9%	-28%	-64%
River groundwater loss*	0.1	41%	-24%	5%	60%	-13%	16%	74%
Sub-total	**158.1**	**-59%**	**-7%**	**-22%**	**-58%**	**-8%**	**-23%**	**-58%**
Net evaporation**	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**158.1**	**-59%**	**-7%**	**-22%**	**-58%**	**-8%**	**-23%**	**-58%**
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

* Values in the row are those that were used in the river modelling. The correct value for Scenario A, to be consistent with the groundwater modelling, is 1.6 GL/year. The percentage change values for other scenarios are correct.

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

Reach 6 - Loddon River from downstream Loddon Weir to downstream Appin South (end-of-system)

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	0.0	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
From u/s Loddon (Reach 5)	91.7	-68%	-8%	-27%	-63%	-9%	-28%	-64%
Sub-total	**91.7**	**-68%**	**-8%**	**-27%**	**-63%**	**-9%**	**-28%**	**-64%**
River groundwater gains*	0.0	10%	19%	6%	0%	19%	4%	-7%
Sub-total	**91.7**	**-68%**	**-8%**	**-27%**	**-63%**	**-9%**	**-28%**	**-64%**
Diversions								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	0.0	0%	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%	0%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Channel / pipe loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End-of-system outflow								
To d/s Appin South (EOS)	54.0	-60%	-7%	-23%	-55%	-7%	-24%	-55%
To flood breakouts	35.8	-83%	-10%	-34%	-78%	-12%	-37%	-79%
River groundwater loss**	0.1	-37%	-12%	-15%	-31%	-12%	-15%	-28%
Sub-total	**89.8**	**-70%**	**-9%**	**-27%**	**-64%**	**-9%**	**-29%**	**-65%**
Net evaporation***	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**89.8**	**-70%**	**-9%**	**-27%**	**-64%**	**-9%**	**-29%**	**-65%**
Unattributed fluxes								
River unattributed loss	1.9	-3%	-1%	0%	-5%	-2%	0%	-6%

* Values in the row are those that were used in the river modelling. The correct value for Scenario A, to be consistent with the groundwater modelling, is 0.4 GL/ year. The percentage change values for other scenarios are correct.

** Values in the row are those that were used in the river modelling. The correct value for Scenario A, to be consistent with the groundwater modelling, is 1.8 GL/ year. The percentage change values for other scenarios are correct.

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

Reach 7 - Waranga Western Channel from downstream Rochester West off-takes to West Loddon, Boort Lake and Normanville

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	0.0	0%	0%	0%	0%	0%	0%	0%
Inflows								
Subcatchments								
Directly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
From u/s Waranga Western Channel (Campaspe Reach 5)	263.6	-24%	0%	-4%	-30%	0%	-4%	-30%
From Loddon (Reach 5)	66.4	-45%	-4%	-15%	-51%	-6%	-15%	-51%
From Serpentine Creek (Reach 4)	0.4	-86%	-8%	-39%	-94%	-9%	-34%	-94%
Sub-total	**330.4**	**-28%**	**-1%**	**-6%**	**-34%**	**-1%**	**-6%**	**-34%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**330.4**	**-28%**	**-1%**	**-6%**	**-34%**	**-1%**	**-6%**	**-34%**
Diversions								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	256.9	-29%	-1%	-6%	-35%	-1%	-6%	-35%
Stock and domestic	1.9	0%	-1%	-1%	0%	-1%	-1%	0%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**258.8**	**-29%**	**-1%**	**-6%**	**-35%**	**-1%**	**-6%**	**-35%**
Channel / pipe loss	65.3	-28%	-1%	-6%	-34%	-1%	-6%	-35%
Sub-total	**324.1**	**-29%**	**-1%**	**-6%**	**-35%**	**-1%**	**-6%**	**-35%**
Outflows								
End-of-system outflow								
To Wimmera Mallee	6.3	0%	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**6.3**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Net evaporation*	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**6.3**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Unattributed fluxes								
River unattributed loss	0.0	0%	0%	0%	0%	0%	0%	0%

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

Reach 8 - Avoca River from downstream Coonooer Bridge to upstream Kerang

	A	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A						
Storage volume								
Change over period	**-0.2**	**-1%**	**0%**	**-2%**	**-2%**	**0%**	**-2%**	**-2%**
Inflows								
Subcatchments								
Directly gauged	83.8	-48%	-4%	-15%	-44%	-4%	-15%	-44%
Indirectly gauged	0.0	0%	0%	0%	0%	0%	0%	0%
From u/s	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**83.8**	**-48%**	**-4%**	**-15%**	**-44%**	**-4%**	**-15%**	**-44%**
River groundwater gains	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**83.8**	**-48%**	**-4%**	**-15%**	**-44%**	**-4%**	**-15%**	**-44%**
Diversions								
Water use								
Licenced private diverters	0.0	0%	0%	0%	0%	0%	0%	0%
Irrigation districts	0.0	0%	0%	0%	0%	0%	0%	0%
Stock and domestic	0.0	0%	0%	0%	0%	0%	0%	0%
Urban supply	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Channel / pipe loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End-of-system outflow								
To Kerang	25.4	-80%	4%	-23%	-59%	4%	-23%	-59%
River groundwater loss	0.0	0%	0%	0%	0%	0%	0%	0%
Sub-total	**25.4**	**-80%**	**4%**	**-23%**	**-59%**	**4%**	**-23%**	**-59%**
Net evaporation*	18.1	-25%	4%	-3%	-13%	4%	-3%	-13%
Sub-total	**43.4**	**-57%**	**4%**	**-15%**	**-40%**	**4%**	**-15%**	**-40%**
Unattributed fluxes								
River unattributed loss	40.5	-37%	-13%	-16%	-48%	-13%	-16%	-48%

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

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 historical 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 historical 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 historical 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	**407203 Loddon @ Laanecoorie**	**Reach 1**
Upstream gauge	**407210 Loddon @ Cairn Curran**	

Reach length (km)	26
Area (km^2)	2617
Outflow/inflow ratio	1.77
Net gaining reach	

Land use	ha	%
Dryland	259,240	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	2,420	1
Open water*	-	-

* averages for 1990–2006

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

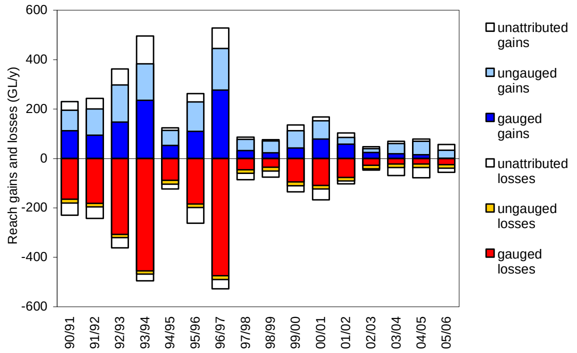
Some of the inflows are gauged. Estimated local runoff explains most of the ungauged gains but a small adjustment was required. There are no recorded diversions and ungauged losses are small.

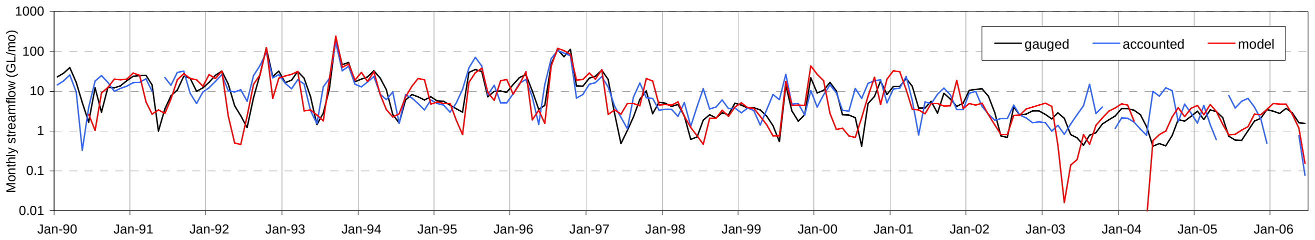
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are greater than river model uncertainty, generally much greater for annual flows.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.43	0.76	0.59
Attributed	0.83	0.83	0.83
Fraction of variance			
Gauged	0.68	0.96	0.82
Attributed	0.95	0.95	0.95

Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	**-0.83**	-0.35	-0.02	-0.17	
Tributary inflows	-0.00		-0.00		
Main gauge outflows	**-0.95**	**-0.74**	-0.06	-0.01	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.74**	-0.31	-0.15	-0.29	Adjusted -4.0%



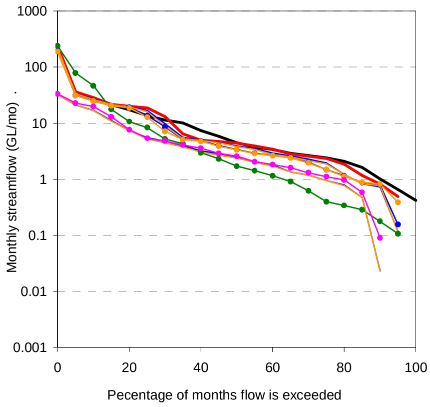


Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	90	82	8
Tributary inflows	0	0	0
Local inflows	66	78	-11
Unattributed gains and noise	-	32	-32
Losses	GL/y	GL/y	GL/y
Main stem outflows	150	145	5
Distributary outflows	0	0	0
Net diversions	1	0	1
River flux to groundwater	0	-	0
River and floodplain losses	2	15	-13
Unspecified losses	3	-	3
Unattributed losses and noise	-	32	-32
	0	0	0

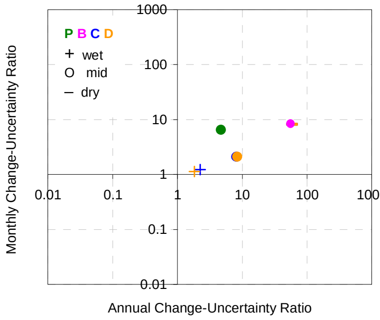
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.89	0.87
Log-normalised	-	-
Ranked	0.60	0.36
Low flows only	<0	<0
High flows only	0.93	0.83
Annual		
Normal	0.99	0.96
Log-normalised	0.96	0.89
Ranked	0.95	0.94

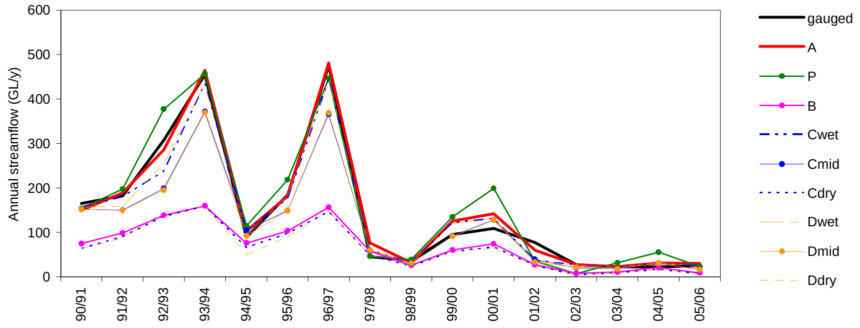
Definitions:

- low flows (flows<10% percentile) : 1.0 GL/mo
- high flows (flows>90% percentile) : 25.2 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.7	55.6	2.2	8.1	58.6	1.8	8.3	58.5
Monthly streamflow	6.5	8.4	1.2	2.1	8.2	1.1	2.1	8.2





Downstream gauge	**407224 Loddon @ D/S Loddon Weir**	**Reach 2**
Upstream gauge	**407203 Loddon @ Laanecoorie**	

Reach length (km)	69
Area (km^2)	1629
Outflow/inflow ratio	0.49
Net losing reach	

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

Most of the inflows are gauged. There are llarge recorded diversions.

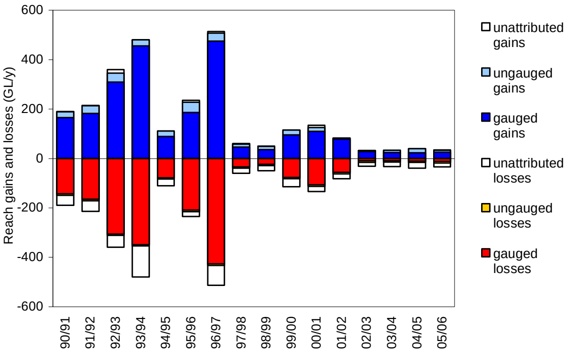
Baseline model performance is very good. Accounting explains observed flows well.

The projected changes are generally greater than river model uncertainty.

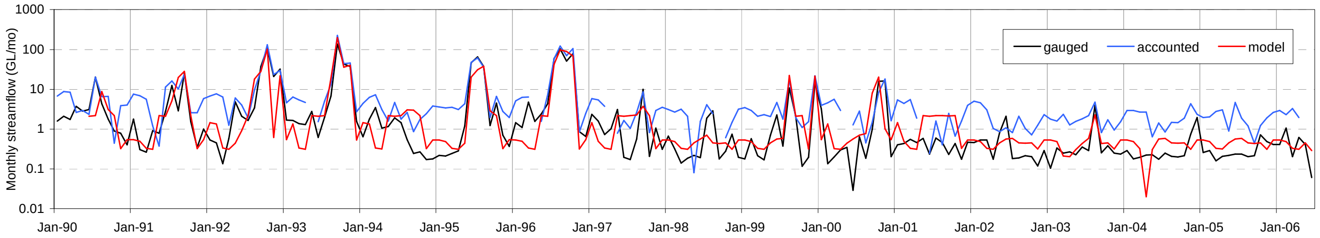
Land use	ha	%
Dryland	162,130	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	780	0
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.87	0.75	0.81
Attributed	0.98	0.79	0.89
Fraction of variance			
Gauged	0.98	0.91	0.95
Attributed	1.00	0.91	0.96



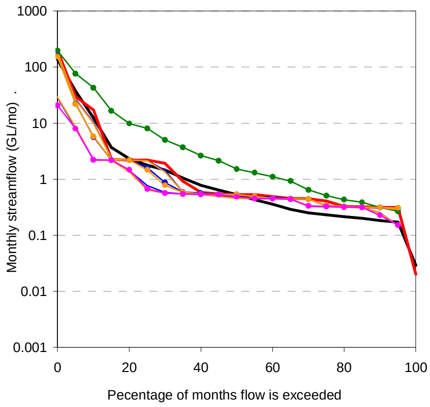
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.12	-0.08	**-0.81**	**-0.54**	
Tributary inflows	-0.00		-0.00		
Main gauge outflows	-0.40	-0.49	**-0.61**	-0.09	
Distributary outflows	-	-	-	-	
Recorded diversions	-0.11	-0.05	-0.13	-0.29	
Estimated local runoff	**-0.78**	-0.48	-0.17	-0.45	



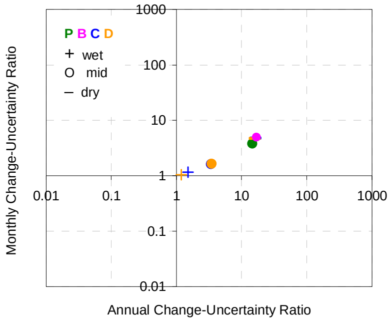
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	150	145	5
Tributary inflows	0	0	0
Local inflows	17	20	-2
Unattributed gains and noise	-	3	-3
Losses	GL/y	GL/y	GL/y
Main stem outflows	71	71	0
Distributary outflows	0	0	0
Net diversions	69	55	14
River flux to groundwater	0	-	0
River and floodplain losses	0	6	-6
Unspecified losses	28	-	28
Unattributed losses and noise	-	36	-36
	0	0	0

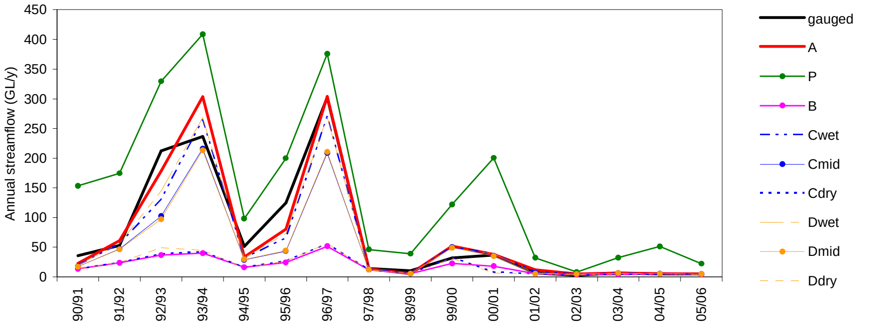
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.84	0.82
Log-normalised	0.57	#NUM!
Ranked	0.03	0.13
Low flows only	<0	<0
High flows only	0.67	0.58
Annual		
Normal	0.94	0.78
Log-normalised	0.94	0.54
Ranked	0.94	0.95

Definitions:
- low flows (flows<10% percentile) : 0.2 GL/mo
- high flows (flows>90% percentile) : 12.4 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	14.6	16.8	1.5	3.4	16.3	1.2	3.4	15.8
Monthly streamflow	3.8	5.0	1.2	1.6	4.8	1.0	1.6	4.7





Downstream gauge	**407205 Loddon @ Appin South**	**Reach 3**
Upstream gauge	**407224 Loddon @ Loddon Weir**	

Reach length (km)	53
Area (km^2)	5710
Outflow/inflow ratio	0.73
Net losing reach	

Land use	ha	%
Dryland	555,837	97
Irrigable area	-	-
Open water*	-	-
River and wetlands	15,190	3
Open water*	-	-

* averages for 1990–2006

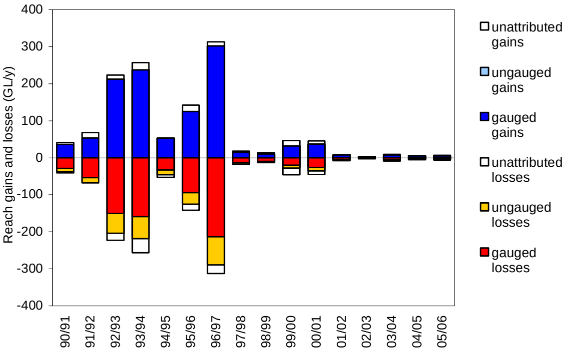
This is a losing reach. Flows are dominated by inflows from upstream.

Most of the inflows are gauged. There are no recorded diversions but ungauged losses are considerable.

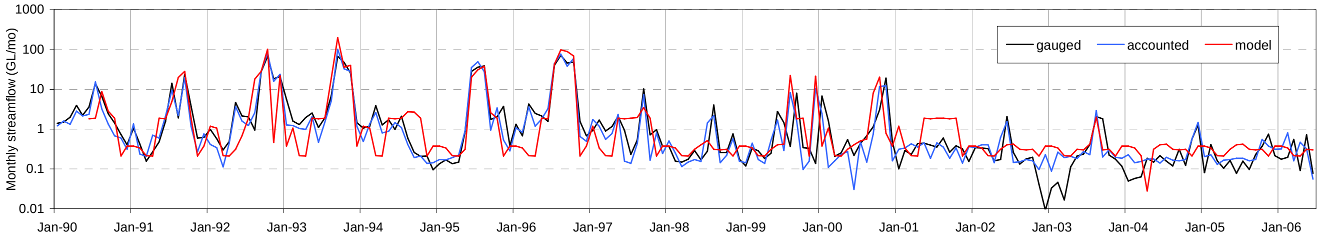
Baseline model performance is poor. Accounting explains observed flows very well.

The projected changes are generally less than river model uncertainty, except for the P scenario and the annual flows in the Cdry and Ddry scenarios where the projected changes are greater than uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.91	0.66	0.78
Attributed	0.91	0.89	0.90
Fraction of variance			
Gauged	0.99	0.84	0.92
Attributed	0.99	0.97	0.98



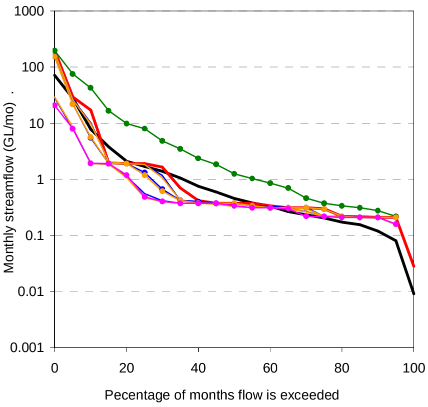
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.02	-0.11	**-0.93**	-0.49	
Tributary inflows	-0.00		-0.00		
Main gauge outflows	-0.15	-0.45	**-0.80**	-0.10	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.18	-0.22	**-0.66**	-0.19	Adjusted -100.0%



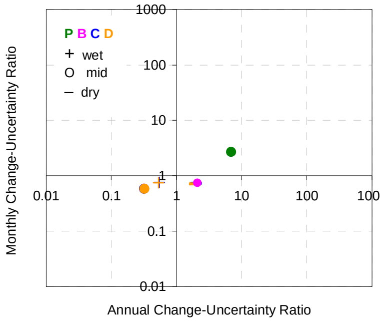
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	71	71	0
Tributary inflows	0	0	0
Local inflows	0	0	0
Unattributed gains and noise	-	7	-7
Losses	GL/y	GL/y	GL/y
Main stem outflows	69	52	17
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	18	-18
Unspecified losses	2	-	2
Unattributed losses and noise	-	9	-9
	0	0	0

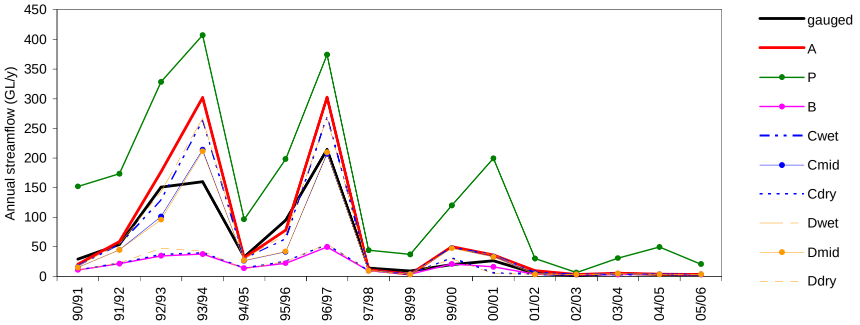
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.05	0.90
Log-normalised	0.41	-
Ranked	0.02	0.61
Low flows only	<0	<0
High flows only	<0	0.61
Annual		
Normal	0.55	0.99
Log-normalised	0.89	-
Ranked	0.91	0.99

Definitions:
- low flows (flows<10% percentile) : 0.1 GL/mo
- high flows (flows>90% percentile) : 7.8 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.9	2.1	0.5	0.3	2.0	0.5	0.3	1.9
Monthly streamflow	2.7	0.7	0.8	0.6	0.7	0.7	0.6	0.7





Downstream gauge	**408203 Avoca @ Quambatook**	**Reach 4**
Upstream gauge	**408200 Avoca @ Coonooer**	

Reach length (km) 71
Area (km^2) 745
Outflow/inflow ratio 0.41
Net losing reach

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

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.

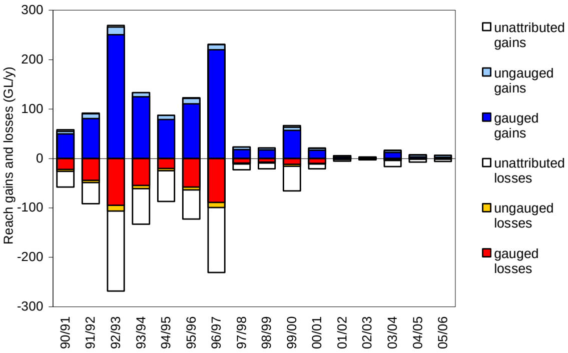
Baseline model performance is excellent. Accounting does not explains observed flows well.

The projected changes are greater than river model uncertainty.

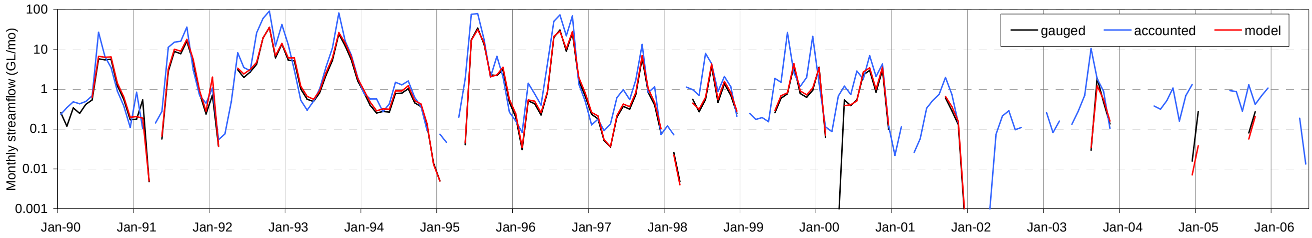
Land use	ha	%
Dryland	64,420	86
Irrigable area	-	-
Open water*	-	-
River and wetlands	10,070	14
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.90	0.37	0.63
Attributed	0.99	0.42	0.70
Fraction of variance			
Gauged	1.00	0.55	0.77
Attributed	1.00	0.60	0.80



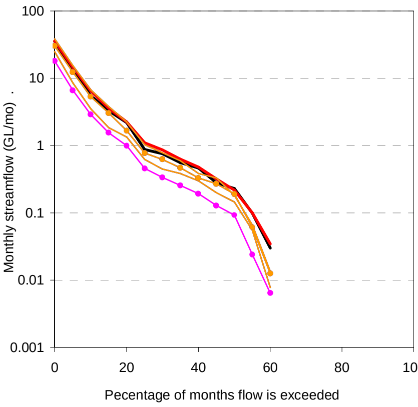
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.05	-0.20	**-0.99**	**-0.65**	
Tributary inflows	-0.00		-0.00		
Main gauge outflows	-0.06	-0.33	**-0.88**	-0.40	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.01	-0.11	**-0.84**	**-0.56**	Adjusted -12.6%



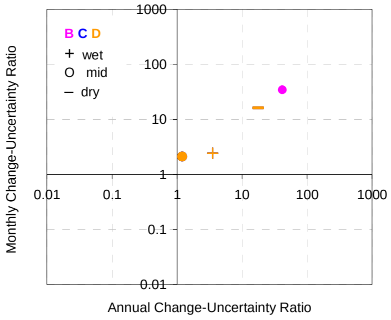
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	65	65	0
Tributary inflows	0	0	0
Local inflows	0	6	-6
Unattributed gains and noise	-	1	-1
Losses	GL/y	GL/y	GL/y
Main stem outflows	28	27	2
Distributary outflows	30	0	30
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	4	-4
Unspecified losses	7	-	7
Unattributed losses and noise	-	42	-42
	-1	0	-1

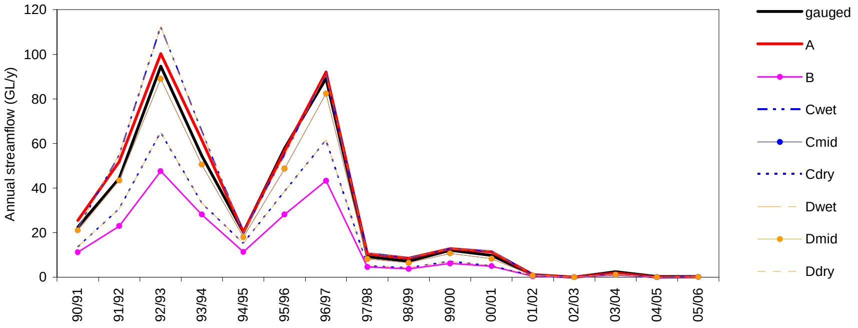
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.99	<0
Log-normalised	-	-
Ranked	0.99	0.38
Low flows only	-	-
High flows only	0.96	<0
Annual		
Normal	0.99	<0
Log-normalised	-	-
Ranked	0.99	0.94

Definitions:
- low flows (flows<10% percentile) : 0.0 GL/mo
- high flows (flows>90% percentile) : 5.5 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow		41.6	3.5	1.2	17.7	3.5	1.2	17.7
Monthly streamflow		34.5	2.5	2.1	16.2	2.5	2.1	16.2





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