Water Availability in the Namoi

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

December 2007

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Murray-Darling Basin Sustainable Yields Project acknowledgments

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

Citation

CSIRO (2007). Water availability in the Namoi. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 154pp

Publication Details

ISSN 1835-095X

Photo on cover : The Peel River upstream from the Chaffey Dam near Tamworth, NSW, courtesy of CSIRO Land and Water 1996

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 Namoi 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 Namoi region is in north-eastern New South Wales and represents 3.8 percent of the total area of the MDB. The region is based around the Namoi, Manilla and Peel Rivers. The population is 88,000 or 4.5 percent of the MDB total, concentrated in the major centres of Tamworth, Gunnedah, Boggabri, Narrabri and Wee Waa. The dominant land use is cattle and sheep grazing. Wheat, cotton and other broadacre crops are grown along the alluvial floodplains. Approximately 112,000 ha of land were irrigated in the year 2000, and around 80,000 ha (or over 70 percent) of the irrigated area was used for cotton production. The Namoi region has one wetland of national importance, Lake Goran, located adjacent to the Liverpool Plains. Surface and groundwater are used for irrigation. Surface water diversions were around two-thirds of the total water use in 2000/01 and around one-third of total water use in 2003/4. The region uses 2.6 percent of the surface water diverted for irrigation in the MDB. Keepit and Split Rock dams regulate the Namoi and enable management of water supply for irrigation. Groundwater resources in the Namoi region are the most intensively developed in New South Wales. The region has one of the largest levels of groundwater extraction within the MDB and uses 15.2 percent (255 GL/year in 2004/05) of the MDB groundwater resource.

Key Messages

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

Historical climate and current development (Scenario A)

The average annual rainfall for the entire Namoi region is 633 mm and modelled average annual runoff is 24 mm. Rainfall is generally higher in the summer half of the year and runoff is relatively uniform throughout the year. The region generates about 3.2 percent of the total runoff in the MDB.

The average total surface water resource in the Namoi region is 965 GL/year and on average about 359 GL/year (or 37 percent) of this water is used. This use is comprised of net surface water diversions of 260 GL/year and eventual total streamflow losses induced by groundwater use of 99 GL/year. This is a high level of development. Flows in the Namoi River are highly regulated; Split Rock Dam regulates 93 percent of all inflows and Keepit Dam regulates 77 percent of all inflows. Chaffey Dam on the Peel River regulates 41 percent of all inflows.

General security water in the Namoi system is highly utilised with 59 percent of the allocated general security water used. General security water use is not highly utilised in the Peel system with 20 percent of the allocated general security water used.

Historical groundwater extraction has impacted, and will continue to impact, on streamflow in the tributaries of the Namoi River. The additional average impact on tributary streamflow by 2010 will be a loss to groundwater of 19 GL/year. The additional eventual impact will be an average loss to groundwater of 36 GL/year to make the total eventual impact a streamflow loss of 99 GL/year. The larger impacts of current groundwater extraction were included in the river modelling. This indicates an additional eventual reduction in average inflows to the main river of 11 GL/year. Also, the river modelling indicates additional eventual streamflow losses of 6 GL/year and 19 GL/year in the Peel and Namoi Rivers respectively due to streamflow leakage induced by current levels of groundwater extraction from the Peel alluvium and extraction at the long-term average extraction limit from the Upper and Lower Namoi alluvia. The streamflow loss to the Namoi alluvia would be offset by a 3 GL/year gain from groundwater elsewhere in the system; the net leakage impact would thus be an additional 22 GL/year loss of streamflow to groundwater.

Current groundwater use represents 49 percent of current total water use in the Namoi region. In years of minimum surface water diversions, current levels of groundwater use represent 78 percent of total water use.

Groundwater extraction in the Namoi region for 2004/05 is estimated to have been 255 GL. About 39 percent of this extraction was from the Upper Namoi Alluvium Groundwater Management Unit (GMU) and 35 percent was from the Lower Namoi Alluvium GMU.

Extraction from the Lower Namoi Alluvium GMU currently exceeds the long-term average extraction limit (LTAEL) due to supplementary licences with entitlements that decrease to zero by 2015 when the existing Water Sharing Plan ends. (The reduction in entitlements to the LTAEL level is funded by the New South Wales and Australian governments under the ‘Achieving Sustainable Groundwater Entitlements’ program).

The LTAEL for the Lower Namoi Alluvium GMU exceeds total long-term groundwater recharge from all sources and exceeds annual recharge in most years. Extraction at this level, given the current spatial pattern of pumping bores, is not sustainable. Responses will be required from both groundwater users and resource managers as groundwater levels fall. These responses would reduce extraction in areas of falling groundwater levels. The lower Namoi River has changed from a river that gained water from groundwater prior to development to one that now loses considerable streamflow volumes to groundwater.

Extraction at the long-term average extraction limit from the six major zones of Upper Namoi Alluvium GMU represents 95 percent of recharge from all sources, including 24 GL/year from streams. This is a very high level of development and can only be sustained by surface water losses. The close connection between surface water and groundwater means that 85 percent of any change in groundwater recharge or extraction is offset by a change in water flux from the river.

Extraction at 2004/5 levels for the Miscellaneous Alluvium of the Barwon Region GMU exceeds rainfall recharge by 15 percent. This is a very high level of development although recharge may occur from streamflow and lateral flow. Extraction at 2004/05 levels from the Peel River Alluvium GMU represents about 55 percent of rainfall recharge. This is a moderate level of development although again there may be recharge from other sources.

Water resource development to-date has increased the average period between flooding of the Namoi River billabongs and wetlands from 3 months to 3.8 months (around 27 percent). The maximum period between flooding events has increased by around 50 percent. The size of events has decreased and the average annual flood volume is now 28 percent (or 150 GL) lower. This level of hydrologic change is likely to have had consequences for ecological processes and is likely to have altered aspects of the ecological character of these ecosystems. However, an assessment of the nature and magnitude of any such impacts is beyond the scope of this project.

Recent climate and current development (Scenario B)

The average annual rainfall and runoff for the past ten years (1997 to 2006) are 5 percent and 17 percent higher respectively than the long-term (1895 to 2006) average values. However, because of the high inter-annual variability and the relatively short ten-year period used as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the long-term averages, even at a significance level of $\alpha = 0.2$. A scenario based on the last ten years was therefore not modelled for the region.

Future climate and current development (Scenario C)

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Namoi region is more likely to decrease than increase. The best estimate 2030 climate scenario is a 6 percent reduction in mean annual runoff. The extreme estimates from the high global warming scenario range from a 31 percent reduction to a 39 percent increase in mean annual runoff. The extreme estimates from the low global warming scenario range from a 10 percent reduction to a 10 percent increase in mean annual runoff.

Under the best estimate 2030 climate there would be a 5 percent reduction in water availability, an 8 percent reduction in end-of-system flows and a 1 percent reduction in diversions overall. Diversion impacts would differ between water products. General security water use would increase by 6 percent in the Peel system and decrease by 3 percent in the Namoi system. Surplus access and Tamworth town water use would increase by 1 percent, and high security stock and domestic use in the Namoi would decrease by 1 percent.

The climate extremes for 2030 indicate that under the wet extreme there would be increases of 38 percent in water availability, 52 percent in end-of-system flows and 10 percent in total diversions.

Under the dry extreme there would be decreases of 30 percent in water availability, 39 percent in end-of-system flows and 17 percent in total diversions. No reduction in Tamworth town water supply or Peel stock and domestic supply would be expected under any 2030 climate.

The best estimate 2030 climate scenario indicates minimal change in surface–groundwater exchanges around the Lower Namoi Alluvium GMU. Under either the dry or the wet extreme 2030 climate the changes in recharge would be partially offset by changes in river losses; the net result, however, would be a reduction in groundwater storage expressed as lower groundwater levels.

The best estimate 2030 climate scenario indicates that due to reductions in rainfall recharge groundwater extraction from the Miscellaneous Alluvium of the Barwon Region GMU would exceed rainfall recharge by 30 percent. No change would be expected for the Peel River Alluvium GMU.

Under the best estimate 2030 climate there would be a small additional increase in average period between flooding of the Namoi River wetlands and billabongs. However, the considerable uncertainty around the best estimate 2030 climate means the average period between flooding could almost return pre-development levels (wet extreme) or increase by a further 36 precent (dry extreme). The degree of change in flood frequency associated with the dry extreme 2030 climate would considerably alter the connectivity between the river and the billabongs and wetlands; this would be likely to alter nutrient transfer processes with consequences for the aquatic fauna of the river and the billabongs and wetlands. The minimum flow rule for environmental purposes in the Namoi Regulated River Water Sharing Plan is met under all modelled scenarios.

Future climate and future development (Scenario D)

The projected growth in commercial forestry plantations in the Namoi region is negligible. Total farm dam storage volume over the entire Namoi region is projected to increase by 19,500 ML by 2030. This is an increase of 13 percent over current farm dam storage volume. This projected increase in farm dams would reduce mean annual runoff by about 1.5 percent (about one-quarter of the median climate change impact on runoff) leading to an average reduction of river inflows (under the best estimate future climate) of 29 GL/year.

Projected average groundwater extraction by 2030 for the region is 450 GL/year. This is an increase of 77 percent over current levels. At this extraction level groundwater use would represent 66 percent of total water use for the region on average. In years of minimum surface water diversions, groundwater use would represent 94 percent of total water use. Most of the increase in groundwater extraction is expected to occur in the New England Fold Belt, Gunnedah Basin and Oxley Basin GMUs.

The 2030 groundwater extraction levels for the Miscellaneous Alluvium of the Barwon Region GMU (under best estimate 2030 climate) would exceed rainfall recharge by nearly 130 percent. The 2030 groundwater extraction levels for the Peel River Alluvium GMU (under best estimate 2030 climate) would exceed rainfall recharge by about 10 percent. These are very high levels of development. Determining whether these levels of development are sustainable requires greater supporting information – particularly of non-rainfall recharge sources – than is currently available.

The total eventual impact of groundwater extraction at projected 2030 levels would be an average streamflow reduction of 113 GL/year; of this, 76 GL/year is caused by the projected increases in groundwater extraction. The streamflow reduction is a combination of tributary inflow reductions and increased leakage to groundwater in alluvial reaches. Because the tributary inflow reductions would be distributed across multiple subcatchments, some of the smaller reductions would be difficult to measure. Thus only the larger inflow reductions at a subcatchment level were included in the river modelling. As a result, 71 GL/year (the total estimate impact of 113 GL/year) is included in the river modelling.

Future development (farm dams and increased groundwater extraction) together lead to a 3 percent reduction in river inflows and 14 percent increase in leakage to groundwater over and above best estimate 2030 climate impacts. Total diversions would be affected considerably more by these future developments than by the best estimate 2030 climate. Diversions would reduce by an additional 4 percent to be 5 percent lower than current. The amplified impact on diversions is due to the leakage of streamflow to groundwater induced by additional groundwater extraction. The impact on average end-of-system flows would be a total reduction (development and climate impacts) of 11 percent. The relative level of use would be 41 percent – this is a very high level of development and is 4 percent higher than the current level.

For the Namoi billabongs and wetlands, future development (new farm dams and increased groundwater use) would have only small additional impacts on the average period between flood events and on the average annual flooding volume. These would be unlikely to have a noticeable impact on the ecology of these systems.

Uncertainty

The runoff estimates in the Namoi region are relatively robust 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 are the climate change projections (global warming level) and the modelled implications of global warming on regional rainfall. The results from 15 global climate models were used but there are large differences amongst these models in terms of regional rainfall predictions. Improvements in the ability to predict the hydrological consequences of climate change would have substantial benefits for water management. There are considerable uncertainties associated with the future development projections for commercial forestry plantations and farm dams. Future development could be very different should governments impose different policy controls on these activities.

Overall the river model for the Namoi region is robust and is suitable for the purpose of assessing changes in water availability and the impacts of these changes on water sharing. The large proportion of inflows that are ungauged and the narrow range of climate for which the model was calibrated leads to uncertainty in the projected impacts of climate change on inflows and thus on the river water balance. However, this uncertainty is considerably less than the uncertainty associated with the climate change predictions themselves. There is greater uncertainty in the assessment of end-of-system flow volumes than there is in assessing flow volumes within the Namoi region. River losses to groundwater are important in the middle reaches. However, these have been quantified in this project using groundwater models and the assessed fluxes have been incorporated in the river model.

The groundwater models for the Lower and Upper Namoi alluvia are suitable for assessing whether the current pattern of extraction at the long-term average extraction limit is sustainable, and for assessing the degree to which streams are impacted by groundwater extraction. The models could be improved to reduce the uncertainty in the predictions.

There is considerable uncertainty in the future projections of groundwater development outside of the Lower and Upper Namoi Alluvium GMUs, but the estimates do show the importance of development in these areas. The projections of groundwater extraction are considered to generally represent the upper limit of groundwater development as it can be constrained by pumping rules, groundwater quality and land suitability. However, the estimates of development impacts are dependent on the use of connectivity estimates based on conservative 'best guess' analysis.

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

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1 Introduction

1.1 Background

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

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

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

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

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

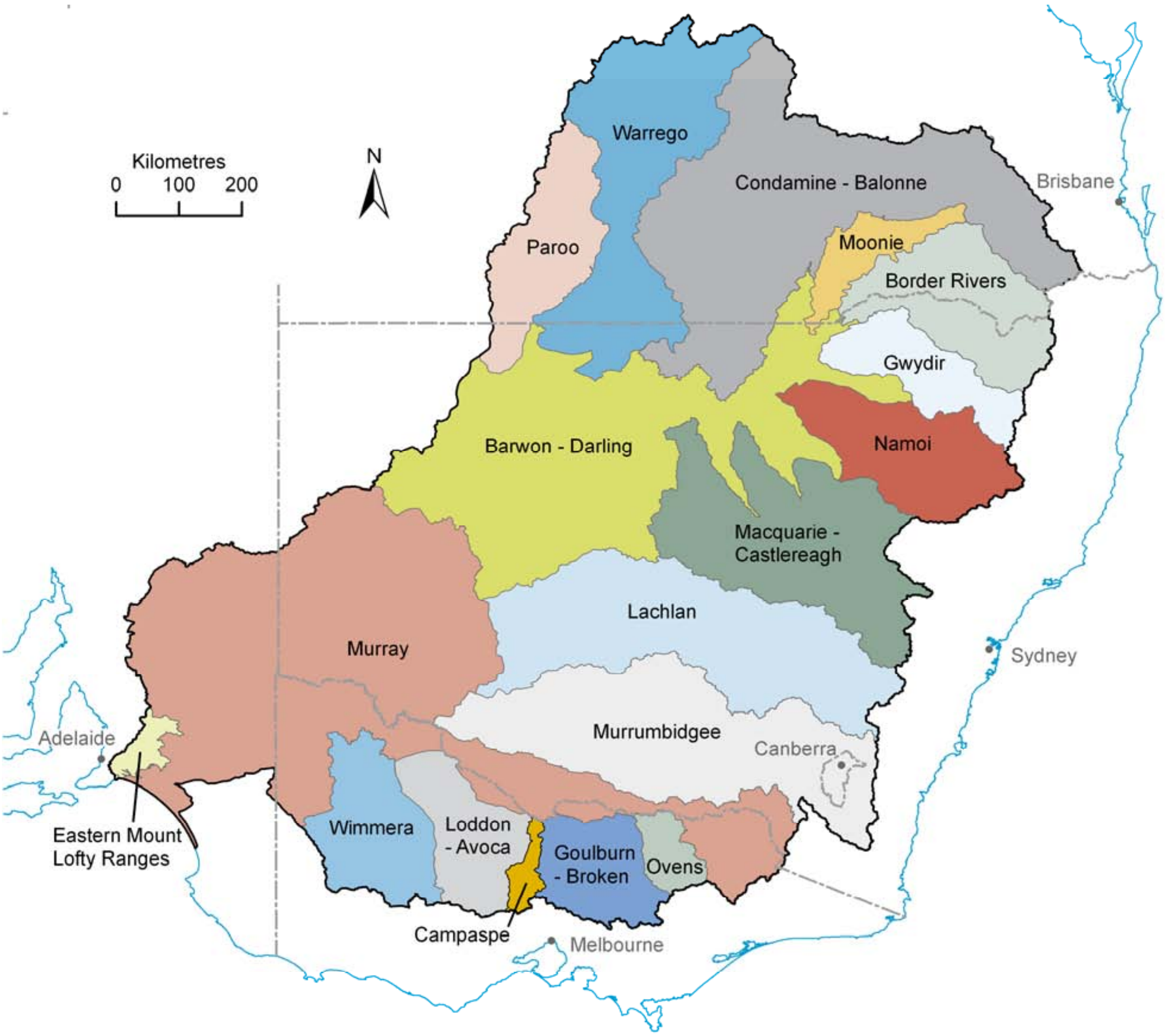

Figure 1-1. Region by region map of the Murray-Darling Basin

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

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

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

1.2 Project methodological framework

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

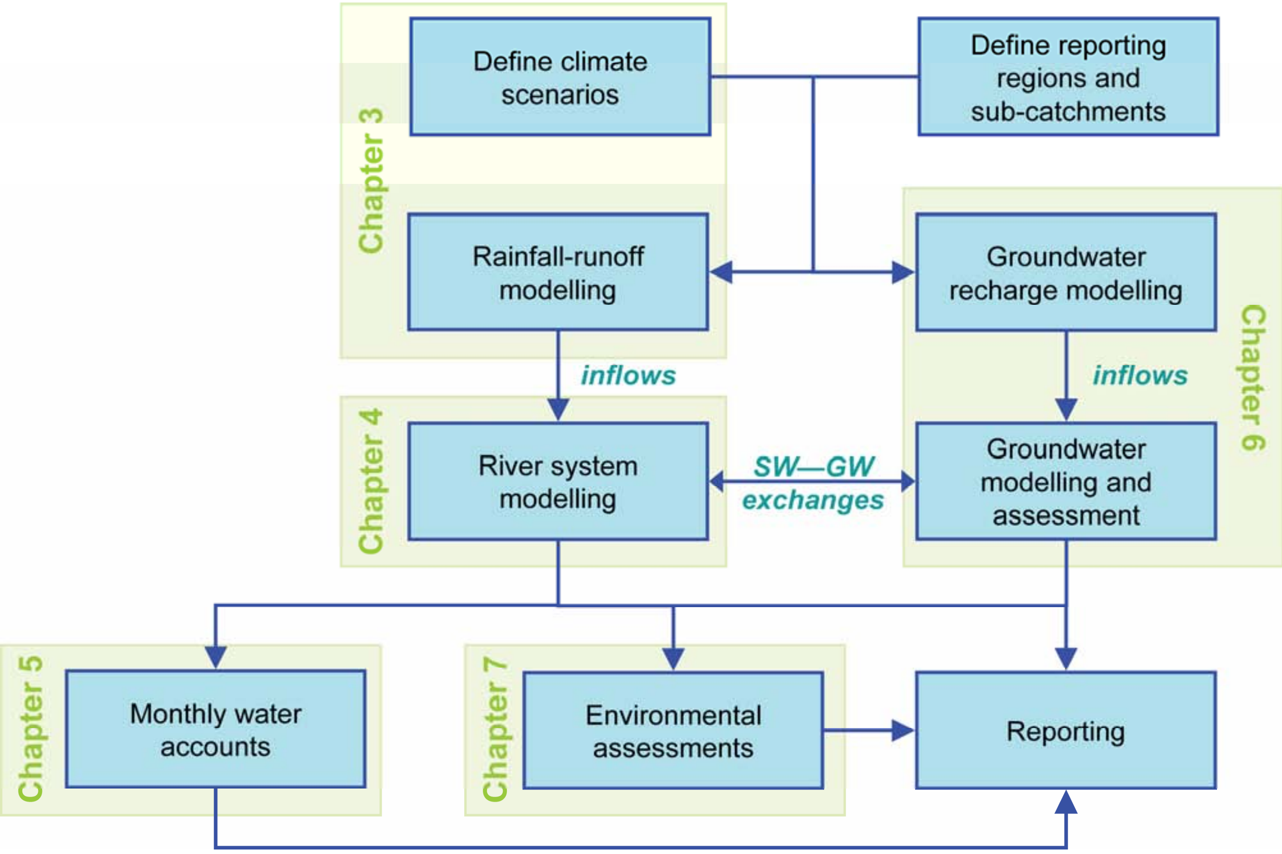

Figure 1-2. Methodological framework for the Murray-Darling Basin Sustainable Yields Project

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

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

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

1.3 Climate and development scenarios

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

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

These scenarios are described in some detail below with full details provided in Chiew et al. (2007a).

1.3.1 Historical climate and current development

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

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

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

1.3.2 Recent climate and current development

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

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

1.3.3 Future climate and current development

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

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

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

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

1.3.4 Future climate and future development

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

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

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

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

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

1.4 Rainfall-runoff modelling

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

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

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

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

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

The same model parameter values are used for all the simulations. The future climate Scenario C simulations therefore do not take into account the effect on forest water use of global warming and enhanced atmospheric CO_2 concentrations. There are compensating positive and negative global warming impacts on forest water use, and it is difficult to estimate the net effect because of the complex climate-biosphere-atmosphere interactions and feedbacks. This is discussed in Marcar et al. (2006) and in Chiew et al. (2007b).

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., 2007b).

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

The rainfall-runoff model SIMHYD is used because it is simple and has relatively few parameters and, for the purpose of this project, provides a consistent basis (that is automated and reproducible) for modelling historical runoff across the entire MDB and for assessing the potential impacts of climate change and development on future runoff. It is possible that, in data-rich areas, specific calibration of SIMHYD or more complex rainfall-runoff models based on expert judgement and local knowledge as carried out by some state agencies would lead to better model calibration for the specific modelling objectives of the area. Chiew et al. (2007b) provide a more detailed description of the rainfall-runoff modelling, including details of model calibration, cross-verification and regionalisation with both the SIMHYD and Sacramento rainfall-runoff models and simulation of climate change and development impacts on runoff.

1.5 River system modelling

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

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

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

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

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

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

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

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

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

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

1.5.1 Surface–groundwater interactions

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

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

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

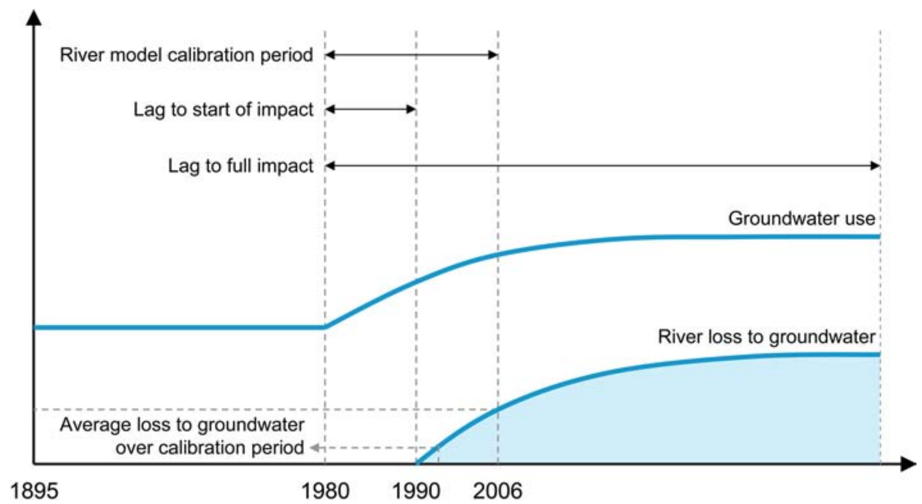

Figure 1-3. Timeline of groundwater use and resultant impact on river

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

1.6 Monthly water accounts

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

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

The water accounting methodology invokes models and indirect estimates of water balance components where direct measurements are not available. These water accounts are not an absolute point of truth. They provide an estimate of the degree to which the river water balance is understood and gauged, and a comparison between river model and water account water balances provides one of several lines of evidence to inform our (inevitably partially subjective) assessment of model uncertainty and its implications for the confidence in findings. The methods for water accounting are based on existing methods and those used by Kirby et al. (2006) and Van Dijk et al. (2007) and are described in detail in Kirby et al. (2007).

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., 2007). The two methods are constrained using direct on-ground AET measurements at seven study sites and catchment streamflow observations from more than 200 catchments across Australia. Both methods provide AET estimates at 1 km resolution.

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

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

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

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

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

1.6.2 Calculation and attribution of apparent ungauged gains and losses

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

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

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

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

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

The water accounting model includes the following components:

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

These model components are will be described in greater detail in Kirby et al. (2007) and are only used where the data or ancillary information suggests their relevance. Each component has a small number of unconstrained or partially constrained parameters that need to be estimated. A combination of direct estimation as well as step-wise or simultaneous automated optimisation is used, with the goal to attribute the largest possible fraction of apparent ungauged gains and losses. Any large residual losses and gains suggest error in the model or its input data.

1.7 Groundwater modelling

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

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

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

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

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

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

1.8 Environmental assessment

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

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

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

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

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

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

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2 Overview of the region

The Namoi region is in north-eastern New South Wales and represents 3.8 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the Namoi, Manilla and Peel Rivers. The population is 88,000 (or 4.5 percent of the MDB total), concentrated in the major centres of Tamworth, Gunnedah, Boggabri, Narrabri and Wee Waa. The dominant land use is cattle and sheep grazing, with wheat, cotton and other broadacre crops grown along the alluvial floodplains. Approximately 112,000 ha of land were irrigated in 2000 of which 80,000 ha or over 70 percent was used for cotton production. Irrigation is both from surface water and groundwater with surface water diversions being around two-thirds of the total use in 2000. The Namoi region has one wetland of national importance, Lake Goran, which is located adjacent to the Liverpool Plains.

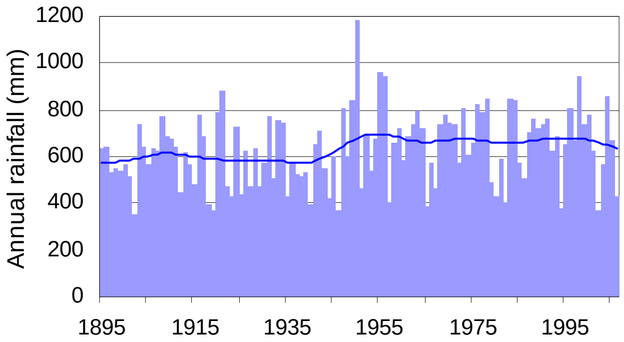
The region uses 2.6 percent of the surface water diverted for irrigation in the MDB. The Namoi River is regulated by large storages (Keepit and Split Rock dams) that enable management of water supply for irrigation. Groundwater resources in the Namoi region are the most intensively developed in New South Wales. The region has one of the highest levels of groundwater extraction within the MDB and groundwater use is 15.2 percent of the MDB total.

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

2.1 The region

The Namoi region is located in northeastern New South Wales and covers 39,781 km^2 or 3.8 percent of the MDB. It is bounded to the east by the Great Dividing Range, to the north by the Gwydir region, to the south by the Macquarie-Castlereagh region and to the west by the Barwon-Darling region. The region terminates at the gauging station on the Namoi River at Walgett 3 km above the junction with the Barwon River. The Namoi River and its main tributary, the Peel River, rise in the Great Dividing Range at elevations over 1000 m, falling to 250 m where the two rivers meet near Gunnedah. Nearly two-thirds of the region is comparatively flat. The Peel River valley is a subcatchment of the Namoi River basin and is around 10 percent of the area of the Namoi catchment.

Major water resources in the Namoi region include the Namoi and Peel Rivers, alluvial aquifers, wetlands and water storages. Associated with these water storages are both private and public infrastructure, including Chaffey and Dungowan dams on the Peel River, Keepit Dam on the Namoi River system, and Split Rock Dam on the Manilla River.



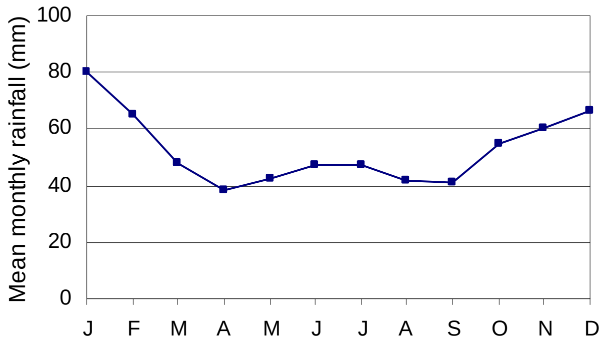


Figure 2-1. 1895–2006 annual and monthly rainfall averaged over the region. The curve on the annual graph shows the low frequency variability

The mean annual rainfall within the region is 633 mm varying from 1300 mm in the east to 400 mm in the west. Rainfall is generally higher in the summer half of the year with the highest average monthly falls occurring between December and February. The region's average annual rainfall has remained relatively consistent over the past 50 years (Figure 2-1) and at a level slightly higher than the preceding 50 years. The mean annual rainfall over the past ten years (663 mm) is around 5 percent higher than the long term 111-year (1895 to 2006) mean.

The Namoi region contributes about 3.2 percent of the total runoff in the MDB. The mean annual modelled runoff over the region for the past 112-year period is 24 mm and is relatively uniform through the year. The mean annual runoff over the ten-year period 1997 to 2006 is around 17 percent higher than the long-term mean. The runoff estimates in the Namoi region are relatively good compared to the western and northwestern parts of the MDB because there are many gauged catchments within the region.

The regional population is approximately 88,000 or 4.5 percent of the MDB. The population is concentrated mostly along the Namoi River and its tributaries between Tamworth and Narrabri. Major towns include Tamworth in the east, and Gunnedah, Boggabri, Narrabri and Wee Waa moving westwards. Most of the region is used for cattle and sheep grazing, with wheat, cotton and other broadacre crops grown along the alluvial floodplains. There were around 112,000 ha of irrigated cropping in 2000. Cotton was the major crop grown over 71 percent of the irrigated area.

The land use map (Figure 2-2) and 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 (BRS, 2000). Irrigation estimates are based on crop areas recorded as irrigated in the census.

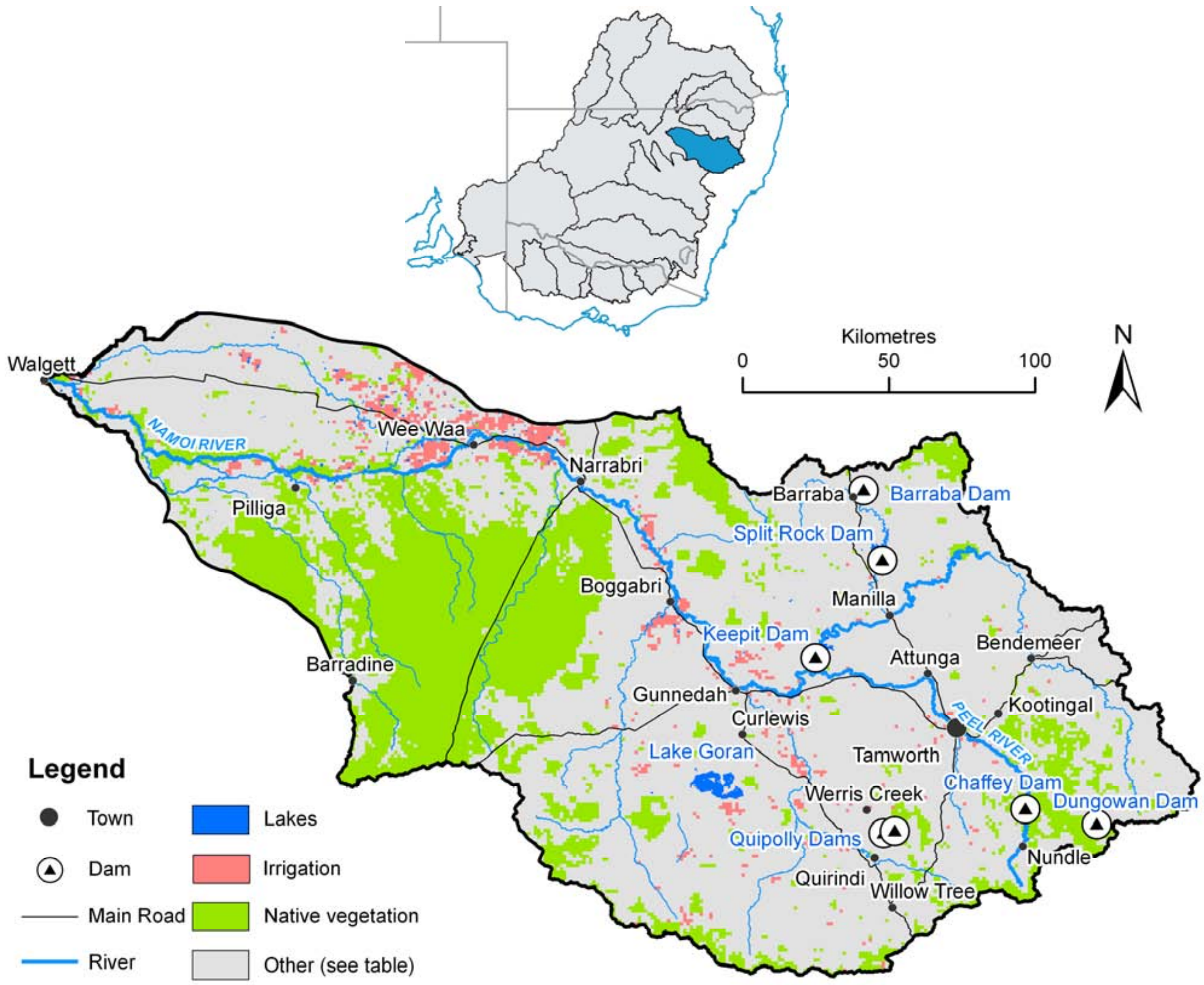


Figure 2-2. Map of dominant land uses of the Namoi region with inset showing the region's location within the Murray-Darling Basin

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

Land use	Area		
	percent		ha
Dryland crops	15.4%		612,200
Dryland pasture	54.6%		2,171,600
Irrigated crops	2.8%		112,400
Cereals		*17.0%*	*19,100*
Cotton		*71.4%*	*80,300*
Horticulture		*1.6%*	*1,800*
Orchards		*1.6%*	*1,800*
Pasture and hay		*8.4%*	*9,400*
Native vegetation	25.6%		1,017,600
Plantation forests	0.3%		12,500
Urban	0.9%		34,400
Water	0.4%		13,900
Total	**100.0%**		**3,974,600**

Source: BRS, 2000

A regional catchment plan, the Namoi Catchment Action Plan, is the strategic framework which will guide natural resource management in the Namoi catchment over the next ten years. It was prepared under the Catchment Management Authorities Act 2003 and commenced in June 2006. The Catchment Action Plan establishes Catchment and Management Targets which address significant impacts on the four key regional resources: native plants and animals, surface water and groundwater ecosystems, the landscape, and people and their communities. The Management Targets define the desired outcomes for each resource and Management Actions provide the strategies to achieve these targets (NCMA, 2006).

The key regional resource condition target for Surface Water and Groundwater Ecosystems includes surface water and groundwater quality, including salinity, wetlands, floodplains, and the riverine zone made up of stream bed and banks, riparian vegetation and aquatic biota. It also covers access to water, including the environmental water required to maintain surface water and groundwater dependant ecosystems, social values of water including Indigenous and European cultural values, recreation and aesthetics, and the beneficial uses that people gain from water, including agricultural and industrial production, and drinking water.

The catchment target for surface water and groundwater ecosystems is: “From 2006, there is an improvement in the condition of surface and groundwater ecosystems”. The intent is to maintain or improve water quality and provide access for all people, while maintaining the productive uses that provide significant wealth for the region. This will be achieved through improving the way land and industries are managed, in order to minimise point source and diffuse source pollution from sediment, nutrients and pesticides. Additional measures to improve the state of the water ecosystems include revegetation, riverine rehabilitation, river flow management and water sharing plans. Improvements in water use efficiency are sought from all water users.

Improvement in surface water and groundwater ecosystems requires a landscape level approach. The adoption of Best Management Practice, which encompasses all aspects of natural resource management, by all industries, is the key to improving water quality and the condition of the ecosystem. In order to achieve this catchment target, positive change will be achieved through four management targets and actions focusing on:

- riverine ecosystems
- surface water and groundwater quality, including river salinity
- aquatic biodiversity
- Water Management Plans.

2.2 Environmental description

The Namoi region supports a diversity of landscapes ranging from the Liverpool, Warrumbungle and Kaputar ranges, all of which include National Parks, through the rolling hills of the sedimentary slopes, to the open floodplains of the Liverpool Plains and Darling Riverine Plains in the western part of the region. The relatively young volcanic geology of the region and extensive alluvial floodplains derived from these materials results in very productive heavy black and grey clays that are sought after for farming and irrigation. However, the impact of agricultural systems on the soil resource resulted in more than 10 percent of the Namoi region being moderately to severely eroded by the early 1990s. The extent of erosion is declining in some farming areas due to reduced tillage farming practices.

Much of the landscape is cleared, including cropping land on the lower slopes, and most of the grazing country on the upper slopes and tablelands. Grazing land, particularly on the western slopes and plains, still retains native grasses, but much of the over-storey is removed (NCMA, 2006).

The Namoi River system provides a wide range of aquatic habitats and is ecologically important. The floodplain downstream of Narrabri contains large areas of anabranches and billabongs. When flooded these areas are considered to be important and work on similar rivers has established they provide large amounts of dissolved organic carbon, which is essential to aquatic ecosystem functioning (Thoms et al., 2005). The draft water sharing plan (DIPNR, 2004) identifies environmental objectives including:

- native fish breeding
- maintenance of instream features such as bars, benches and low level wetlands
- increases in the frequency and duration of flooding to more closely simulate the natural flow regime.

The only wetland of national importance in the Namoi region is Lake Goran (Environment Australia, 2001), which is located adjacent to the Liverpool Plains (Table 2-2). The lake is at the end of an internal drainage basin that does not connect to the Namoi River (Environment Australia, 2001).

Table 2-2. Ramsar wetlands and wetlands of national importance located within the Namoi region

Site code	Directory of Important Wetlands in Australia name	Area[1]	Ramsar sites
		ha	
NSW005	Lake Goran	6385	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
Source: Environment Australia, 2001

2.3 Surface water resources

2.3.1 Rivers and storages

The major river, the Namoi, flows in a westerly direction from its headwaters in the Great Dividing Range. Its main tributary, the Peel River, joins the Namoi River near Gunnedah. Other major tributaries of the Namoi River include the Manilla, and McDonald rivers which flow into Split Rock Dam, Coxs Creek and the Mooki and Cockburn rivers, all of which join the Namoi upstream of Boggabri. The Namoi River then flows westerly across the western plains and joins the Barwon River near Walgett. The Pian creek and Gunidgera Creek system is an anabranch of the Namoi River which flows in a westerly direction from Wee Waa further north of the Namoi River and joins the Namoi upstream of Walgett. Stock and domestic replenishment flows are passed down Pian Creek below Dundee Weir from the Namoi River which is located approximately midway between Wee Waa and Walgett.

The major water storages in the region include the Keepit Dam on the Namoi River with a capacity 423 GL and the Split Rock Dam on the Manilla River with a capacity of 397 GL. Major irrigation diversions are also made from Mollee and Gunidgera weirs on the Namoi River. The Chaffey Dam located on the Peel River with a storage capacity of 62 GL provides water to Tamworth and to downstream users. The smaller Dungowan Dam located on the Dungowan Creek with a storage capacity of 6 GL supplies water to Tamworth. The estimated volume of hillside farm dams with their own catchments is 145 GL (Chapter 3). Additionally, the river model includes about 209 GL of private on-farm storages for irrigation (Chapter 4).

2.3.2 Surface water management institutional arrangements

The Water Management Act 2000 in New South Wales requires the implementation of ten-year plans defining water sharing arrangements between the environment and water users and amongst water user groups.

The plans aim to protect rivers and aquifers and their dependent ecosystems, and to provide water users with clarity and certainty regarding water access rights.

Water use is constrained to a long-term average annual extraction limit. The basic rights (native title, domestic and stock) and access licences for domestic and stock use and local water utilities are volumetric and are granted highest access priority.

High and general security access licences are based on shares of the water available with high security having priority over general security. Most general security access licences are expressed as a relative unit share of the available water rather than as an annual volume. Licensing continues under the Water Act 1912 in areas where water sharing plans are not yet gazetted.

The Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources was gazetted in 2003 (DIPNR, 2004a). The Upper Namoi Regulated Water Source applies to the Manilla River downstream of Split Rock Dam and the Namoi River from the junction of the Manilla River downstream to Keepit Dam. The Lower Namoi Regulated Water Source applies to the section of the Namoi River downstream of Keepit Dam to its junction with the Barwon River. Other rivers in the Namoi region are not covered by the Plan and are the subject of separate plans or planning processes. The Pian Creek downstream of Dundee Weir receives stock and domestic replenishment flows from the regulated water source but is not itself part of the water source covered by the Upper Namoi and Lower Namoi Regulated River Water Source Plan. A plan is yet to be finalised for the Peel River. However, the Upper Namoi and Lower Namoi Regulated River Water Source Plan includes an extraction limit for Tamworth's water supply from the Peel River. Growth in use for Tamworth water supply is off-set by reductions in use by lower priority users in the upper Namoi and lower Namoi.

The Upper Namoi and Lower Namoi Regulated River Water Sources Plan was based on 1999/2000 development conditions, infrastructure and management rules and the model results were based on the simulation period 1892 to 2000. The water sharing modelling detailed in Chapter 4 is based on 2003/04 development and uses the simulation period 1892 to 2006 which represents the water sharing plan operating under the latest development conditions.

The average diversion limit set in the Namoi Water Sharing Plan is currently estimated to be 238 GL/year. This is based on the Water Sharing Plan rules and 1999/00 levels of development. This model differes from the scenario A modelled use in this study The remaining surface water resource provides the majority of environmental flows some of which is according to prescribed rules including:

- thresholds for permitting extraction of uncontrolled flows by supplementary water access licences
- limits on the amount of uncontrolled flow that can be extracted by supplementary water access licences, namely either 10 or 50 percent of the volume of each uncontrolled flow event (percentage limit depends on the time of year)
- allowances for replenishment flows of up to 14 GL/year which can be provided for the environment and unregulated river access licences in Pian Creek downstream of Dundee Weir, if required.

A water sharing plan was gazetted for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources in 2003 (DIPNR, 2004b). The Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources are located on the northern slopes of the Namoi region. These water sources are tributaries of the Namoi Regulated River, entering through the Mooki River upstream of Gunnedah. The Phillips Creek Water Source has an area of about 530 km^2, the Mooki River Water Source an area of about 836 km^2, the Quirindi Water Source an area of about 841 km^2 and the Warrah Creek Water Source an area of about 1534 km^2.

These water sources have variable river flows throughout the year and are ephemeral systems. Highest demand for water extraction occurs through the summer months, although on-farm storage development in the Mooki River Water Source results in extraction occurring year round. The development of these water sources has resulted in changing river flow patterns through the extraction and use of water for irrigation and domestic and stock purposes, and changes in land use (DIPNR, 2004b).

Table 2-3. Summary of surface water sharing arrangements

Water products	Priority of access	Upper Namoi Regulated Water Source Plan	Lower Namoi Regulated Water Source Plan	Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Source Plan
		Allocated entitlement		
		ML/y		
Basic rights				
Stock and domestic rights		160	1,776	4.8 ML/day
Native title		none	none	none
Extraction shares				
Total licensed (long-term) extraction limit			238,000	Not specified
Local water utilities	high	150	2,271	
High security access	high	80 unit shares	3,418 unit shares	
General security access	medium	9,729 unit shares	246,692 unit shares	30,597 unit shares
Supplementary access	low	0 unit shares	115,503 unit shares	
Domestic and stock		46	1967	Not specified
Environmental provisions				
Total environmental share			632,000*	**
Environmental allocation	high	0	0	

* By limiting long-term average annual extractions to an estimated 238,000 ML/y this plan ensures that approximately 73 percent of the long-term average annual flow in this water source (estimated to be 870,000 ML/y) will be preserved and will contribute to the maintenance of basic ecosystem health.

** There are cease to pump conditions on most licenses when the flow is at or below 2 Ml/day for the Phillips and Quirindi Creeks, 100 ML/day (rising river) and 50 ML/day (falling river) for the Mooki River and 4ML/day for the Warrah Creek. Environmental flows are the stream flows in excess of the basic landholder rights and the total daily extraction limit for each flow class.

2.3.3 Water products and use

Major irrigation development followed the completion of Keepit Dam on the Namoi River in 1961 and Split Rock Dam on the Manilla River in 1987. Irrigation releases from the Keepit Dam are re-regulated by Mollee and Gunidgera weirs on the Namoi River.

Chaffey Dam (completed in 1979) and the small Dungowan Dam supply water to Tamworth in addition to the water released for irrigation purposes from the Chaffey Dam. General security use accounts for an average of 96 percent of the surface water diverted within the region. During high flow, water in excess of the agreed environmental flow provisions and water orders is subject to extraction under supplementary access licences.

Annual surface water use is strongly influenced by the seasonal rainfall patterns which cause inflows into the Keepit and Split Rock dams and the access by irrigators to supplementary water during periods of high river flow. Surface water diversions in 2000 for the combined Namoi and Peel River systems were 315 GL, including an estimated 42 GL of use by unregulated stream licenses. This total diversion represents 2.6 percent of the total surface water diversions within the MDB (MDBC, 2007). Diversions ranged from 173 to 359 GL during the period from 1996/97 and 2004/05. Stock and domestic water use accounts for less than 1 percent of the annual use. Further growth in surface water diversions is restricted under current water plans.

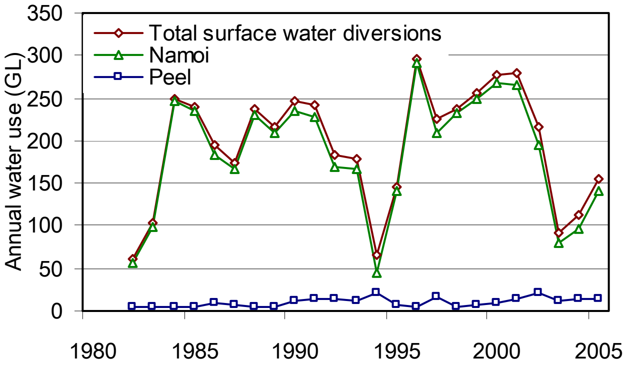


Figure 2-3. Historical surface water diversions

Note: The data in different years are not always comparable because the areas defined in each catchment changed, as did the definitions of water uses. Even where data sets should refer to the same records, data from state and Murray-Darling Basin Commission databases often vary.
Sources: MDBC, 2005; MDBC, 2007

2.4 Groundwater

2.4.1 Groundwater management units – the hydrogeology and connectivity

Groundwater resources in the Namoi region are the most intensively developed in New South Wales and lie in a geologically complex region. Groundwater is primarily extracted from the alluvial aquifers associated with the main rivers and prior channels. Most groundwater is extracted from the coarse-grained Gunnedah Formation and the underlying Cubbaroo Formation in the central and western parts of the Namoi region. This central and western part is also underlain by the consolidated sandstones, shales and mudstones that form the multi-layered aquifers of the Great Artesian Basin (GAB). The groundwater resources within these aquifers are not considered in this assessment except where intake beds for the GAB outcrop within the region, since groundwater in these outcrop areas can potentially to be connected to surface water systems and where there is interaction with other aquifer systems such as those in the Lower Namoi.

The Namoi region can be further subdivided into the two major areas of alluvium – the Upper and Lower Namoi Alluvium – and the remainder lying in the headwaters of the region further to the east.

The aquifers of the areas of the Namoi region other than the two major areas of alluvium are generally found in the uplands of the eastern areas and consist largely of a variety of different fractured rock types of Palaeozoic and Mesozoic age. Rock types include sedimentary and metamorphic rocks, basalts and granites. Other important aquifers in the region include unconsolidated highland alluvium deposited in valley floors. Regional groundwater flows are from east to west (URS, 2006). However, the groundwater flow systems within all of these aquifers are generally local to intermediate in scale.

Fractured rock and granite aquifers are recharged where soils are thin, on mid to upper slopes and discharge to adjacent streams, valley floors and at breaks in slope. The basalts are highly porous and well flushed. Recharge to these aquifers occurs throughout the landscape. Alluvium deposited in valley floors is recharged throughout the landscape depending upon the nature of soils and weathered rock above the watertable and on the frequency of flooding (URS, 2006).

Within the highland alluvial systems groundwater discharges typically to drainage lines, local changes in soil texture, around the break-of-slope and at the base of terraces. Salt storage in the finer grained units of these systems is high and groundwater salinity is variable from fresh to saline with lower salinity levels being characteristic of the coarser sediments. The response of these systems to a change in the water balance can be relatively fast (URS, 2006).

Upper Namoi Alluvium hydrogeology

The aquifer system of the Upper Namoi Alluvium comprises unconsolidated sediments associated with the Namoi and Mooki rivers and Coxs Creek. The alluvial sediments consist mainly of sand, gravel and clay and their thickness is largely controlled by the bedrock topography. The total area of alluvium is in the order of 3000 km^2 and is up to 130 m thick (DLWC, 2000a). A palaeochannel runs through the central area of the valley and represents the deepest parts of the aquifer.

Good quality groundwater can be found in high yielding aquifers across wide areas of the alluvial plain. However, the most productive aquifer is in the main palaeochannel. The coarseness of the palaeochannel sediments allows for high groundwater extraction rates (DLWC, 2000a).

Lower Namoi Alluvium hydrogeology

The aquifer system of the Lower Namoi Alluvium is made up of the unconsolidated sediments, namely inter-bedded clays, sands and gravels, associated with the Namoi River and its tributaries downstream of Boggabri. They accumulated over more than 15 million years within a broad valley of the old Namoi River, to a maximum depth of about 120 m and an areal extent of about 5100 km^2. To the north-west, the Lower Namoi Alluvium joins the alluvium associated with the Barwon and Gwydir rivers. In the north-east and south it is bounded by colluvium associated mostly with weathered GAB sediments and basalt flows. To the south-west the Namoi River alluvium joins the alluvium associated with the Barwon and Castlereagh rivers (DLWC, 2000b).

In most areas of the Lower Namoi Alluvium there are two general aquifer systems identified, the shallow Narrabri Formation and the deeper Gunnedah Formation, with a third aquifer associated with the palaeochannel, the Cubbaroo Formation below the Gunnedah Formation. In some areas to the east, there is no discernible difference between the identified aquifer systems and they may act as a single aquifer. The Gunnedah Formation (middle aquifer) is the most extensive over the area and generally occurs between 40 to 90 m depth. The Cubbaroo Formation (palaeochannel) occurs 90 m below the ground surface and is restricted to the main palaeochannel.

Connectivity

Within the highland areas of the region, recharge to the fractured rock systems flows through the fractures to discharge into adjacent streams and valley floors. The rivers of the highland valleys tend to be gaining in nature.

All streams in the western parts of the region on the alluvial plain run across the top of the Narrabri Formation. At the eastern margin of the plain, the rivers are in direct hydraulic contact with the watertable. Further west, an unsaturated zone develops where the watertable falls well below the streams and surface water leaks to the underlying aquifer whilst streamflow persists. At the far western edge of the alluvial plain, watertables are found closer to the surface and saturated conditions are re-established. The Gunnedah Formation is recharged via infiltration from the overlying Narrabri Formation. Recharge to the groundwater system on the alluvial plain is primarily from leakage from the stream channel under normal flows, leakage from overbank flooding, and infiltration from rainfall. In the eastern parts of the plain, there is a downward movement of groundwater from the Narrabri to the Gunnedah Formation, whilst at the western margin the direction is reversed.

The Peel River Alluvium is highly connected to the Peel River and more than 80 percent of the groundwater extracted is drawn ultimately from the river.

For management purposes the Namoi region is subdivided into 12 groundwater management units (GMUs). These units are three-dimensional in nature, allowing for the layered nature of geological formations at different depths.

The 12 GMUs cover the entire valley and were devised based on an appreciation of the hydrogeological setting of the groundwater resource in each case. Figure 2-4 is a map of GMUs and they are listed in Table 2-4. Two GMUs are completely contained within the region and a further ten GMUs partially overlap with adjoining regions. Two GMUs are categorised as very high priority or high priority according to the degree of development and the stress on the water resource.

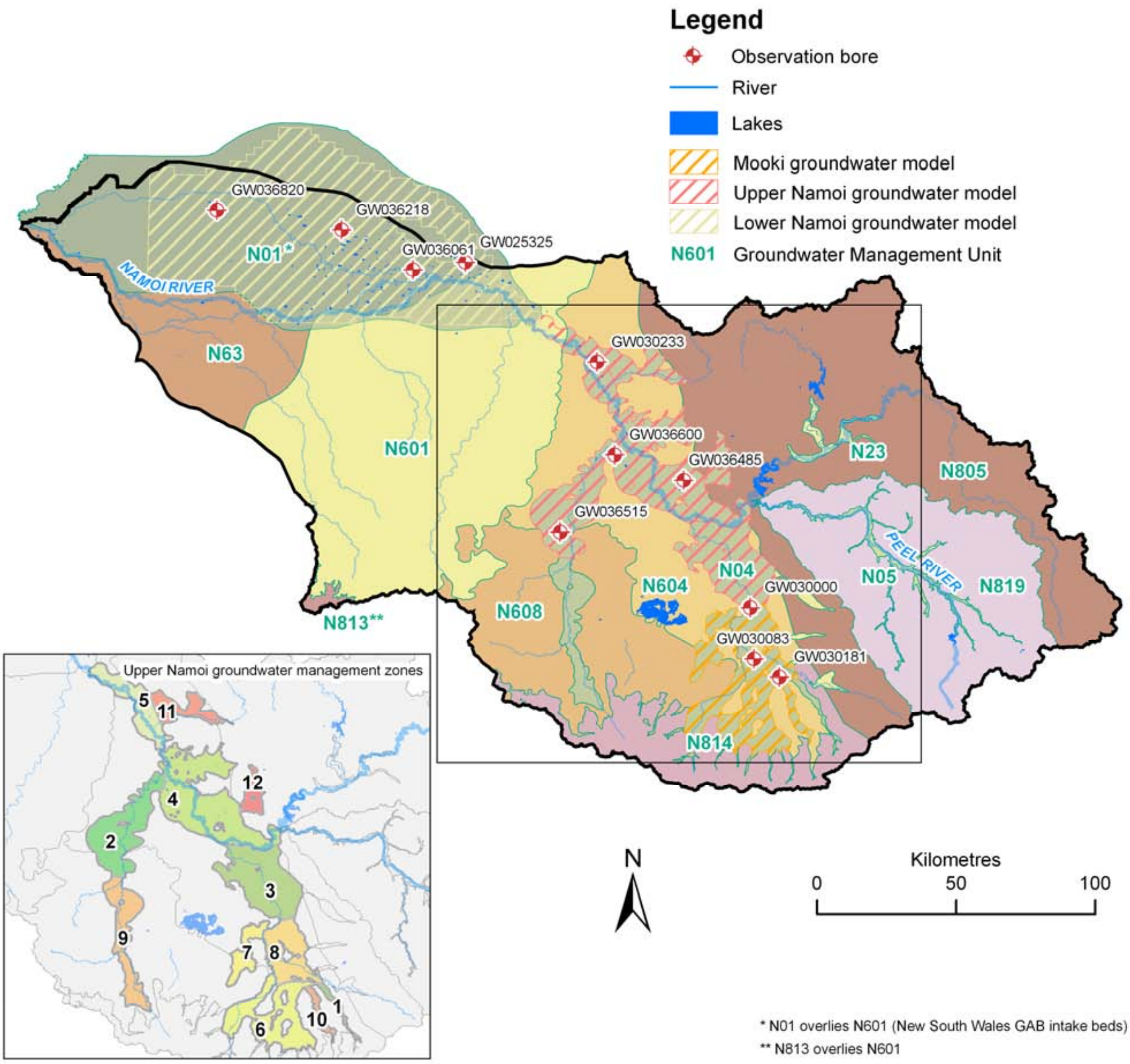


Figure 2-4. Map of groundwater management units in the Namoi region with inset showing Upper Namoi groundwater management zones (Chapter 6)

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

Code	GMU	Priority	Entitlement	Current extraction (2004/05)*	Long term average extraction limit***	Recharge**
			GL/y			
N01	Lower Namoi Alluvium	high	89.30	89.04	86 (plus basic landholder rights)	86 (plus basic landholder rights)
N04	Upper Namoi Alluvium	very high	119.24	100.3	122.1 (plus basic landholder rights)	122.1 (plus basic landholder rights)
N05	Peel Valley Alluvium	low	51.35	10.32	14.1	20.12
N23	Miscellaneous Alluvium of the Barwon Region	low	7.16	4.06	1.74	3.49
N63	GAB Alluvial	very low	0.39	0.33	9.92	16.53
N601	GAB Intake Beds	very low	3.85	0.83	4.06	189.8
N604	Gunnedah Basin	low	6.66	5.62	87.19	124.56
N608	Oxley Basin	low	12.58	9.24	77.21	110.31
N805	New England Fold Belt	low	10.79	7.55	113.23	226.46
N813	Warrumbungle Tertiary Basalt	very low	0.01	0.01	0.53	1.05
N814	Liverpool Ranges Basalt	low	3.66	2.48	23.74	47.49
N819	Peel Valley Fractured Rock	low	35.75	25.06	70.48	140.97

* Current groundwater extraction for Macro Groundwater Sharing Plan areas is based on metered and estimated data provided by DWE. Data quality is variable depending on the location of bores and the frequency of meter reading. Where indicated the recharge volume does not include the volume of groundwater available for basic rights, which is an additional volume.

** This value represents only rainfall recharge in Macro Groundwater Sharing Plan areas. The volume of recharge does not include recharge to national park areas, which has generally been allocated to environmental purposes and is not available for consumptive use. Where indicated the recharge volume does not include the volume of groundwater available for basic rights, which is an additional volume. For the Lower and Upper Namoi Alluvium GMUs, it represents the recharge as defined in the Water Sharing Plans.

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

2.4.2 Water management institutional arrangements

The Water Management Act 2000 in New South Wales requires the implementation of ten-year plans defining water sharing arrangements between the environment and groundwater users and amongst water user groups in a similar way to that required for surface water diversions. Water sharing plans are prepared for the more highly developed GMUs to protect rivers and aquifers and their dependent ecosystems, and to provide water users with clarity and certainty regarding water access rights. In the past, and prior to the implementation of the current water sharing plan, groundwater extraction exceeded the extraction limit, though staying below the level of entitlement. As part of the planning process, the overall level of entitlement was set to the latest estimate of the extraction limit for the GMU. This led to the situation where some users had been extracting at rates higher than their new entitlement, once this entitlement had been modified in the plan to match the long-term average extraction limit (LTAEL). To deal with this issue, supplementary licences were granted to users in the water sharing plan, allowing users to extract at higher rates for a short time to allow them to adjust to the new plan limits. This supplementary volume will decrease to zero within ten years of commencement of the water sharing plan.

The 'Achieving Sustainable Groundwater Entitlements' structural adjustment program, funded jointly by the New South Wales and the Australian governments under the National Water Initiative, aims to reduce entitlements to equal the LTAEL. The LTAEL is to be achieved by the end of the Water Sharing Plan for the Upper and Lower Namoi groundwater sources 2003.

This WSP commenced in 2006 and specifies a long-term average annual extraction limit of 208.1 GL/year for the Lower and Upper Namoi aquifers (DIPNR, 2006). The volume of the Supplementary Licences was set at a total of 59.08 GL/year at the commencement of the plan and reduces annually to zero by 2015. The plan indicates that environmental provisions will be met from aquifer storage minus supplementary water access. At this stage, there are no specific environmental provisions made in the WSP.

Groundwater extraction in the other parts of the region, excluding the GAB and Peel Valley Alluvium systems, will be controlled by Macro WSPs which will set a groundwater extraction limit and environmental provisions. Groundwater extraction records for the Macro WSP regions are generally poor. The Macro WSPs are planned to commence in 2009. The Peel River Alluvium is not covered by the existing plans. However, the New South Wales Department of Water and Energy (DWE) have indicated that a separate water sharing plan will be developed for the Peel Alluvium GMU. Table 2-5 provides a summary of the groundwater management plans.

Table 2-5. Summary of groundwater management plans

Description	Upper and Lower Namoi Alluvium	Great Artesian Basin (Intake Beds)	Remaining GMUs
Name of plan	Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003	Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources	Macro Groundwater Sharing Plan
Year of plan	2006	2007	*
Environmental provisions			
Planned share	0 GL/y	Volume required to maintain pressure levels experienced under the level of water extraction associated with water entitlements, infrastructure and management rules in place plus 30% water savings under Cap and Pipe Bores up to a maximum for each zone (for more detail refer Part 4, section 17(2) of WSP).	30–50% of rainfall recharge
Adaptive provisions	Left or taken as required on an access licence	Refer Part 4 section 18 of WSP	None as yet
Basic rights			
	GL/y		
Domestic and stock rights	6.14	0.61	37.73
Native title	0	0	none identified yet
Access licences			
Urban	11.19	0.13	2.05
Planned share	191.22	3.11	88.57
Announced allocation	Planned share + supplementary		None
Supplementary provisions	59.08 reducing to 0 by 2015	0	0

*Unpublished data supplied by DWE. Macro Water Sharing Plans will commence in 2009.

2.4.3 Water products and use

Groundwater extraction within the Namoi region accounts for 15.2 percent (254.82 GL in 2004/5) of the total annual groundwater use from the MDB. This volume is extracted by around 14,820 users and 95 percent is used for irrigation.

Groundwater extraction in the Lower Namoi Alluvium GMU varied considerably in recent decades while extraction in the Upper Namoi Alluvium GMU has gradually increased. Groundwater extraction for 2004/05 was 89 GL in the Lower Namoi Alluvium GMU and 100 GL in the Upper Namoi Alluvium GMU excluding groundwater extraction for stock and domestic purposes and covered by supplementary licences. The Lower Namoi Alluvium GMU has a long history of groundwater extraction and was one of the first major groundwater sourced irrigation areas in New South Wales. Extraction in the Lower Namoi Alluvium GMU peaked in the drought years of 1982/83, 1994/95 and again in the early 2000s. The total extraction for both GMUs increased from around 130 GL in the late 1980s to a peak in 1994/95, where they contributed similarly to an extracted volume of 324 GL. Extracted volumes reduced during the higher rainfall years in the late 1990s but increased to around 250 GL in subsequent drier years.

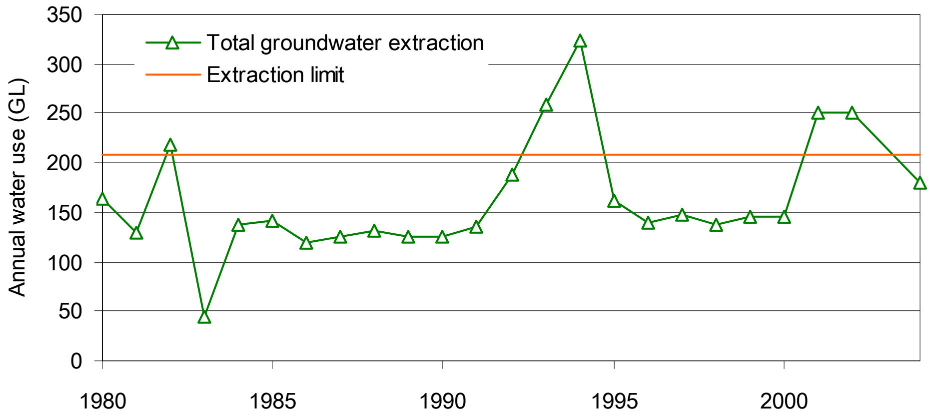


Figure 2-5. Historical groundwater extractions in the Upper and Lower Namoi Alluvium relative to the long-term average extraction limit imposed by the 2003 Water Sharing Plan

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3 Rainfall-runoff modelling

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

3.1.2 Key messages

- The mean annual rainfall and modelled runoff averaged over the Namoi region are 633 mm and 24 mm respectively. Rainfall is generally higher in the summer half of the year and runoff is relatively uniform throughout the year. The Namoi region covers about 3.8 percent of the MDB and contributes about 3.2 percent of the total runoff in the MDB.
- The mean annual rainfall and runoff over the ten-year period 1997 to 2006 are 5 percent and 17 percent higher respectively than the 1895 to 2006 long-term means. However because of the inter-annual variability and the relatively short ten-year period used as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the long-term means, even at a significance level of $\alpha = 0.2$.
- Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Namoi region is more likely to decrease than increase. Two-thirds of the results show a decrease in runoff and one-third of the results show an increase in runoff. The best estimate (median) is a 6 percent reduction in mean annual runoff by ~2030 relative to ~1990. The extreme estimates, which come from the high global warming scenario, range from a 31 percent reduction to a 39 percent increase in mean annual runoff. By comparison, the range from the low global warming scenario is a 10 percent reduction to a 10 percent increase in mean annual runoff.
- The projected growth in commercial forestry plantations in the Namoi region is negligible. The total farm dam storage volume over the entire Namoi region is projected to increase by 19,500 ML (or an increase of 13 percent relative to current farm dam volume) by 2030. This projected increase in farm dams will reduce mean annual runoff by about 1.5 percent, about one-quarter of the median climate change impact on runoff. The best estimate of the combined impact of climate change and farm dam development is a 7 percent reduction in mean annual runoff (with extreme estimates ranging from -32 percent to +38 percent).

3.1.3 Uncertainty

- Scenario A – historical climate and current development
  The runoff estimates in the Namoi region are relatively good because there are many gauged catchments in the region from which to estimate the model parameter values. Rainfall-runoff model verification analyses for the MDB indicate that the mean annual runoff estimated for ungauged catchments using optimised parameter values from nearby catchments has an error of less than 20 percent in more than half the catchments and less than 50 percent in almost all the catchments.

- 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 global warming projections (IPCC, 2007). The results are then presented as a best 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 plantations in the Namoi region (BRS, 2000). The increase in farm dams is estimated by considering trends in historical farm dam growth and current policy controls in New South Wales and there is uncertainty both as to how landholders will respond to these policies and how governments may set policies in 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. (2007). A brief summary is given below.

The lumped conceptual daily rainfall-runoff model, SIMHYD, with a Muskingum routing method 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 rainfall-runoff model is calibrated against 1975 to 2006 streamflow from about 180 small and medium size unregulated catchments (50 to 2000 km^2). In the model calibration, the six parameters of SIMHYD are optimised to maximise an objective function that incorporates the Nash-Sutcliffe efficiency 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 runoff for a 0.05^{o} grid cell in an ungauged subcatchment is modelled using optimised parameter values for a calibration catchment closest to that subcatchment.

The rainfall-runoff model SIMHYD is used because it is simple and has relatively few parameters 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. 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 may lead to better model calibration for the specific modelling objectives of the area.

3.2.2 Rainfall-runoff modelling for the Namoi region

The rainfall-runoff modelling is done to estimate runoff in 0.05^{o} grid cells in 29 subcatchments as defined for the river system modelling in Chapter 4 for the Namoi region (Figure 3-1). Optimised parameter values from eight calibration catchments are used. Seven of these calibration catchments are in the Namoi region and their optimised parameter values are used for the subcatchments in the middle and eastern parts of the region. The other calibration catchment is in the Macquarie-Castlereagh region southwest of the Namoi region (not shown in Figure 3-1). Its optimised parameter values are used for the subcatchments in the westernmost parts of the Namoi region.

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

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 in the Namoi region.

The increase in farm dams in each subcatchment is estimated as the lower of the available harvestable right volumes based on current policy control and the projected additional storage volume based on extrapolation of historical farm dam growth rate. This resulted in an estimated increase of 19,500 ML in farm dam storage volume by ~2030 over the entire Namoi region. The projected increase in farm dam storage volumes for each subcatchment is given in Appendix A.

The farm dam projection is dependent on three factors: current farm dam storage volume, growth rate of farm dams; and maximum harvestable right volumes in New South Wales (NSW Government, 2000). The current farm dam storage volume is estimated from the satellite imagery captured between 2004 and 2006 (Geosciences Australia, 2007). The limited farm dam data from Agrecon (2005) for 1999 to 2004, which covers less than 1 percent of New South Wales, indicates a growth rate of up to 4 percent in northeastern New South Wales and 0.6 percent elsewhere. The higher estimates are unreliable as they are partly influenced by inclusion of some large on-farm irrigation storages outside of the main runoff producing areas in the analyses (D. Black and R. Beecham, pers. comm.). Furthermore, the New South Wales harvestable rights policy is framed so that the amount of water that can be stored is adequate of stock and domestic requirements but not enough to sustain any economically significant on-farm irrigation (D. Black and R. Beecham, pers. comm.). For these reasons the lower rate of 0.6 percent was used to model farm dam growth in New South Wales.

The maximum harvestable right volume is estimated by multiplying the area of each land parcel by the harvestable right dam capacity per unit area multiplier for that property and then aggregating the values for all of the individual properties across the region. The maximum harvestable right volume across rural land in the Namoi region is about 199,000 ML. The estimate of current farm dam storage volume over the entire Namoi is about 145,000 ML, with these farm dams utilising about 57,000 ML of the harvestable right volume. There are farm dams capturing more than the maximum harvestable right volume that was later defined by the Water Management Act 2000. The available harvestable right volume is therefore about 142,000 ML. The projection of a 19,500 ML increase in farm dam storage volume over the entire Namoi by ~2030 is therefore an increase of about 13 percent of current farm dam storage volume and about 14 percent of the available harvestable right volume.

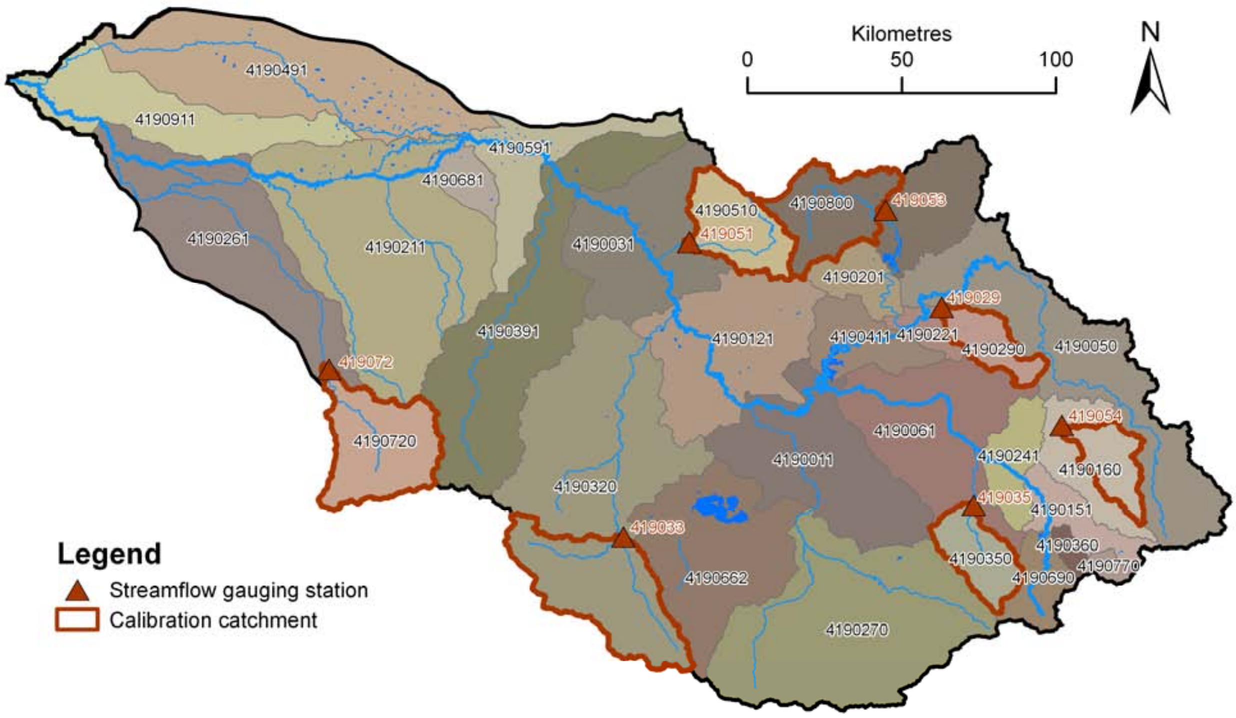

Figure 3-1. Map of modelling subcatchments and calibration catchments

3.2.3 Model calibration

Figure 3-2 compares the modelled and observed monthly runoff and the modelled and observed daily flow duration curves for the 8 calibration catchments. The results indicate that the SIMHYD calibration can reproduce reasonably satisfactorily the observed monthly runoff series (Nash-Sutcliffe E values generally greater than 0.7) and the daily flow duration characteristic (Nash-Sutcliffe E values generally greater than 0.8). The volumetric constraint used in the model calibration ensures that the total modelled runoff is within 5 percent of the total observed runoff.

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

The runoff estimates for the Namoi region are relatively good because there are many calibration catchments in the region 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 runoffs for ungauged catchments are under or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in more than half the catchments and by less than 50 percent in almost all the catchments.

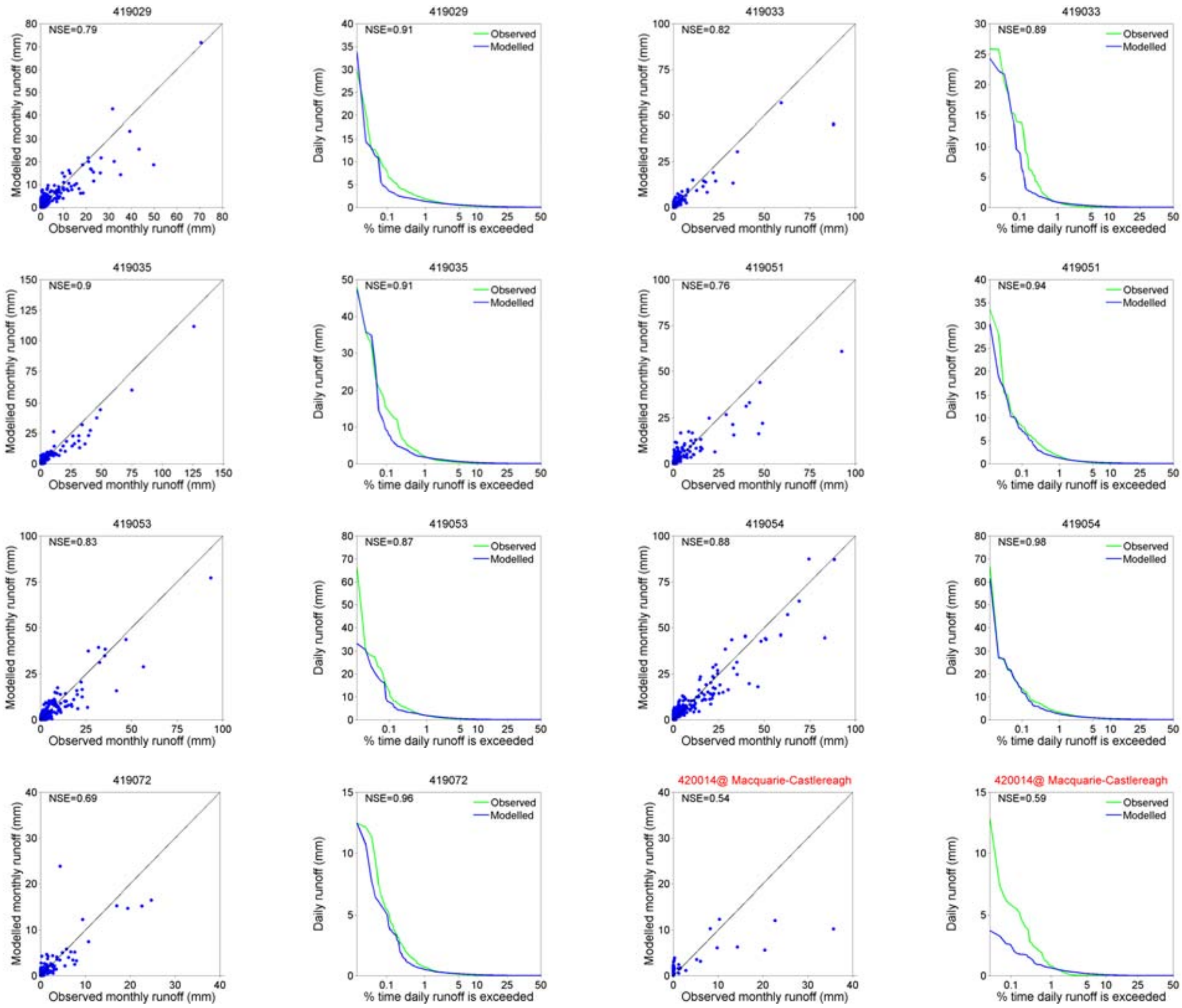

Figure 3-2. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

3.3 Modelling results

3.3.1 Scenario A – historical climate and current development

Figure 3-3 shows the spatial distribution of mean annual rainfall and modelled runoff for 1895 to 2006 across the Namoi 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 Namoi region are 633 mm and 24 mm respectively. The mean annual rainfall varies from about 1000 mm in the east to 450 mm in the west. The modelled mean annual runoff varies from 150 mm in the east to 5 mm in the west (Figure 3-3). Rainfall is generally higher in the summer half of the year and runoff is fairly uniform throughout the year (Figure 3-5). The Namoi region covers about 3.8 percent of the MDB and contributes about 3.2 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 Namoi are 0.25 and 0.82 respectively, close to the median values in the 18 MDB regions. The 10th percentile, median and 90th percentile values across the 18 regions are 0.22, 0.26 and 0.36 respectively for rainfall and 0.54, 0.75 and 1.19 for runoff. The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 5 percent and 17 percent higher respectively than the 1895 to 2006 long-term means. However, because of the inter-annual variability and the relatively short ten-year period used as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the 1895 to 1996 long-term means even at a significance level α = 0.2 (with the Student-t and Rank Sum tests). Potter et al. (2007) present a more detailed analysis of recent rainfall and runoff across the MDB.

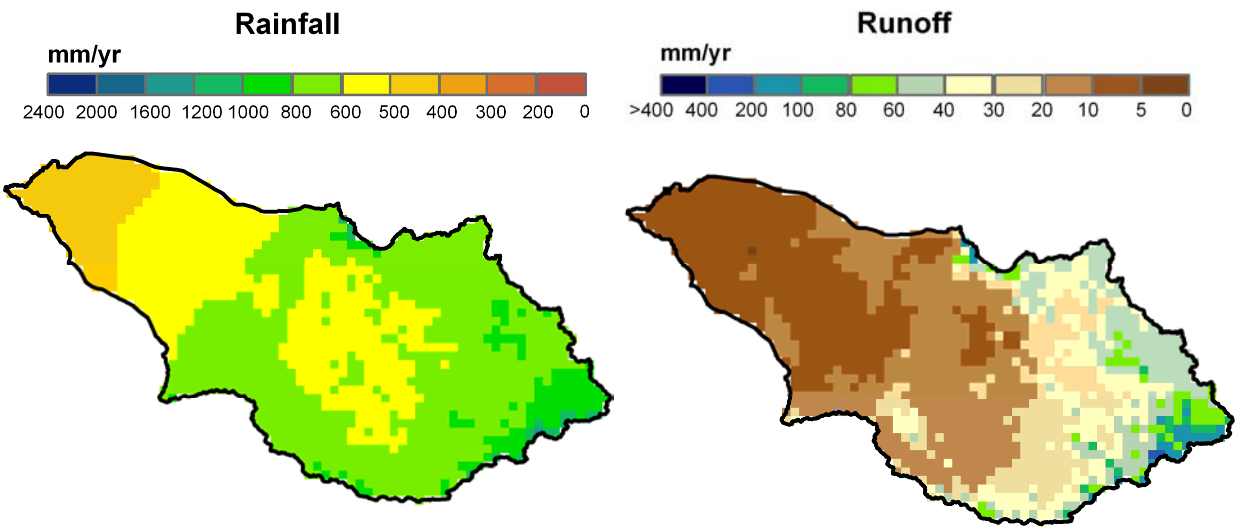

Figure 3-3. Spatial distribution of mean annual rainfall and modelled runoff averaged over 1895–2006

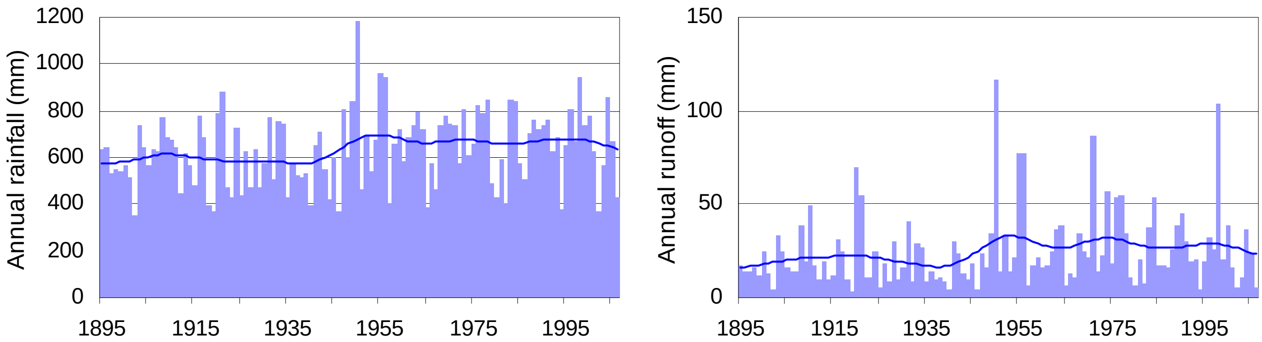

Figure 3-4. 1895–2006 annual rainfall and modelled runoff series averaged over the region (the curve shows the low frequency variability)

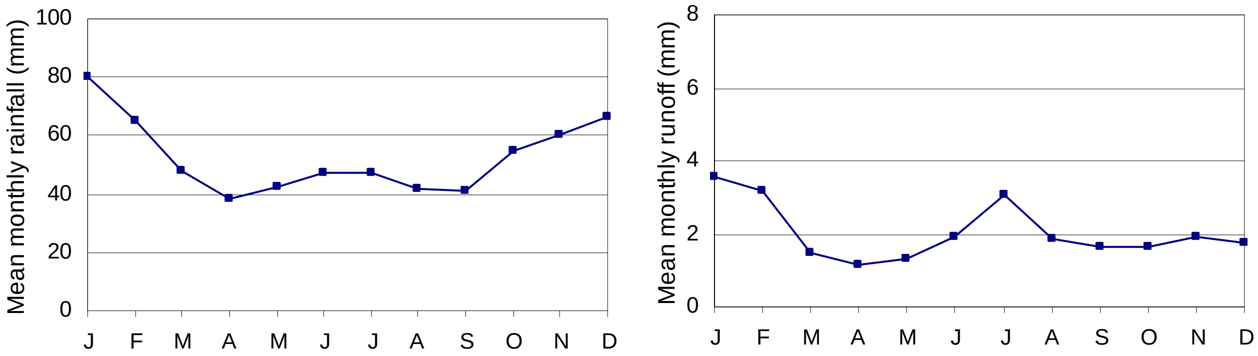

Figure 3-5. Mean monthly rainfall and modelled runoff (averaged over 1895–2006 for the region)

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 Namoi region under Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and the percentage change in mean annual rainfall from the corresponding GCMs are also tabulated in Table 3-1.

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

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

In subsequent reporting here and in other sections, only results from an extreme ‘dry’, ‘mid’ and extreme ‘wet’ variant are shown (referred to as Cdry, Cmid and Cwet). For the Cdry scenario, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. For the Cwet scenario, results from the second highest increase in mean annual runoff from the high global warming scenario are used. For the Cmid scenario, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table 3-1, with the Cdry, Cmid and Cwet scenarios indicating -31, -6 and +39 percent changes in mean annual runoff. By comparison, the range based on the low global warming scenario is -10 to +10 percent change in mean annual runoff.

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

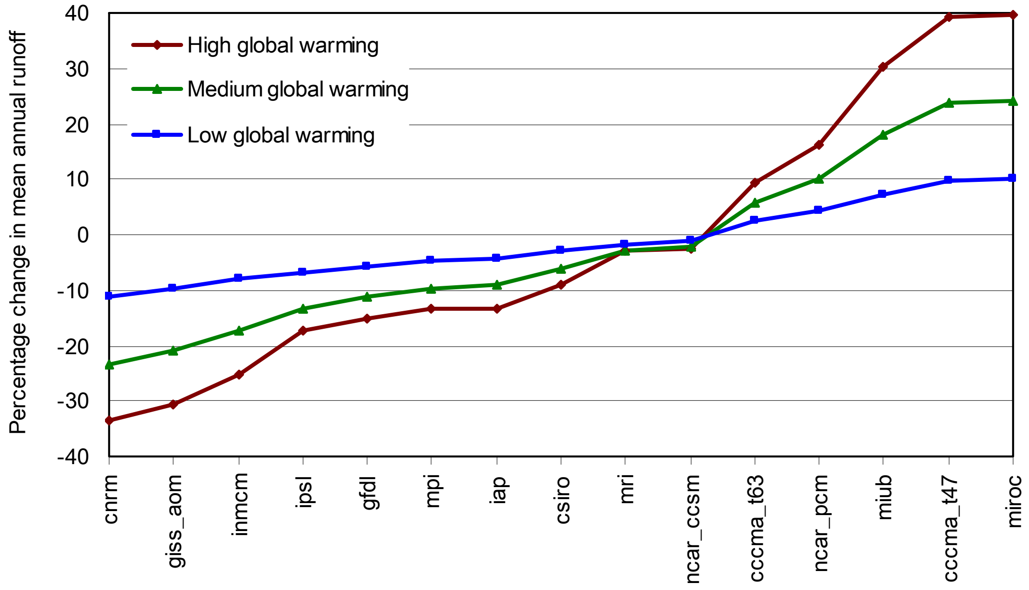

Figure 3-6. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A runoff

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

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Runoff	GCM	Rainfall	Runoff	GCM	Rainfall	Runoff
cnrm	-10	-33	cnrm	-7	-23	cnrm	-3	-11
giss_aom	**-10**	**-31**	giss_aom	-6	-21	giss_aom	-3	-10
inmcm	-7	-25	inmcm	-4	-17	inmcm	-2	-8
ipsl	-3	-17	ipsl	-2	-13	ipsl	-1	-7
gfdl	-4	-15	gfdl	-2	-11	gfdl	-1	-6
mpi	-6	-13	mpi	-4	-10	mpi	-2	-5
iap	-3	-13	iap	-2	-9	iap	-1	-4
csiro	-3	-9	**csiro**	**-2**	**-6**	csiro	-1	-3
mri	-3	-3	mri	-2	-3	mri	-1	-2
ncar_ccsm	2	-3	ncar_ccsm	1	-2	ncar_ccsm	1	-1
cccma_t63	5	9	cccma_t63	3	6	cccma_t63	2	3
ncar_pcm	5	16	ncar_pcm	3	10	ncar_pcm	1	4
miub	8	30	miub	5	18	miub	2	7
cccma_t47	**13**	**39**	cccma_t47	8	24	cccma_t47	4	10
miroc	12	39	miroc	8	24	miroc	3	10

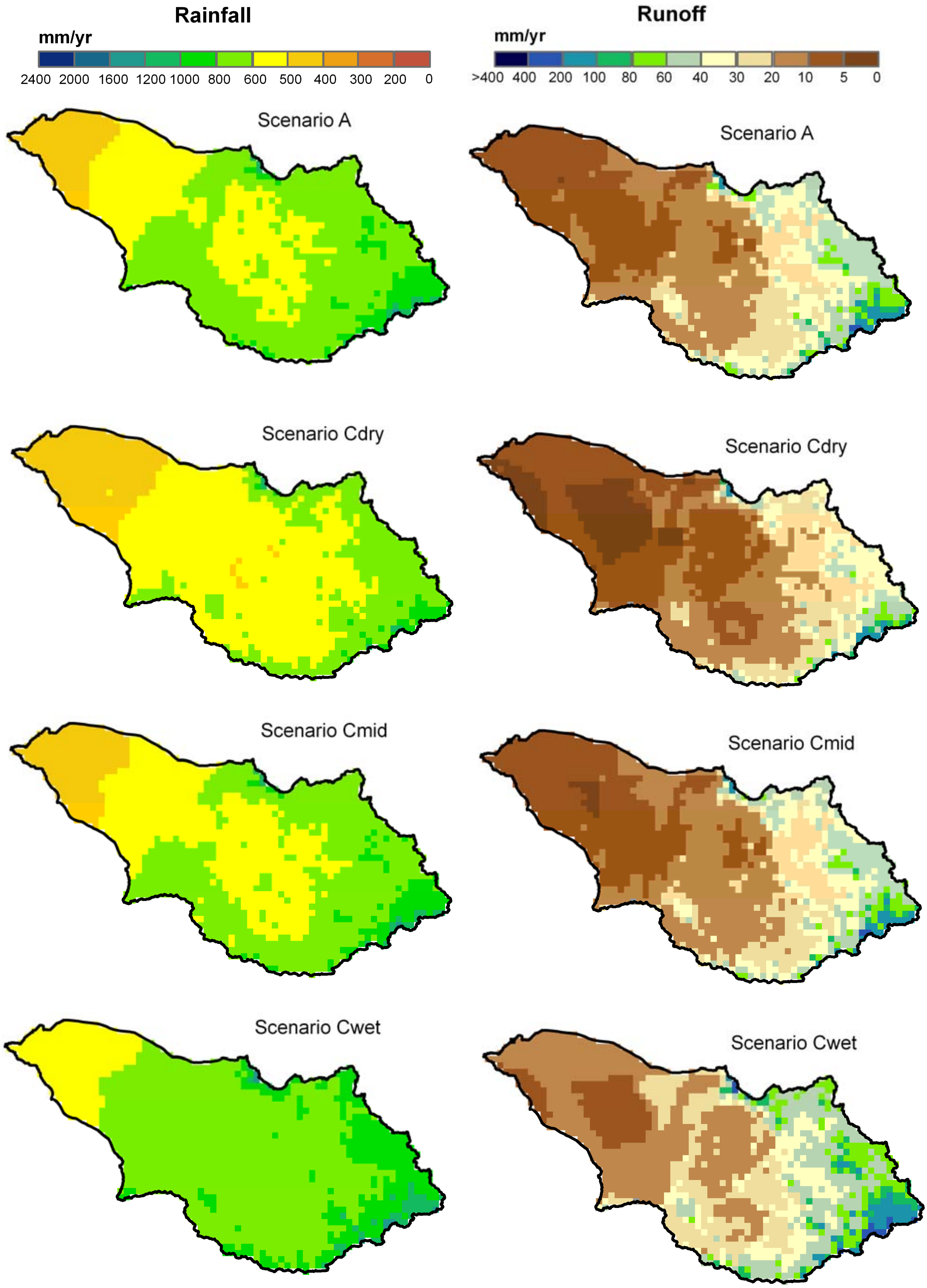

Figure 3-7. Mean annual rainfall and modelled runoff under scenarios A, Cdry, Cmid and Cwet

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 Namoi 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 Namoi region are summarised in Appendix A.

The Cmid (or Cdry or Cwet) results are from rainfall-runoff modelling using climate change projections from one GCM. As the Cmid scenario is chosen based on mean annual runoff (Section 3.3.2), the comparison of monthly and daily results in Scenario Cmid relative to Scenario A in Figure 3-8 and Figure 3-9 should be interpreted cautiously. However, the C range results shown in Figure 3-8 are based on the second driest and second wettest results for each month separately from the high global warming scenario, and the C range results shown in Figure 3-1 are based on the second lowest and second highest daily rainfall and runoff results at each of the rainfall and runoff percentiles from the high global warming scenario. The lower and upper limits of C range are therefore not the same as the Cdry and Cwet scenarios reported elsewhere and used in the river system and groundwater models. Although two-thirds of the GCMs show a reduction in mean annual rainfall, more than half of the GCMs indicate that the extreme rainfall that is exceeded 0.1 percent of the time will be more intense (Figure 3-9).

As explained earlier, Scenario B (recent climate and current development) modelling was not carried out for the Namoi region because the mean annual rainfall and modelled runoff for 1997 to 2006 are not statistically significantly different to the long-term means. The Scenario B results would therefore be essentially the same as the Scenario A results.

The modelling results indicate a best estimate of -6 percent change in mean annual runoff by ~2030 (Scenario C). However, there is considerable uncertainty in the climate change impact estimate with extreme estimates ranging from -31 to +39 percent.

The projected growth in commercial forestry plantations in the Namoi region is negligible. The total farm dam storage volume over the entire Namoi region is projected to increase by 19,500 ML by 2030. The modelled reduction in mean annual runoff from the projected increase in farm dams alone is about 1.5 percent, about one-quarter of the median climate change impact on runoff. The median estimate of the combined impact of climate change and farm dam development (Scenario D) is a 7 percent reduction in mean annual runoff (with extreme estimates from -32 to +38 percent).

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

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	633	24	609
		percent change from Scenario A	
B	–	–	–
Cdry	-10%	-31%	-9%
Cmid	-2%	-6%	-2%
Cwet	13%	39%	12%
Ddry	-10%	-32%	-9%
Dmid	-2%	-7%	-2%
Dwet	13%	38%	12%

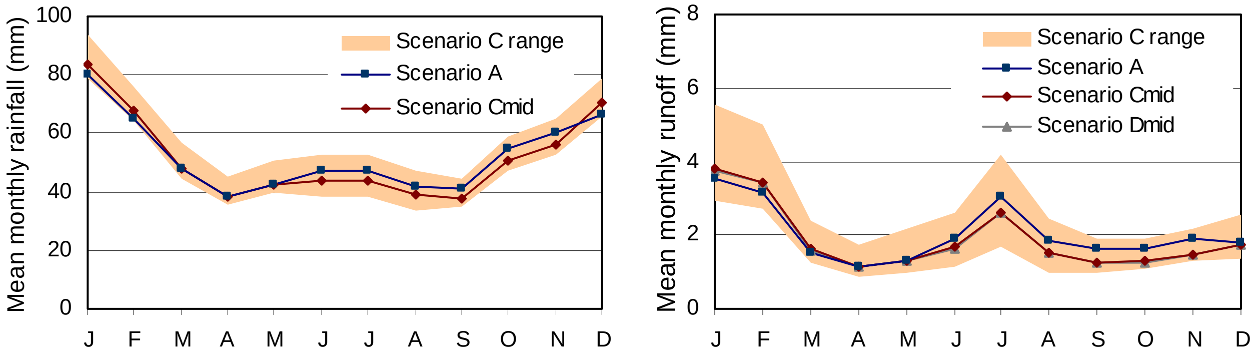

Figure 3-8. Mean monthly rainfall and modelled runoff under scenarios A, C and D averaged over 1895–2006 across the region (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

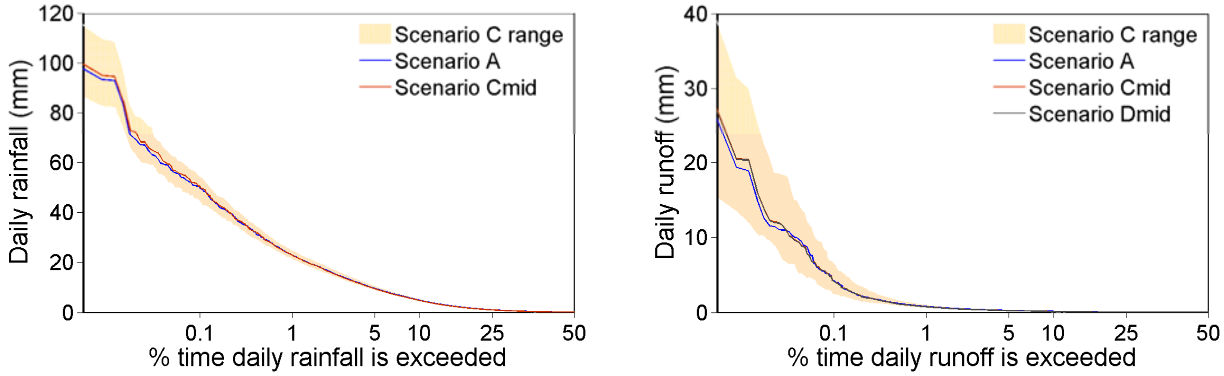

Figure 3-9. Flow duration curves for daily rainfall and runoff under scenarios A, C and D averaged over the region (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

3.4 Discussion of key findings

The mean annual rainfall and modelled runoff averaged over the Namoi region are 633 mm and 24 mm respectively. The mean annual rainfall varies from about 1000 mm in the east to 450 mm in the west. The modelled mean annual runoff varies from 150 mm in the east to 5 mm in the west. Rainfall is generally higher in the summer half of the year and runoff is fairly uniform throughout the year. The Namoi region covers about 3.8 percent of the MDB and contributes about 3.2 percent of the total runoff in the MDB.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 5 percent and 17 percent higher respectively than the 1895 to 2006 long-term means. However, because of the inter-annual variability and the relatively short ten-year period used as the basis for comparison, the 1997 to 2006 rainfall and runoff are not statistically different to the 1895 to 1996 long-term means, even at a significance level $\alpha = 0.2$.

The runoff estimates for the Namoi region are relatively good because there are many calibration catchments in the region from which to estimate the rainfall-runoff model parameter values.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Namoi region is more likely to decrease than increase. Two-thirds of the modelling results show a decrease in mean annual runoff and one-third shows an increase in mean annual runoff. However, although two-thirds of the results indicate a decrease in mean annual rainfall and runoff, more than half of the results also indicate that the extreme rainfall and runoff events will be more intense.

The median estimate is a 6 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 -31 to +39 percent. These extreme estimates come from the high global warming scenario, and for comparison the range from the low global warming scenario is a -10 to +10 percent change in mean annual runoff. The main sources of uncertainty are in the global warming projections and the global climate modelling of local rainfall response to the global warming. The uncertainty in the rainfall-runoff modelling of climate change impact on runoff is small compared to the climate change projections.

The projected growth in commercial forestry plantations in the Namoi region is negligible. The total farm dam storage volume over the entire Namoi region is projected to increase by 19,500 ML by ~2030. The modelled reduction in mean annual runoff from the projected increase in farm dams alone is about 1.5 percent, about one-quarter of the median climate change impact on runoff. The median estimate of the combined impact of climate change and farm dam development is a 7 percent reduction in mean annual runoff (with extreme estimates ranging from -32 to +38 percent).

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

3.5 References

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4 River system modelling

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

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

The information in this chapter comes from the calibrated IQQM models for the Peel and Namoi river systems of the New South Wales Department of Water and Energy (DWE) (DIPNR, 2005 and 2006).

4.1 Summary

4.1.1 Issues and observations

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

- Scenario O
  This scenario represents the latest version of the water sharing plan river system model supplied by New South Wales DWE. It covers the planning period 1 October 1892 to 30 June 2006 with the 2003/04 level of development.
- Scenario A0
  This scenario incorporates the Scenario O model but covers the shorter common historical climate period (1 June 1895 to 30 June 2006) and represents 2003/04 levels of development. It does not include the effects of current groundwater extraction at dynamic equilibrium.
- Scenario A – historical climate and current development
  This scenario incorporates Scenario A0 and the effects of current groundwater extraction at dynamic equilibrium. It is a baseline for comparison with all other scenarios.
- Scenario P – pre-development
  This scenario incorporates the model for Scenario A0 and covers the common historical climate period. Current levels of development such as public storages and demand nodes are removed from the model to represent pre-development conditions. Natural water bodies, fixed diversion structures and existing catchment runoff characteristics are not adjusted.
- 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 for the Scenario A current level of development.
- Scenario D – future climate and future development
  Scenarios Dwet, Dmid and Ddry incorporate Scenario C with flow inputs adjusted for the 2030 projected development in farm dams, commercial forestry plantations and groundwater. Future groundwater effects on river reaches are also considered. The farm dam and commercial forestry plantation projections are discussed in Chapter 3 while groundwater development is discussed in Chapter 6.

These scenarios may not eventuate but they describe consequences that might arise if no management changes were made. Consequently results from this assessment highlight pressure points in the system, both now and in the future. This assessment does not elaborate on what management actions might be taken to address any of these pressure points.

The Namoi region is described by the Peel and the Namoi river models. The Peel model joins the Namoi model at the Carrol Gap gauge (419006) on the Peel River.

The Peel model:

- represents general security usage with a fixed crop area. The crop area has been fixed to represent observed areas and the model has been calibrated to represent observed history of use
- simulates irrigation demands using a soil moisture accounting model with fixed areas and monthly demand patterns that ensure that historic water usage is replicated. Consequently the demands do not reflect the variation in demands due to change in area as a function of water availability
- reflects Tamworth town water supply by a demand that varies as a function of temperature and population. The temperature inputs are adjusted for each of the climate change scenarios and hence the model considers the change in demand due to climatic influences for the current population. Note that for Scenario D, population growth is not considered. The Tamworth town water supply is a high security user and has Dungowan Dam as its primary source of water. Chaffey Dam supplements the supply when Dungowan Dam falls below 50 percent. The only time Tamworth's demand will not be met is when both Dungowan and Chaffey dams are at dead storage capacity.

The Namoi model:

- represents the current level of irrigation development. This includes farm infrastructure, irrigated areas and the crop mix. The model also represents practices of farm storage use including floodplain and runoff harvesting. Modelled demands may not match history of use as farm development is not static over time
- simulates irrigation demands using a soil moisture accounting model with areas, soil depth, crop mixes, farm dams and farm infrastructure that best represents current levels of development. The model also includes a risk function that adjusts areas planted as a function of water availability. Consequently the model represents the change in demand as a function of available resource and climatic conditions
- reflects town water supplies and stock and domestic demands with a fixed demand pattern that does not vary with water availability or climatic conditions. The only time that these demands are not met is when supply storages reach dead storage capacity, as these are high security users.

Some of the irrigation nodes in the Namoi model represent combined surface water and groundwater use. The model constrains the total use based on allocation but treats the groundwater resources as infinite. The interaction between these extractions and groundwater models is not considered.

Analysis of the pre-development flows along the Namoi system indicates that the river changes from a gaining to a losing stream for the combination flows of the Namoi at Bugilbone gauge (419021) and Pian Creek (410049). The combined pre-development average annual flow at these locations over the modelling period is 888 GL/year.

There are subcatchments in the Namoi region that have significant irrigation development that is not included in the river system models. Three of the major subcatchments include the Mooki River (and it's tributaries), Lake Goran and Coxs Creek. The inflows for the Mooki River and Coxs Creek partially represent current use and are adjusted for climate change and future development and consequently represent the subsequent change of inflows into the Namoi river system; however, irrigation water use is these areas is not modelled explicitly. The Mooki River is covered by the Water Sharing Plan for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources (see Chapter 2). Lake Goran does not contribute any inflow to the Namoi River and consequently is not considered in this project.

4.1.2 Key messages

- The average total surface water resource in the Namoi region is 965 GL/year and on average about 359 GL/year (or 37 percent) of this water is used. This use is comprised of net surface water diversions of 260 GL/year and eventual total streamflow losses induced by groundwater use of 99 GL/year. This is a high level of development.
- Flows in the Namoi River are highly regulated. Split Rock Dam regulates 93 percent of all inflows and Keepit Dam regulates 77 percent of all inflows. Flows in the Peel River are less regulated with Chaffey Dam regulating 41 percent of all inflows.

- General security water in the Namoi system is highly utilised with 59 percent of the allocated general security water used. General security water in the Peel system is not highly utilised with 20 percent of the allocated general security water used.
- Current levels of groundwater extraction in the upper parts of the region are expected to eventually reduce average inflows to the main river system by 11.4 GL/year. Additionally, total streamflow losses of 6.1 GL/year and 19.3 GL/year would eventually occur in the Peel and Namoi rivers respectively as a result of current levels of groundwater extraction from the Peel alluvium and Upper and Lower Namoi alluvia. The streamflow loss to the Namoi alluvia would be offset by a 3.1 GL/year gain from groundwater elsewhere in the system; the net impact would thus be a 22.3 GL/year loss of streamflow to groundwater.
- Under the best estimate 2030 climate there would be a 5 percent reduction in water availability, an 8 percent reduction in end-of-system flows and a 1 percent reduction in diversions overall. Diversion impacts would differ between water products. General security water use would increase by 6 percent in the Peel system and decrease by 3 percent in the Namoi system. Surplus access and Tamworth town water use would increase by 1 percent, and high security stock and domestic use in the Namoi would decrease by 1 percent.
- The climate extremes for 2030 indicate:
  - under the wet extreme there would be increases of 38 percent in water availability, 52 percent in end-of-system flows and 10 percent in total diversions
  - under the dry extreme there would be decreases of 30 percent in water availability, 39 percent in end-of-system flows and 17 percent in total diversions
  - no reduction in Tamworth town water supply or Peel stock and domestic supply.
- Projected future development (additional groundwater extraction and farm dams) would reduce inflows (under the best estimate future climate) by 59 GL/year. Of this, 29 GL/year would be due to future farm dams and 30 GL/year would be due to future groundwater extraction. There would also be an additional 5 GL/year average reduction in streamflow due to increased net leakage to groundwater
- The impact of projected future development would be a further 3 percent reduction in inflows and a 14 percent increase in leakage to groundwater (in addition to the impacts of the best estimate 2030 climate). Total diversions would be affected considerably more by these future developments than by the best estimate 2030 climate. Diversions would reduce by an additional 4 percent to be 5 percent lower than current. The amplified impact on diversions is due to the leakage of streamflow to groundwater induced by additional groundwater extraction. The impact on average end-of-system flows would be a total reduction (development and climate impacts) of 11 percent. The relative level of use would be 41 percent – this is a very high level of development and is 4 percent higher than the current level.

4.1.3 Robustness

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

During this test, allocations were at zero percent for 24 years in the Peel and 30 years in the Namoi. Chaffey Dam was the only dam drawn down below active storage at 2360 ML. Both models behaved robustly.

The model response to increases and decreases in inflow was reasonable with the change in diversions and end-of-system flows consistent with the change in inflow. Mass balance over the modelling period was within 0.2 percent for all scenarios (Appendix B).

4.2 Modelling approach

This section provides a summary of the generic river modelling approach, a description of the Namoi and Peel river models and how the models were developed. Chapter 1 contains more details on the overall project methodology.

4.2.1 General

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

4.2.2 Model description

The Namoi region is described by the Namoi system models (Figure 4-1). The system is made up of two linked models: the Peel and the Namoi.

Peel model

The Peel is modelled by an IQQM V7.61.1 implementation of the river system. The model commences with headwater inflows from the Peel into Chaffey Dam and Dungowan Creek into Dungowan Dam. The model ends at the Carrol Gap gauge (419006). The outflow at Carrol Gap is an inflow into the Namoi model.

The model represents the Peel system with 67 links and 69 nodes arranged into nine river sections. There are no natural weir pools or floodplains included in the Peel model. There are two regulated storages in the model: Dungowan Dam and Chaffey Dam (Table 4-1). Dungowan Dam is used to supply Tamworth with water while Chaffey Dam supplies both Tamworth and downstream users. The model also includes a storage that models the surface and groundwater interactions in the near-river aquifers.

The water use is modelled by 11 nodes: five general security irrigators, five stock and domestic and Tamworth town water supply (Table 4-2). Tamworth town water supply is drawn from Dungowan Dam up to 22 ML/day with any excess demand passed to Chaffey Dam. When Dungowan Dam reaches 3000 ML storage capacity all demands are passed to Chaffey Dam, for water quality reasons.

The model includes minimum release requirements below each of the storages and at the end of the system. The minimum release requirement below Dungowan Dam is to release inflows up to 10 ML/day when the storage is above 4000 ML capacity. The minimum release requirement below Chaffey Dam is 10 ML/day but it cuts out when the storage reaches 30,000 ML. The minimum flow requirement at Carrol Gap is 10 ML/day from October to February and is supplied from Chaffey Dam.

Surplus flow events are shared across three reaches and supplementary water is declared above thresholds with 50 percent of the surplus volume being allocated for consumptive use. The thresholds for the upper two reaches are 60 ML/day from January to June and 30 ML/day from July to August. The threshold for the lower reach is 100 ML/day from January to May and 60 ML/day from June to December. Supplementary flows are shared to users on a licensed volume basis. There is no cap on surplus diversions, consequently, pump capacity limits the amount that can be diverted (Table 4-3).

Peel general security users operate under an annual accounting scheme. The maximum announced allocation level is 100 percent.

Namoi model

The Namoi is modelled by an IQQM V7.61.1 implementation of the river system. The model commences with headwater inflows from the MacDonald and Manilla rivers into Split Rock Dam and inflow from the Peel model. The model ends at Walgett (419091). The outflow at Walgett is an inflow into the Barwon-Darling region.

The model represents the Namoi system with 227 links and 228 nodes arranged into 21 river sections. There are no natural weir pools and floodplains included in the Namoi model. The model includes three storages: Split Rock Dam and Keepit Dam are the primary supply reservoirs with Mollee Weir as a downstream re-regulating structure (Table 4-1).

The water use is modelled by 80 nodes: 29 general security irrigators, 49 stock and domestic supplies and two town water supplies for Manilla and Walgett (Table 4-2). Note the results in the water sharing plan are based on 1999/00 development conditions while the model provided by DWE for this study represents development conditions for 2003/04.

The model includes minimum flow requirements below Split Rock and Keepit dams as well as an end-of-system minimum flow requirement. The minimum flow requirement below Split Rock Dam is 6 ML/day from October to March and 5 ML/day from April to September. The minimum flow requirement below Keepit Dam is 10 ML/day. The end-of-system minimum flow requirement is 21 ML/day in June, 24 ML/day in July and 17 ML/day in August. The model also includes some replenishment flow requirements at the end of Pian Creek. If there is no flow over five months prior to March or five months prior to September then water is ordered over a four-day period at 250 ML/day to cause flow through the creek.

The model includes maximum flow constraints below Split Rock Dam (1500 ML/day), Pian Creek (200 ML/day), Gunidgera Creek (120 ML/day) and Goangra Gauge (50 ML/day) (Table 4-3).

Supplementary access in the Namoi is declared above a threshold with 50 percent allocated for consumptive use from November to January and 10 percent from July to October. Surplus flows are shared to users on a licensed volume basis. There is a 117.3 GL annual cap on supplementary diversions.

Namoi general security users operate under a continuous accounting scheme. General security users can hold up to 200 percent of their entitlement in storage but are restricted to use 125 percent of their entitlement within a water year but can not use more than 300 percent over a three-year period.

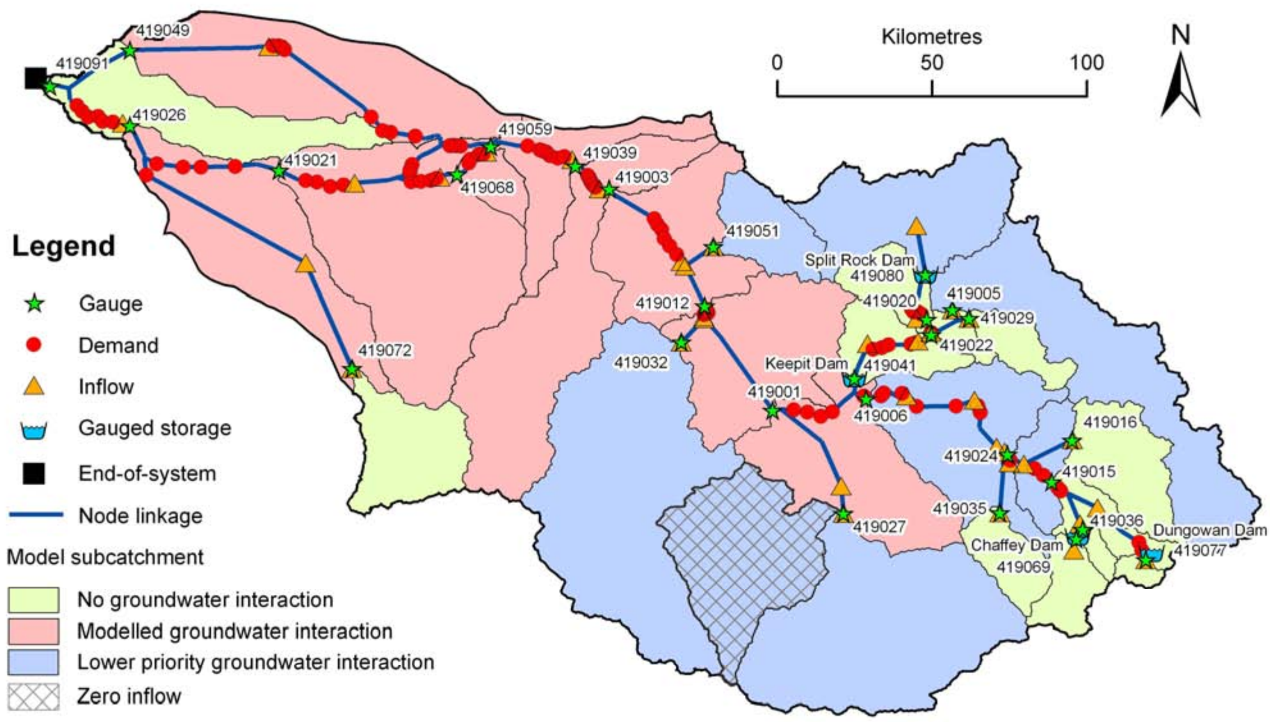


Figure 4-1. River system map showing model subcatchments, inflow nodes, links and gauge locations

Table 4-1. Storages in the river system model

	Active storage	Average annual inflow	Average annual release	Average annual net evaporation	Degree of regulation
	GL	GL/y			
Major supply reservoirs					
Split Rock Dam	394.2	72.3	38.3	28.9	0.93
Keepit Dam	419.0	355.9	211.7	62.3	0.77
Chaffey Dam	59.5	52.7	12.4	9.4	0.41
Dungowan Dam	5.9	13.8	9.8	0.9	0.78
Mollee Weir	2.45	760.4	193.5	1.4	0.26
Private storage	208.5			104.0	
Total	**1089.5**	**1255.2**	**465.7**	**207**	**0.45**

Table 4-2. Modelled water use configuration

Water users	Number of nodes	Licence	Pump constraints	Planted area	Model notes
		GL	ML/d	ha	
Peel					Soil moisture accounting separate store for each crop
General security	5	30.2	415	1,455	Fixed areas
Tamworth town water supply	1	16.4			Fixed demand
High security stock and domestic	5	0.8			Fixed demand
End-of-system flow target	2	1.5			Minimum flow for Peel River at Carrol Gap
Namoi					
General security	29	254.5	9,299	70,940	Soil moisture accounting separate store for each crop
Surplus	29	117.3			On farm storage at nodes
Town water supply	2	2.4			Fixed demand
High security stock and domestic	49	9.1			Fixed demand
Sub-total	**122**	**432**	**9,714**	**72,395**	
Crops					
Cotton				47,069	
Forage				8	
Lucerne				1,853	
Other				615	
Soybeans				1,969	
Summer cereal				12	
Summer crop				976	
Summer pasture				244	
Vegetables				10	
Wheat				33	
Winter cereal				199	
Winter crop				19,356	
Winter pasture				51	
Sub-total				**72,395**	

The irrigated areas reported in Chapter 2 are considerably larger than what is used in the river model. This is partly because a significant fraction of the irrigated area in the region is in the Mooki, Lake Goran and Coxs Creek subcatchments that is not included in the Namoi model as it is not supplied by regulated surface water. Inflows from there areas partially reflect current water use. In addition, there are large areas of irrigated cotton that depend solely on groundwater. These areas are not represented in the river model. The irrigated areas in the Namoi and Peel models are based on information supplied by irrigators and verified by New South Wales government meter inspectors.

Table 4-3. Model water management

Minimum flow requirements	
Below Split Rock Dam	6 ML/d from October–March and 5 ML/d from April–September
Below Keepit Dam	10 ML/d
Namoi River at Walgett	21 ML/d in June, 24 ML/d in July, and 17 ML/d in August
Below Chaffey Dam	The minimum of a function of storage or 10 ML/d
Below Dungowan Dam	Release inflows up to 10 ML/d if storage > 4000 ML
Peel River at Caroll Gap	10 ML/d from October–February, with no minimum flow at other times
Maximum flow constraints	
Split Rock Dam	Order cap of 1500 ML/d
Pian Creek	200 ML/d
Namoi River u/s Bugilbone	120 ML/d on return flows
Namoi River at Goangra	50 ML/d
Environmental flow requirements	
End of Pian Creek	Spring and Autumn requirement of 1000 ML over five months or orders of 250 ML/d over 4 days in either March or September
Surplus flow sharing	
Namoi declared above a threshold	Split 50% to the environment from November–January and 90% to the environment from July–October. It is then shared on a licence volume ratio basis by downstream users
Peel declared above a threshold	Split 50% to the environment and 50% shared equally by downstream users
Peel supplementary flow cap	No cap but limited by pump capacity
Namoi supplementary flow cap	117.3 GL/y
Accounting system	
Namoi system	Continuous accounting 200% max, 125% use/y but not exceeding 300% over 3 years
Peel system	Annual accounting 100% max
Additional information	
Tamworth orders	Sent to Dungowan until it falls below 50%, this is due to water quality problems in Dungowan
Tamworth town water supply	An important rule in the Namoi water sharing plan not modelled is growth in Tamworth town water supply demand which will be worn 5% by Peel irrigators and 95% by Namoi irrigators to meet cap conditions.

4.2.3 Model setup

The original Namoi and Peel river models and associated IQQM V7.61.1 executable code were obtained from DWE. These models were run for the original period of 1 October 1892 to 30 June 2006 and validated against previous results.

The time series rainfall, evaporation and flow inputs to this model did not require extension.

A pre-development version of the models was created by removing Chaffey Dam, Dungowan Dam, Split Rock Dam, Keepit Dam, Mollee Weir, all irrigators and fixed demands. Minimum and environmental flow requirements were also removed. Natural water storages and groundwater storages were not changed as they represent the pre-development physical characteristics of the system. Pian Creek and Gunidgera Creek distributaries were returned to their pre-development relationships. A consequence of this is a different distribution of flows in Pian Creek, Gunidgera Creek and the Namoi River.

The Namoi system contains a large amount of public and private storage. The initial state of these storages can influence modelling results. As the Namoi models start with a warm-up period from 1 June 1895 to 30 June 1895 the initial state of all the public storages and private irrigation storages needs to be determined.

To determine the initial storage state, the model was started with all of these storages empty and run up to 31 May 1895 and the final storage volumes were recorded. This was repeated with all of the storages initially full. The results of this analysis are presented in Table 4-4 and Table 4-5 and show that under both cases the storages converged to a similar result. Each storage was subsequently configured with these respective storage volumes.

The model was configured for an extreme dry climate scenario by applying seasonal factors to rainfall, evaporation and inflows (Table 4-4 and Table 4-5). The model was run and behaved robustly; Chaffey Dam went below active storage volume and general security allocations were zero for 24 years in the Peel and 30 years in the Namoi. Neither Keepit nor Split Rock dams went below active storage.

Table 4-4. Peel model setup information

Peel model setup information			Version	Start date	End date
Peel	IQQM		7.45.14	01/10/1892	30/06/2006
Connection					
Peel River at Carrol Gap	Outflows to the Namoi River upstream of Gunnedah				
Baseline models					
Warm up period				01/06/1895	30/06/1895
Peel	IQQM		7.61.1	01/07/1895	30/06/2006
Connection					
Peel River at Carrol Gap	Outflows to the Namoi River upstream of Gunnedah				
Modifications					
Data	No data extension required				
Inflows	Residual catchments with their own loss node reconfigured as a single time series input				
Groundwater loss and gain nodes	Added 2 loss nodes and no gain nodes				
Initial storage volume Chaffey		51 GL			
Initial storage volume Dungowan		4 GL			

Warm up test results				
Setting initial storage volumes	Storages commence empty	Storages commence full	Difference	Percent of full volume
	GL			percent
Chaffey Dam storage volume 31/05/1895	51.3	51.3	0	0%
Dungowan Dam storage volume at 31/05/1895	4.2	4.2	0	0%
Robustness test results (for final Cdry)				
Chaffey Dam (DSV 2360 ML)	1940			
Dungowan Dam (DSV 400 ML)	never			
Years allocation less than 0.5%	24 years			

Table 4-5. Namoi model setup information

Namoi model setup information		Version	Start date	End date
Namoi	IQQM	7.45.14	01/10/1892	30/06/2006
Connection				
Namoi River at Walgett	Outflows to the Barwon River			
Baseline models				
Warm up period			01/06/1895	30/06/1895
Namoi	IQQM	7.61.1	01/07/1895	30/06/2006
Connection				
Namoi River at Walgett	Outflows to the Barwon River			
Modifications				
Data	No data extension required			
Inflows	Residual catchments with their own loss node reconfigured as a single time series input			
Groundwater loss and gain nodes	Added 11 loss nodes and 8 gain nodes			
Initial storage volume Split Rock (GL)	397			
Initial storage volume Keepit (GL)	419			
Initial storage volume Mollee (GL)	0.8			
Initial storage volume for on-farm storages GL	136			
Warm up test results				
Setting initial storage volumes	Storages commence empty	Storages commence full	Difference	Percent of full volume
	GL			percent
Split Rock Dam storage volume 31/05/1895	231.4	388.9	157.5	39.6
Keepit Dam storage volume 31/05/1895	368.6	403.4	34.8	8.2
Mollee Weir storage volume 31/05/1895	0.6	0.7	0.1	3.3
Private on-farm storage volumes at 31/05/1895	20.9	24.0	3.1	1.5
Storage volume 31 May (1895–2006)				Median
				GL
Split Rock Dam				200.7
Keepit Dam				168.2
Mollee Weir				2.5
Private storages				25.8
Robustness test results (for final Cdry)				
Split Rock Dam (DSV 3160 ML)	never			
Keepit Dam (DSV 6550 ML)	never			
Years allocation less than 0.5%	30 years			

The Peel and Namoi models were configured for an extreme dry climate scenario by applying seasonal factors to rainfall, evaporation, inflows and temperature (see Table 4-6). The models were run and behaved robustly. Allocations in the Peel reached zero in 24 years and in the Namoi reached zero in 30 years. Chaffey Dam was the only storage to go below active storage (2360 ML).

Table 4-6. Rainfall, evaporation and flow factors and incremental temperature increase for Peel and Namoi model robustness test

Season	Rainfall	Evaporation	Flow	Temperature
		factor		°C
DJF	1.00	1.07	1.01	1.6
MAM	0.97	1.06	0.91	1.5
JJA	0.82	1.06	0.46	1.5
SON	0.88	1.08	0.65	1.9

4.3 Modelling results

4.3.1 River system water balance

The mass balance table (Table 4-7) shows the net fluxes for the Namoi River system. Scenario O (the original model scenario) fluxes, Scenario A0 (without groundwater at dynamic equilibrium) and Scenario A (with groundwater at dynamic equilibrium) fluxes are displayed as GL/year, while all other scenarios are presented as a percentage change from Scenario A. The averaging period for Scenario O differs from all other scenarios.

The directly gauged inflows represent the inflows into the model that are based on a river gauge. The indirectly gauged inflows represent the inflows that are derived to achieve mass balance between mainstream gauges. Diversions are listed based on the different water products in the region. End-of-system flows are shown for the Namoi River at the Walgett gauge (419091). The change in storage between 30 June 1895 and 30 June 2006 averaged over the 111-year period is also included. The net evaporation, rainfall harvesting and groundwater use of irrigators is displayed below the mass balance table but is not included in the mass balance as these are indirectly included in the diversion numbers for irrigators.

Appendix B contains mass balance tables for the 15 subcatchments in the model. The mass balance of each of these river reaches and the overall mass balance were checked by taking the difference between total inflows and outflows of the system. In all cases the mass balance error was less than 0.2 percent.

Table 4-7. River system model average annual water balance under scenarios O, A0, A, C and D

River system model average annual water balance	0	A0	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Oct-1892	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									
Public storages									
Split Rock Dam	0.3	-2.7	-2.8	-29%	1%	-1%	-23%	-4%	5%
Keepit Dam	-1.9	-3.0	-3.0	-5%	3%	10%	-5%	10%	7%
Chaffey Dam	-0.1	0.0	-0.1	-103%	104%	241%	-100%	116%	242%
Dungowan Dam	0.0	0.0	0.0	451%	-138%	-198%	450%	-141%	-198%
Mollee Weir	0.0	0.0	0.0	-47%	6%	-28%	-36%	-2%	-32%
Private storages	-0.8	-1.1	-1.1	-8%	0%	3%	-7%	1%	4%
Total change in storage	**-2.5**	**-6.8**	**-7.0**	**-31%**	**-13%**	**-9%**	**-29%**	**-12%**	**-8%**
Inflows									
Subcatchments									
Directly gauged	751.6	738.9	727.6	39%	-6%	-31%	34%	-12%	-36%
Indirectly gauged	1142.0	1133.5	1133.5	39%	-6%	-31%	37%	-8%	-33%
Sub-total	**1893.6**	**1872.4**	**1861.1**	**39%**	**-6%**	**-31%**	**36%**	**-9%**	**-34%**
Effluent return	0.0	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban returns	1.6	1.6	1.6	0%	0%	0%	0%	0%	0%
River groundwater gains	0.0	0.0	3.1	327%	-33%	-89%	214%	-65%	-50%
Sub-total	**1895.2**	**1874.0**	**1865.7**	**40%**	**-6%**	**-31%**	**36%**	**-9%**	**-34%**
Diversions									
Peel licensed private diversions									
General security (entitlement: 30.2 GL)	5.5	5.5	5.3	0%	6%	0%	0%	6%	-2%
Surplus (no cap)	0.8	0.8	0.9	0%	1%	16%	-1%	0%	17%
Town water supply (entitlement: 16.4 GL)	9.0	9.3	9.4	0%	1%	2%	0%	1%	2%
High security stock and domestic (entitlement: 0.8 GL)	0.3	0.2	0.2	0%	0%	0%	0%	0%	0%
Sub-total	**15.6**	**15.8**	**15.9**	**0%**	**2%**	**2%**	**0%**	**2%**	**1%**
Namoi licensed private diversions									
General security (entitlement: 254.5 GL)	196.1	198.0	191.2	10%	-3%	-19%	8%	-7%	-28%
Surplus (cap: 117.3 GL)	36.3	35.3	34.6	12%	1%	-11%	8%	-4%	-16%
Floodplain	16.6	16.5	16.4	27%	4%	-21%	25%	1%	-25%
Town water supply (entitlement: 2.4 GL)	0.1	0.1	0.1	0%	0%	0%	0%	0%	-1%
High security stock and domestic (entitlement: 9.1 GL)	1.4	1.4	1.4	0%	-1%	-1%	0%	-1%	-1%
Sub-total	**250.6**	**251.3**	**243.8**	**11%**	**-2%**	**-18%**	**9%**	**-6%**	**-26%**
Sub-total	**266.2**	**267.2**	**259.7**	**10%**	**-1%**	**-17%**	**9%**	**-5%**	**-24%**
Outflows									
End-of-catchment flows	594.3	590.8	583.0	52%	-8%	-39%	48%	-11%	-42%
River groundwater loss	0.0	0.0	25.4	-31%	7%	35%	-19%	21%	82%
Sub-total	**594.3**	**590.8**	**608.4**	**49%**	**-7%**	**-36%**	**45%**	**-10%**	**-37%**
Net evaporation public storages	53.0	52.9	51.5	11%	-3%	-13%	9%	-5%	-16%
Net evaporation from river channel	18.6	18.1	18.3	2%	6%	9%	1%	5%	9%
Sub-total	**665.9**	**661.8**	**678.2**	**49%**	**-4%**	**-31%**	**45%**	**-7%**	**-32%**
Unattributed fluxes									
River unattributed loss	964.8	950.8	933.8	41%	-9%	-35%	37%	-12%	-38%
Additional information (not in mass balance)									
Net evaporation private storages	52	52	52	3%	2%	-3%	3%	2%	-3%
Rainfall harvesting	79	78	79	15%	-2%	-9%	16%	-1%	-7%
Groundwater use	35	34	36	-17%	15%	53%	-14%	21%	64%

4.3.2 Inflows and water availability

Inflows

There are several ways to calculate total inflows into the river system. The obvious way is to sum all of the subcatchment inflows in the model. For the Namoi IQQM model this is 1861 GL/year (Table 4-7). The table also shows that a large proportion of the inflow is indirectly gauged and therefore estimated as part of model calibration. The approach used to calibrate these inflows varies considerably between model implementations. In some cases inflows are inflated and subsequently compensated for by loss relationships and in other cases the losses are inherent in the inflows. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of these different approaches to calibration.

An alternative to simply totalling modelled inflows is to locate the point of maximum average annual flow in the river system under pre-development conditions. As all river models are calibrated to achieve mass balance at mainstream gauges, the gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated. The pre-development scenario removes the influences of upstream extractions and regulation and gives a reasonable indication of total inflows. However, the subcatchment inflows used as input to the model include existing landuse (farm dams and forest cover) and groundwater use impacts. Additionally the calibrated reaches in the river model implicitly include losses to groundwater. Thus the pre-development scenario is not a representation of pre-European settlement conditions.

The pre-development model has been run for current climate and each of the C climate scenarios. These pre-development scenarios include projected impacts of current groundwater use in the Mooki River and Coxs Creek inflows. Hence to determine total surface water availability a proportional adjustment of pre-development water availability is required to remove these impacts. Additionally, a degree of streamflow leakage induced by current groundwater use in other parts of the region is implicitly included in the river model calibration. As this water is removed from the river due to groundwater extraction, another adjustment to the modelled pre-development water availability is required to assess the total pre-development surface water availability. In determining surface water availability for scenarios A and C no adjustments have been made for the impacts of existing farm dams or changes in forest cover. These impacts are not included as they are difficult to quantify and are not relevant for guiding future policy.

A comparison between scenarios for reaches along the Namoi is shown in Figure 4-2. Displaying this transect for the Namoi system is difficult as there are parallel inflow systems as well as a braided network at the end of the system. The headwater catchment is above Split Rock Dam in this analysis. The transect then follows the Namoi River down to Mollee Weir where the Pian Creek anabranch begins. After this point the combined flows of the Namoi and the Pian Creek and Gunidgera Creek anabranches are considered. Based on this description of the system the location of maximum average annual mainstream flow occurs at Bugilbone gauge (419021) plus the Pian Creek anabranch (419049). The total average annual river flow at this combined location is 888 GL/year for the pre-development Scenario A.

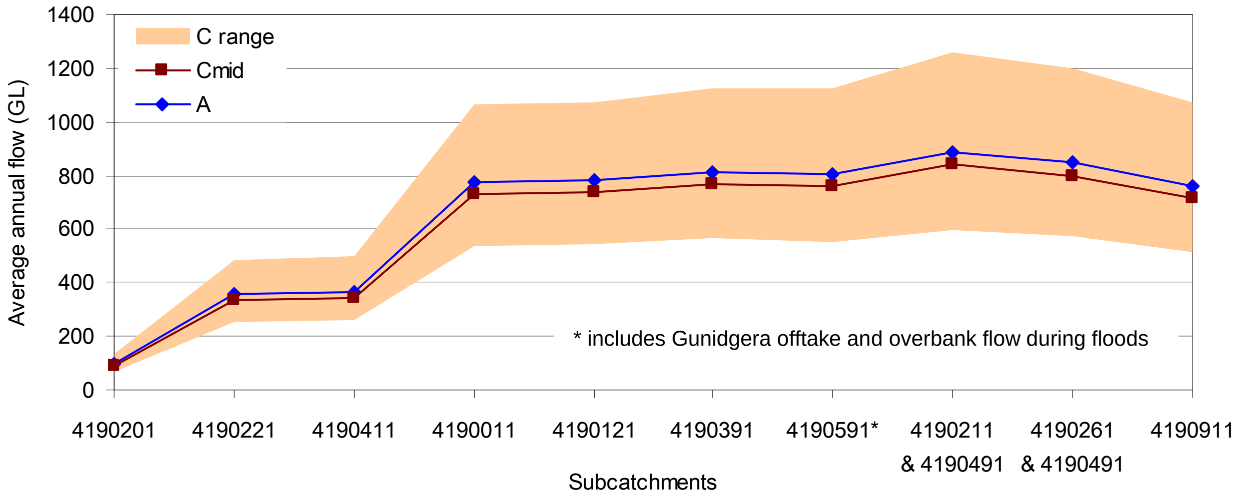


Figure 4-2. Transect of total river flow under pre-development scenarios A and C

Water availability

Table 4-8 shows (in GL/year):

- the maximum mainstream flow under pre-development scenarios A and C. For the Water Sharing Plan (DIPNR, 2004) the point of maximum water availability was taken at Narrabri (a combination of 419003 and 419002) and is based on Scenario O. The value at Narrabri in the Water Sharing Plan is 870 GL/year. The assessed maximum mainstream flow of 888 GL/year (Table 4-8) differs from the Water Sharing Plan value because it is for a different location, is for pre-development conditions, includes groundwater development impacts on inflows from Mooki River and Coxs Creek and is for a shorter modelling period
- the reduction in mainstream flow (at the point of maximum flow) caused by subcatchment inflow reductions that have been included in the model to reflect current groundwater use. This reduction is a combination of groundwater use included in the A scenario inflows (11.3 GL/year) and groundwater use implicit in the existing inflows (10 GL/year). These are then factored based on A scenario maximum average mainstream flow (888 GL/year) divided by total inflows (1861 GL/year)
- the reductions in mainstream flow (at the point of maximum flow) caused by leakage that is induced by current groundwater use and that is implicitly included in the river model calibration (67 GL/year)
- the total surface water availability which is the sum of the above three components.

Table 4-8. Average annual surface water availability under pre-development scenarios A and C

	A	Cwet	Cmid	Cdry
	GL/y			
Modelled pre-development maximum average mainstream flow	888	1259	838	599
Mainstream flow reductions				
Due to reductions in inflows caused by current groundwater use	10	10	10	10
Due to leakage induced by current groundwater use implicit in model calibration	67	67	67	67
Total	**965**	**1336**	**915**	**677**
		percent change from Scenario A		
Change in surface water availability		38%	-5%	-30%

A time series of total annual surface water resource under pre-development Scenario A is shown in Figure 4-3. The lowest annual total surface water availability was 147 GL in 2002 while the greatest total surface water availability was 6264 GL in 1920. Figure 4-4 shows the difference in total annual surface water resource from pre-development Scenario A to pre-development Scenario C.

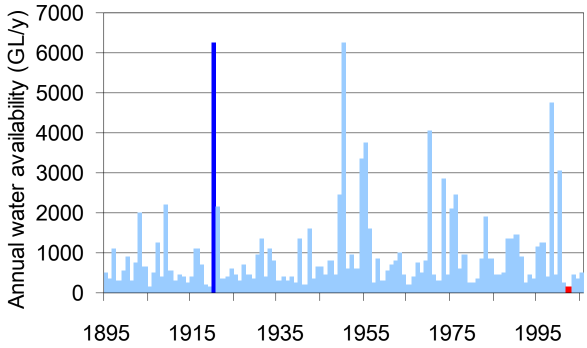


Figure 4-3. Total surface water availability under pre-development Scenario A

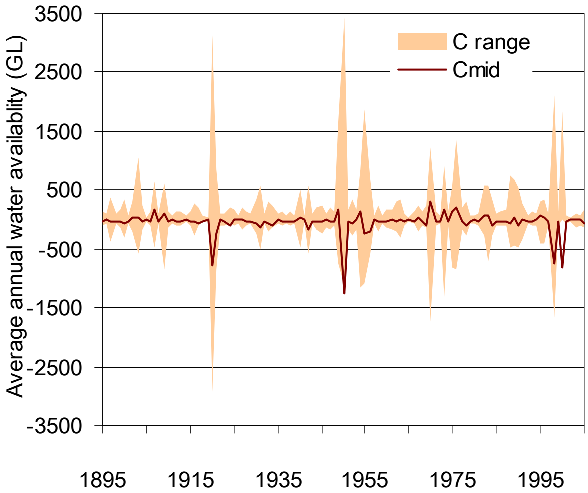


Figure 4-4. Time series of change in total surface water availability relative to pre-development Scenario A under pre-development Scenario C

4.3.3 Storage behaviour

The modelled behaviour of major public storages gives an indication of the level of regulation of a system as well as how reliable the storage is during extended periods of low or no inflows. Table 4-9 shows the lowest recorded storage volume and the corresponding date for Chaffey, Dungowan, Split Rock and Keepit dams for each of the scenarios. The average and maximum years between spills is also provided. The period between spills commences when the storage exceeds full supply volume and ends when the storage falls below 90 percent of full supply volume. The end condition is applied to remove the periods when the dam is close to full and oscillates between spilling and just below full which distorts the analysis.

Table 4-9. Details of storage behaviour for Chaffey Dam, Dungowan Dam, Split Rock Dam and Keepit Dam under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Chaffey Dam							
Minimum storage volume (GL)	14.71	19.31	12.56	2.34	18.6	10.94	2.27
Minimum storage date	21/5/1981	31/5/1966	24/4/1983	10/12/1940	31/5/1966	24/4/1983	10/12/1940
Average years between spills	1.1	0.9	1.2	1.6	0.9	1.2	1.6
Maximum years between spills	5.6	3.3	5.9	13.3	3.3	5.9	13.3
Dungowan Dam							
Minimum storage volume (GL)	2.31	2.59	1.99	1.66	2.59	1.99	1.66
Minimum storage date	29/12/1982	20/8/1902	29/12/1982	29/12/1982	20/8/1902	29/12/1982	29/12/1982
Average years between spills	1	0.4	1.4	2.9	0.4	1.4	2.9
Maximum years between spills	4.8	1.9	6.5	14.5	1.9	6.5	14.5
Split Rock Dam							
Minimum storage volume (GL)	55.37	70.92	55.27	44.31	76.77	30.34	3.11
Minimum storage date	16/11/1995	23/4/1983	16/11/1995	21/5/1981	23/4/1983	16/11/1995	16/11/1995
Average years between spills	7.1	4.4	9.7	13.9	4.7	9.8	17.7
Maximum years between spills	27.4	14.5	38.5	53.8	14.6	38.7	53.9
Keepit Dam							
Minimum storage volume (GL)	6.96	10.25	7.11	7.03	9.10	6.91	7.03
Minimum storage date	24/5/1920	27/10/1994	12/5/1995	15/5/1920	17/5/1995	14/5/1920	26/2/1995
Average years between spills	2.9	1.9	3.4	6.5	1.9	3.1	6.6
Maximum years between spills	13.5	7.8	13.5	16.6	12.8	13.5	16.6

The time series of storage behaviour for Chaffey, Dungowan, Split Rock and Keepit dams under Scenario A and the change under scenarios C and D are shown in Figure 4-5 to Figure 4-8.

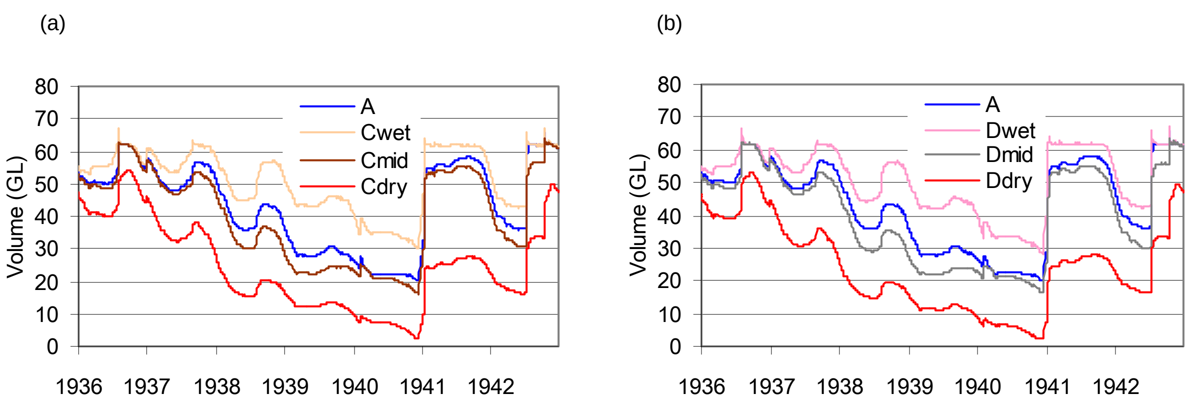


Figure 4-5. Chaffey Dam behaviour over the maximum days between spills under Scenario A and change in storage behaviour under (a) Scenario C and (b) Scenario D

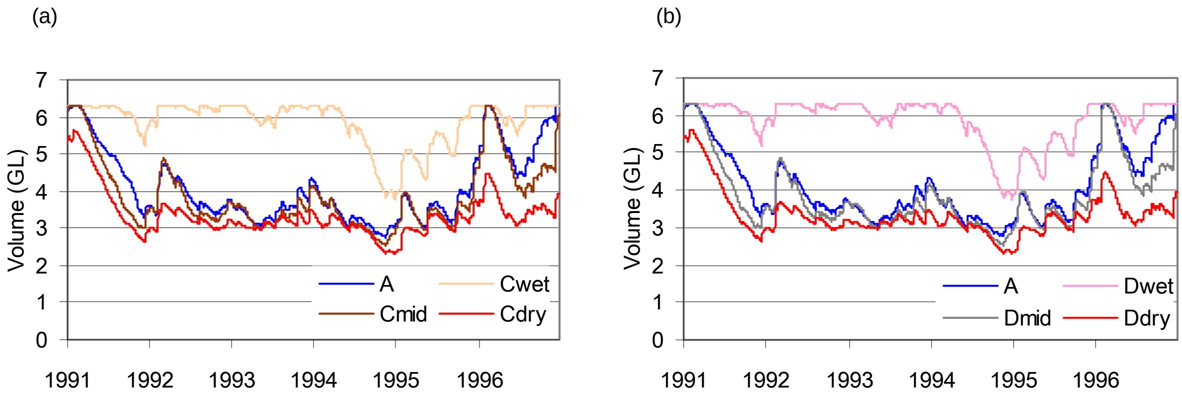


Figure 4-6. Dungowan Dam behaviour over the maximum days between spills under Scenario A and change in storage behaviour under (a) Scenario C and (b) Scenario D

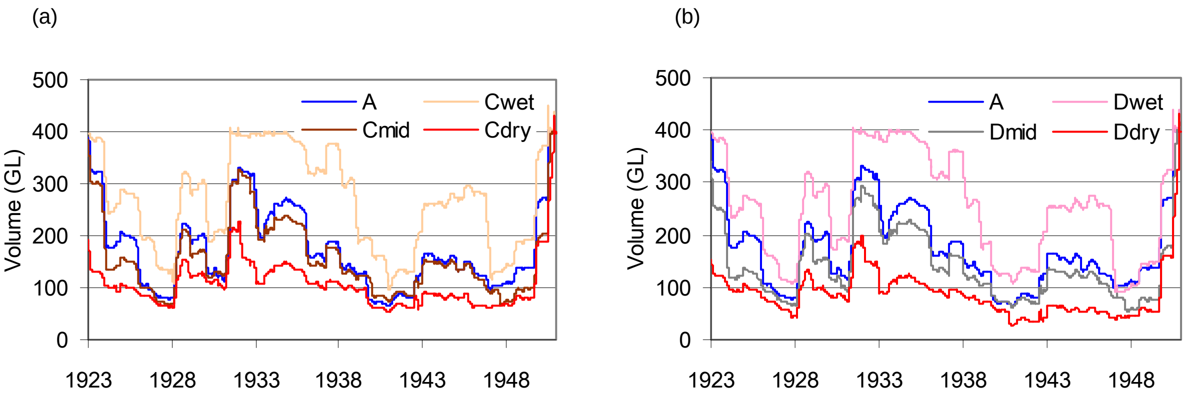


Figure 4-7. Split Rock Dam behaviour over the maximum days between spills under Scenario A and change in storage behaviour under (a) Scenario C and (b) Scenario D

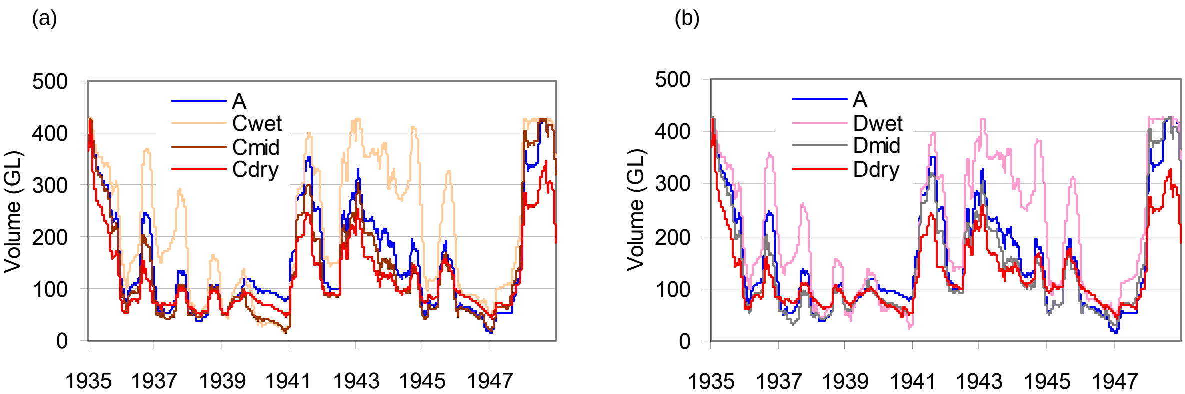


Figure 4-8. Keepit Dam behaviour over the maximum days between spills under Scenario A and change in storage behaviour under (a) Scenario C and (b) Scenario D

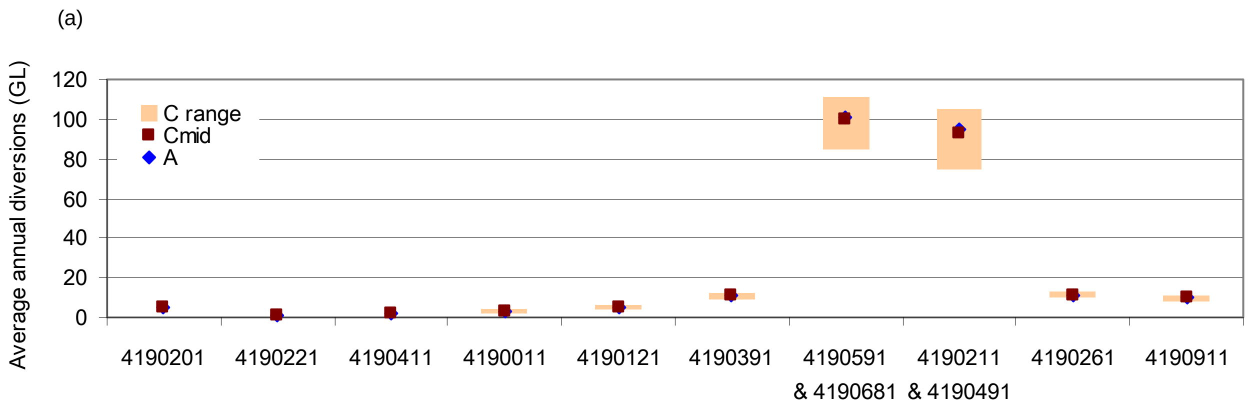
4.3.4 Consumptive water use

Diversions

Table 4-10 shows the total average annual diversions for each subcatchment under Scenario A and the percentage change of all other scenarios compared to Scenario A. Figure 4-9 shows total average annual diversions under scenarios A, C and D from upstream to downstream.

Table 4-10. Change in total diversions in each subcatchment relative to Scenario A

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Reach	GL/y	percent change from Scenario A					
Peel system							
4190151	8.4	8%	-5%	-25%	8%	-5%	-26%
4190241	3.4	-19%	20%	73%	-19%	20%	73%
4190061	4.0	1%	4%	-1%	1%	3%	-3%
Namoi system							
4190201	4.7	1%	7%	-1%	1%	2%	-13%
4190221	0.7	-3%	5%	5%	-3%	3%	-3%
4190411	1.9	0%	8%	2%	0%	3%	-11%
4190011	3.1	15%	-4%	-22%	13%	-8%	-31%
4190121	5.5	15%	-4%	-24%	14%	-8%	-32%
4190391	11.0	14%	-2%	-17%	13%	-5%	-25%
4190591	79.8	10%	-1%	-16%	8%	-5%	-24%
4190681	21.3	12%	-2%	-17%	10%	-6%	-26%
4190211	52.7	11%	-1%	-17%	10%	-5%	-25%
4190261	11.1	19%	0%	-13%	16%	-4%	-20%
4190911	10.0	15%	-2%	-17%	12%	-5%	-22%
4190491	42.1	10%	-4%	-26%	9%	-8%	-35%
Total	**259.7**	**10%**	**-1%**	**-17%**	**9%**	**-5%**	**-24%**



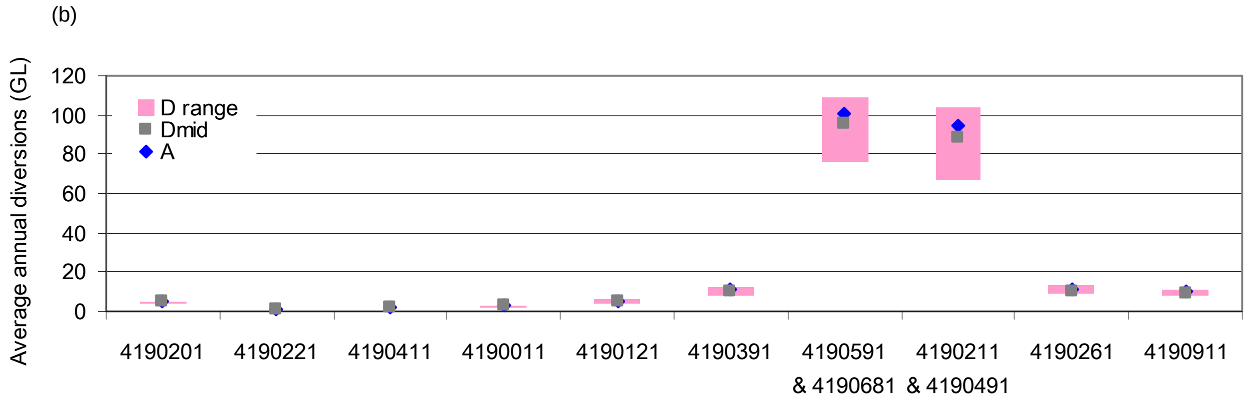


Figure 4-9. Total average annual diversions for subcatchments under (a) scenarios A and C and (b) scenarios A and D

Figure 4-10 shows an annual time series of total diversion under Scenario A and the difference from Scenario A under scenarios C and D. The maximum and minimum diversions under Scenario A are 451 GL in 1951 and 68 GL in 1994 respectively.

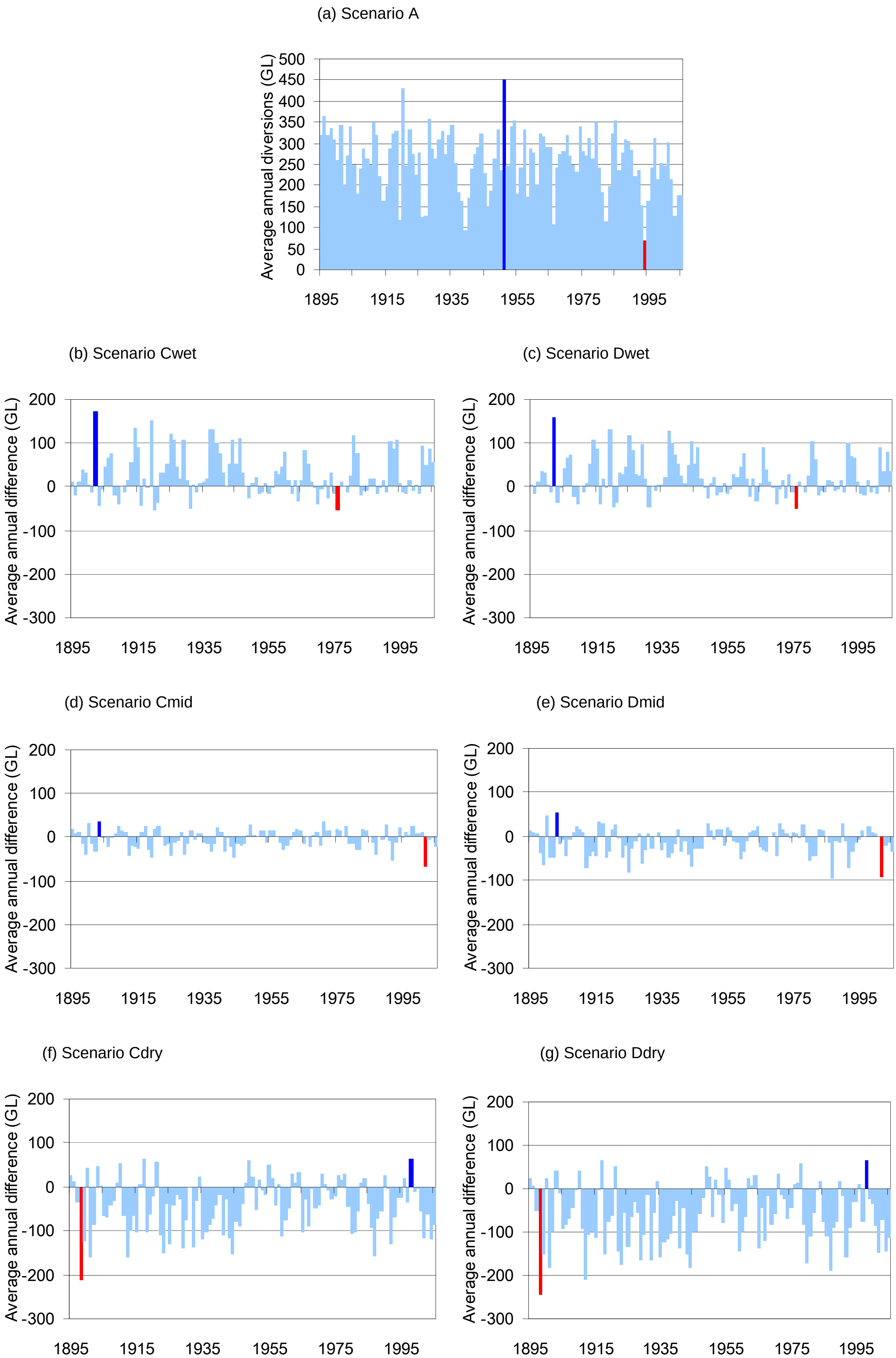


Figure 4-10. Total diversions under (a) Scenario A and difference from Scenario A in total water use under (b) Scenario Cwet, (c) Scenario Dwet, (d) Scenario Cmid, (e) Scenario Dmid, (f) Scenario Cdry and (g) Scenario Ddry

Level of use

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

Subcatchment use includes:

- the inflow impacts due to groundwater use. This includes groundwater use explicitly included in inflows (11.3 GL/year) and an estimate of groundwater use implicit in the inflows during model calibration (10 GL/year)
- inflow impacts due to future farm dams
- an adjustment to these impacts to transfer them to the point of maximum flow. This is done by multiplying all scenarios by the current conditions ratio of flow at the point of maximum flow (888 GL/year) and total inflow (directly and indirectly gauged inflows) (1861 GL/year).

Streamflow use includes:

- leakage to groundwater induced by groundwater use. This includes groundwater use explicitly included in the river model and groundwater use implicit in the river model calibration (67 GL/year)
- total net diversions, which are defined as the net water diverted for the full range of water products. Net diversions are used to reflect the change in mass balance of the system. They do not consider the difference in water quality that may exist between diversions and returns.

Table 4-11 shows the level of use indicators for each of the scenarios. The level of use is moderately high with 37 percent of the total available water resource being diverted for use. The Water Sharing Plan (DIPNR, 2004) gives a long-term average diversion limit for the Namoi of 238 GL/year. This is only for the Namoi system and not for the Peel, and is based on an earlier river model for the Namoi. However, the average annual diversions for the Namoi system of 251 GL/year (Table 4-7) are based on a revised Namoi model. The revised model thus suggests a level of use for the Namoi system of 28 percent. Table 4-11 indicates a current level of use for the entire region of 37 percent. This includes consideration of diversions in the Peel system (15.9 GL/year), the groundwater development impacts and is assessed over a shorter period.

Table 4-11. Relative level of use under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Total surface water availability	965	1336	915	677	1336	915	677
Subcatchment use							
Groundwater use impacts	10	10	10	10	24	24	24
Future farm dam impacts	-	-	-	-	12	8	6
Streamflow use							
Total net diversions	260	287	256	217	282	247	197
Leakage induced by groundwater use	89	71	92	101	78	97	112
Total use	**359**	**368**	**359**	**328**	**396**	**376**	**339**
	percent						
Relative level of use	37%	28%	39%	48%	30%	41%	50%

Use during dry periods

Table 4-12 shows the average use for all water products, as well as the average annual use for the lowest one, three and five-year periods for Scenario A and the percentage change from Scenario A for each other scenario. These figures indicate the impact on water use during dry periods.

Table 4-12. Indicators of level of use under scenarios A, C and D

Annual Diversion	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A					
Lowest 1-year period	68.3	143%	6%	-37%	96%	-22%	-56%
Lowest 3-year period	128.4	51%	2%	-44%	38%	-15%	-61%
Lowest 5-year period	168.8	31%	-7%	-38%	25%	-17%	-52%
Average	259.7	10%	-1%	-17%	9%	-5%	-24%

Reliability

The ratio of total net diversions for each water product to the respective entitlement or share of resource can indicate the average reliability of water products. General security use for the Peel system is compared against a licence volume of 30.2 GL, supplementary flow access against annual pump capacity of 34.2 GL, Tamworth town water supply against a licence volume of 16.4 GL and high security stock and domestic use against a licence volume of 0.8 GL. Namoi general security water use is compared against a licence volume of 254.5 GL, high security stock and domestic use against a licence volume of 2.4 GL, high security town water supply licence volume of 9.1 GL and the supplementary access is compared against the 117.3 GL annual cap. The calculated average reliabilities are shown in Table 4-13.

Table 4-13. Average reliability of Namoi and Peel water products under scenarios A, C and D

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	ratio						
Peel licensed private diversions							
General security (entitlement: 30.2 GL)	0.18	0.18	0.19	0.18	0.18	0.19	0.17
Supplementary access (no cap)	0.02	0.03	0.03	0.03	0.03	0.03	0.03
Town water supply (entitlement: 16.4 GL)	0.57	0.57	0.58	0.58	0.57	0.58	0.58
High security stock and domestic (entitlement: 0.8 GL)	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Namoi licensed private diversions							
General security (entitlement: 254.5 GL)	0.75	0.82	0.73	0.61	0.81	0.70	0.54
Supplementary access (cap: 117.3 GL)	0.29	0.33	0.30	0.26	0.32	0.28	0.25
Town water supply (entitlement: 9.1 GL)	0.02	0.02	0.02	0.02	0.02	0.02	0.02
High security stock and domestic (entitlement: 2.4 GL)	0.58	0.59	0.58	0.58	0.59	0.58	0.58

Use by Peel general security users, high security users and Namoi town water supply are fixed in the model to represent average historical usage. Consequently the reliabilities indicate the level of under-utilisation of these licences. The level of under-utilisation is quite large for Namoi town water supplies where usage is 2 percent of the available licence.

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

Figure 4-11 and Figure 4-12 show the difference between the maximum yearly allocated general security water and the general security use for the Peel and Namoi systems for each of the scenarios in volume reliability plots.

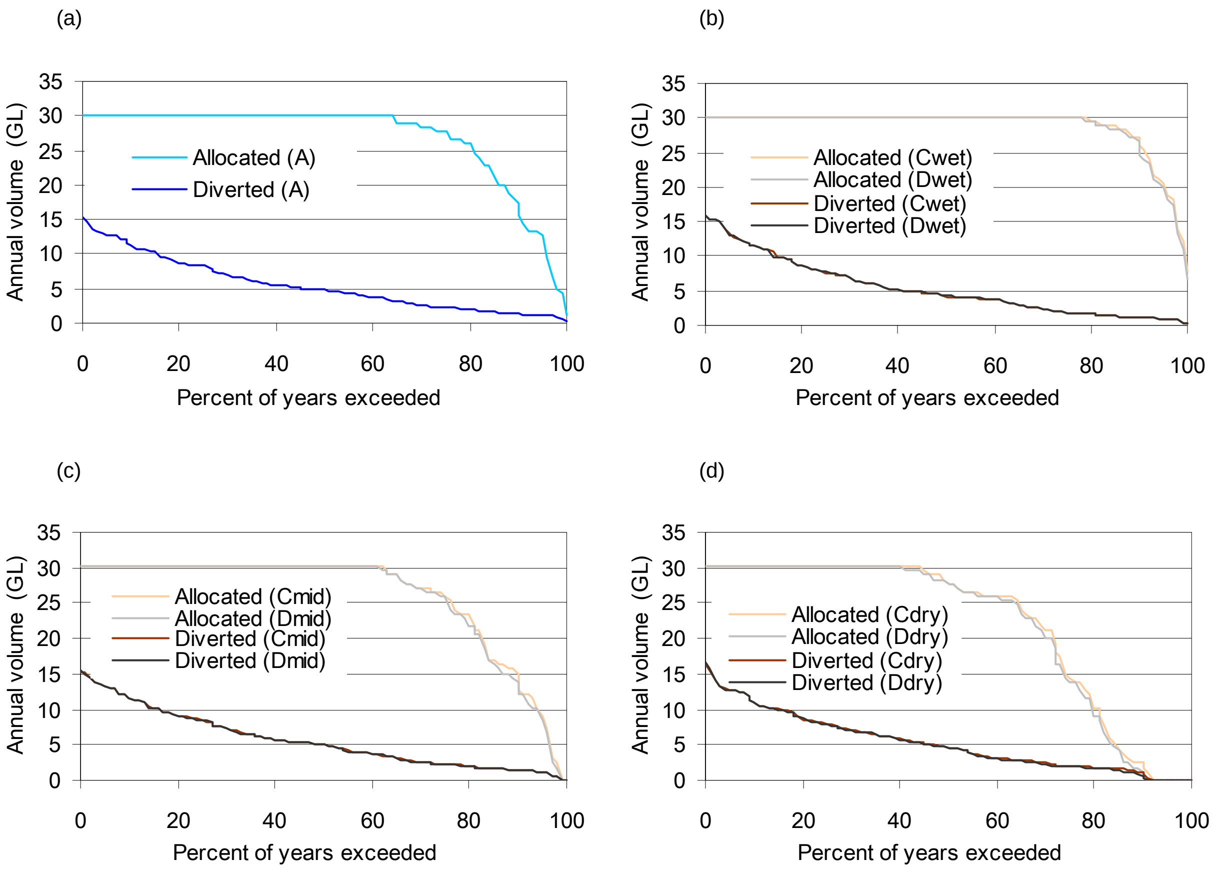


Figure 4-11. Peel general security reliability under scenarios (a) A, (b) Cwet and Dwet, (c) Cmid and Dmid, and (d) Cdry and Ddry

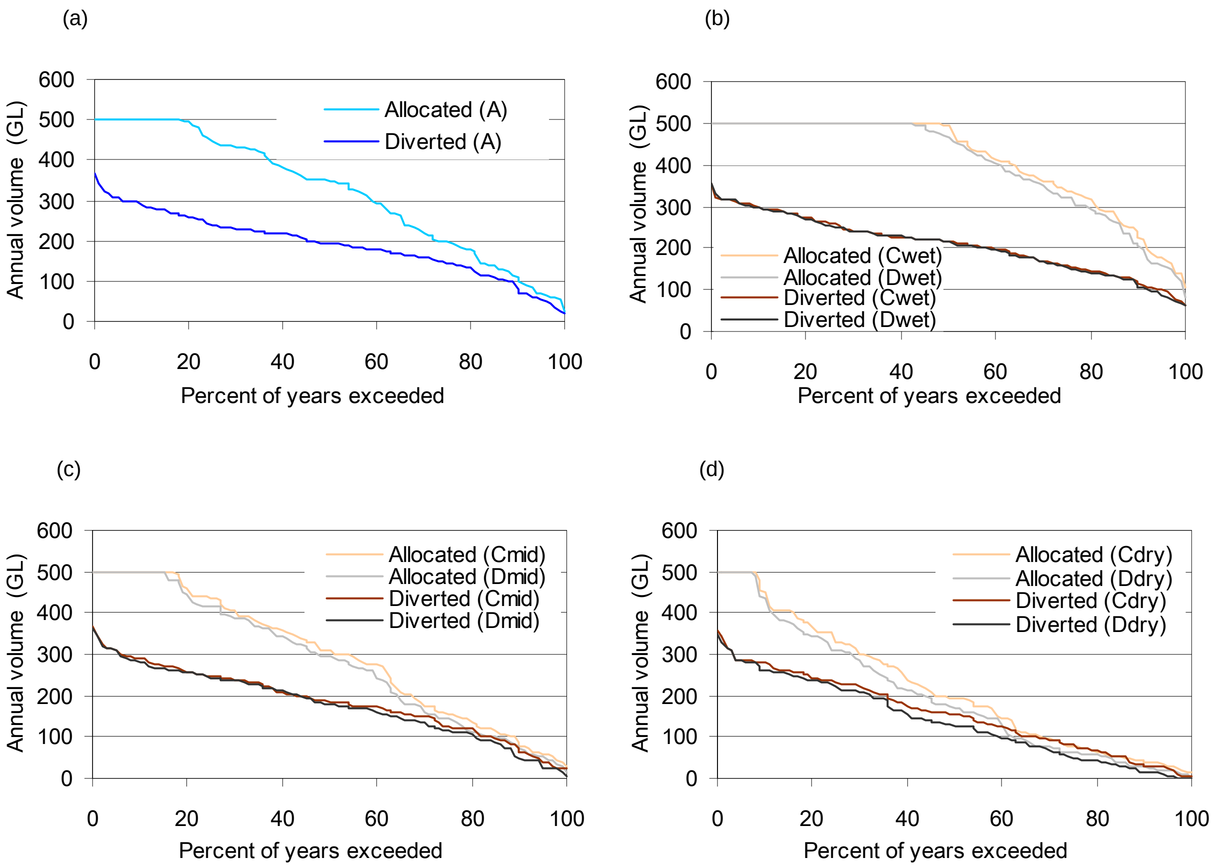


Figure 4-12. Namoi general security reliability under Scenarios (a) A, (b) Cwet and Dwet, (c) Cmid and Dmid, and (d) Cdry and Ddry

Figure 4-13 shows the reliability of supplementary water access for Peel and Namoi irrigators for each of the scenarios.

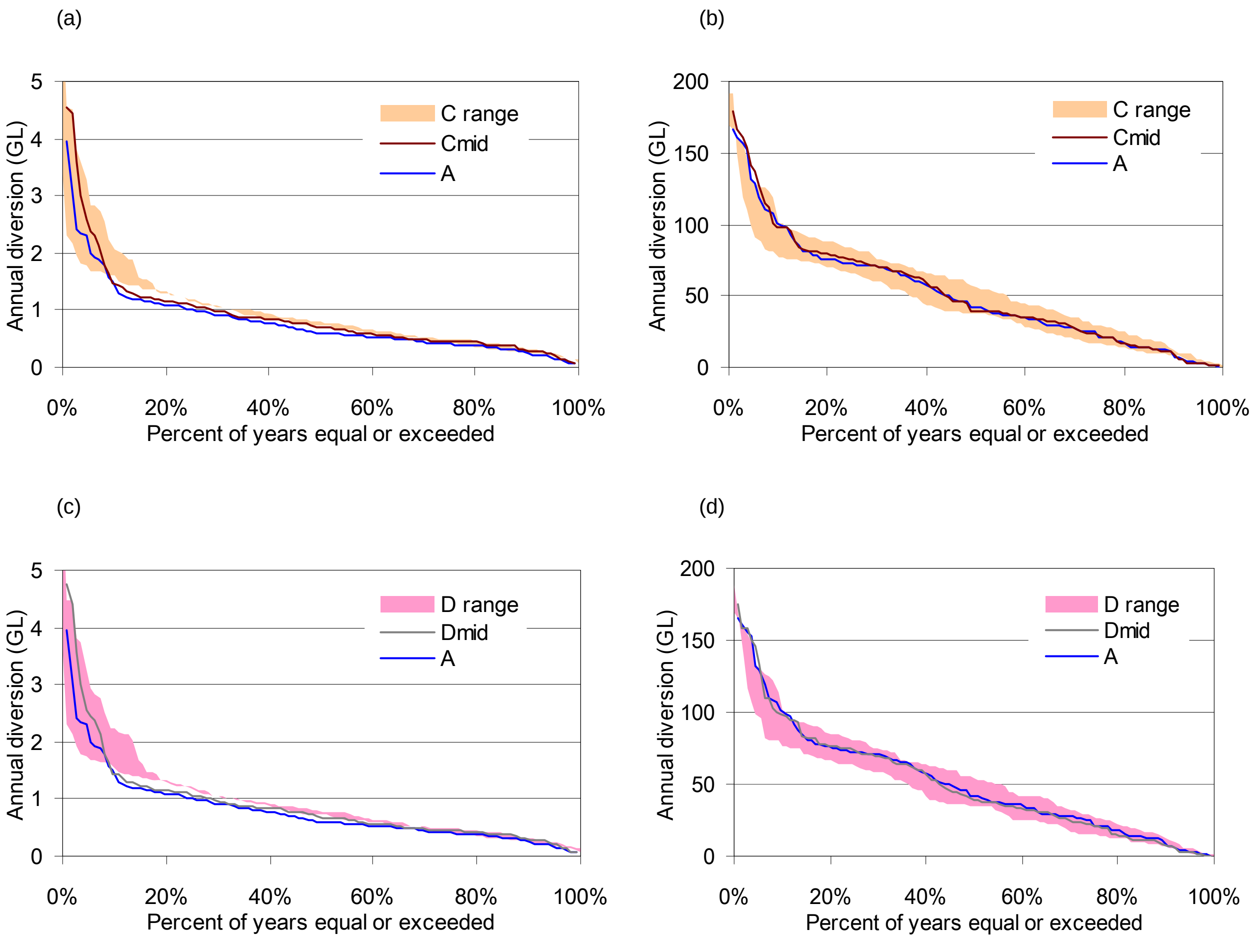


Figure 4-13. Reliability of supplementary access for (a) Peel irrigators under Scenario C, (b) Namoi irrigators under Scenario C, (c) Peel irrigators under Scenario D and (d) Namoi irrigators under Scenario D

Table 4-14 show the average annual difference between available water and diverted water for the respective Peel and Namoi general security water products and give an indication of the level of utilisation of the various water products in the Namoi region. The areas for the Peel system model are fixed to achieve historical demand, which is less than licensed volume. The Namoi figures are distorted by higher allocations (above 254 GL) where the water is allocated to users who may not be allowed to use it because of allocation rules.

Table 4-14. Summary of average general security utilisation

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Peel							
Allocated water	26.9	28.9	26.1	22.2	28.8	25.9	21.9
Diversion	5.5	5.3	5.6	5.3	5.3	5.6	5.2
Difference	21.4	23.6	20.4	16.9	23.4	20.3	16.7
Namoi							
Allocated water	321.4	411.7	297.7	217.2	402	283.9	198.5
Diversion	191.2	209.5	186.3	155.1	206.9	178.8	138.1
Difference	130.2	202.2	111.5	62.1	195.1	105.2	60.4

4.3.5 River flow behaviour

There are many ways of considering the flow characteristics in river systems. For this report three different indicators are provided: daily flow duration, seasonal plot and daily event frequency.

Mid-river flow characteristics

The flow regime will vary depending on which location in the river that is selected. As a representative location the position where the river changes from a gaining to a losing stream is selected as being representative. The selection of this site is discussed in Section 4.3.2. For the Namoi River system this is a combination of flows at Bugilbone gauge (419021) and Pian Creek (419049).

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

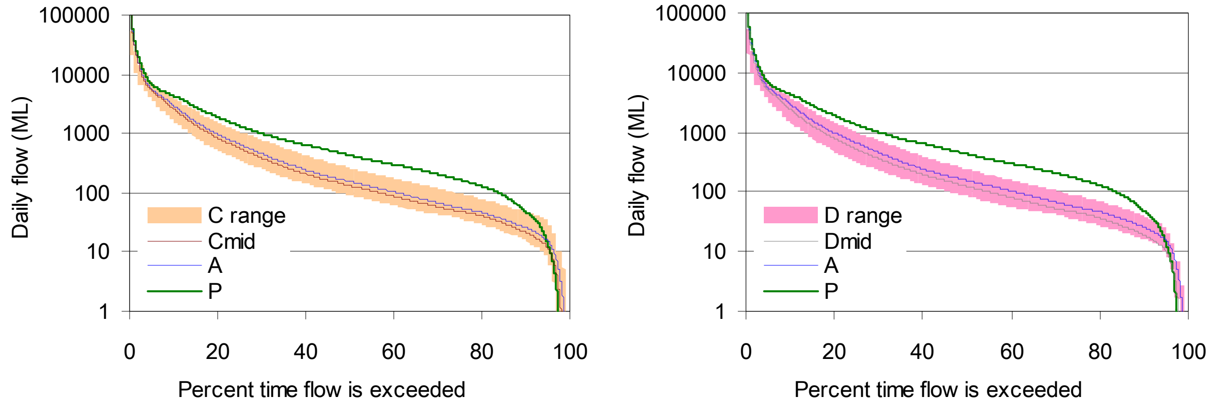


Figure 4-14. Daily flow duration curves for combined Bugilbone and Pian flows under scenarios P, A, C and D

Figure 4-15 shows the mean monthly flow for the pre-development scenario and Scenario A. It shows that the seasonality in the middle of the river is similar between pre-development and Scenario A with the major difference occurring in December when flows are higher to meet downstream demands and in winter when flows are lower due to storages catching water.

For the spring months the Cmid flows are less than the Cdry flows. This is due to the Cmid global climate model (GCM) being selected on an average annual flow basis. Based on this selection methodology it is possible to choose different GCMs for each of the scenarios and hence end up with Cmid seasonal factors that do not necessarily lie within the Cwet and Cdry range of seasonal factors.

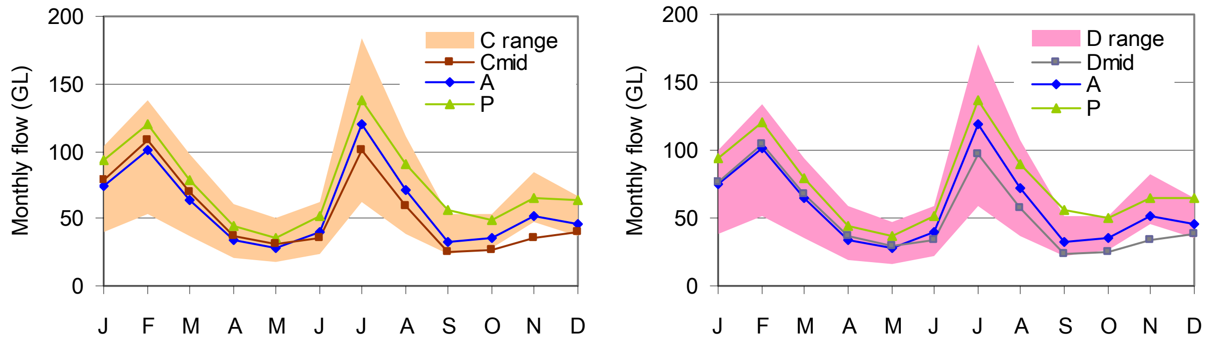


Figure 4-15. Monthly flow for combined Bugilbone and Pian flows under scenarios P, A, C and D

Table 4-15 shows the size of daily events with two, five and ten-year recurrence intervals for scenarios P, A, C and D. This analysis estimates the average peak daily flow and not the peak flow for a day, which is considerably higher in most river systems. The table shows that from pre-development to Scenario A there is a 13 percent reduction in the size of two-year events and only a small change (< 1 percent) in the larger five and ten-year return interval events. The increase in five-year events is due to events occurring downstream of storages on top of the regulated supply.

Table 4-15. Daily flow event frequency for combined Bugilbone and Pian flows under scenarios P, A, C and D

Return interval	P	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
years	ML/d		percent change from Scenario A					
2	24,371	21,227	41%	-16%	-37%	37%	-18%	-41%
5	60,792	61,146	71%	10%	-44%	68%	9%	-46%
10	112,171	111,364	78%	1%	-49%	73%	-1%	-50%

End-of-system flow characteristics

Figure 4-16 shows the flow duration curves for end-of-systems flows at Walgett (419091). Each of the scenarios are plotted.

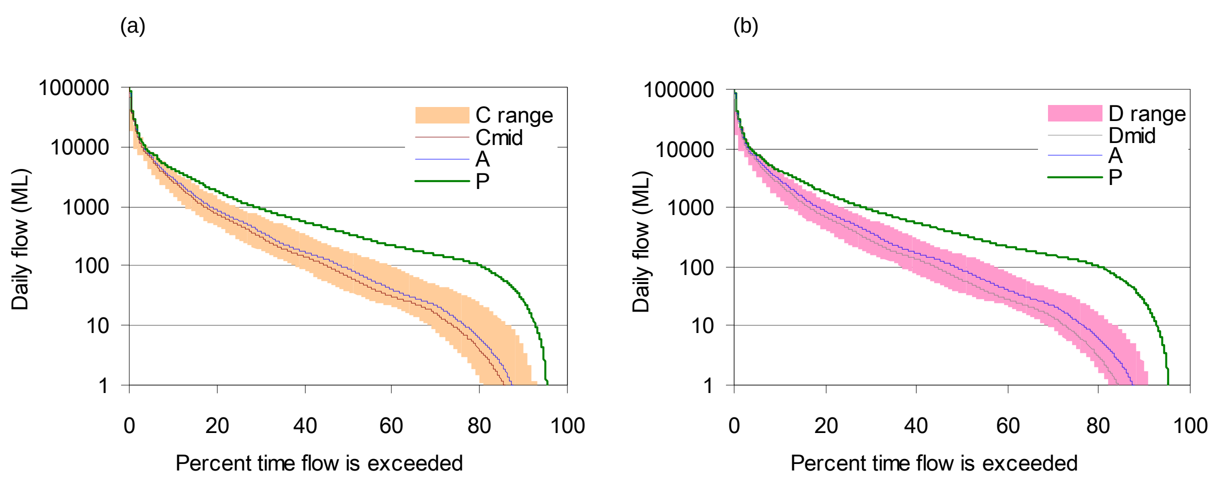


Figure 4-16. Daily flow duration curves for end-of-system flows at Walgett gauge under (a) scenarios P, A, and C, and (b) scenarios P, A and D

Figure 4-17 plot the mean monthly flow for the pre-development scenario, Scenario A, Scenario C and Scenario D for the end-of-system flow gauge. This shows that the seasonality at the end-of-system has not changed in any of the scenarios. It also shows that there has been an overall reduction in flows across all seasons from pre-development.

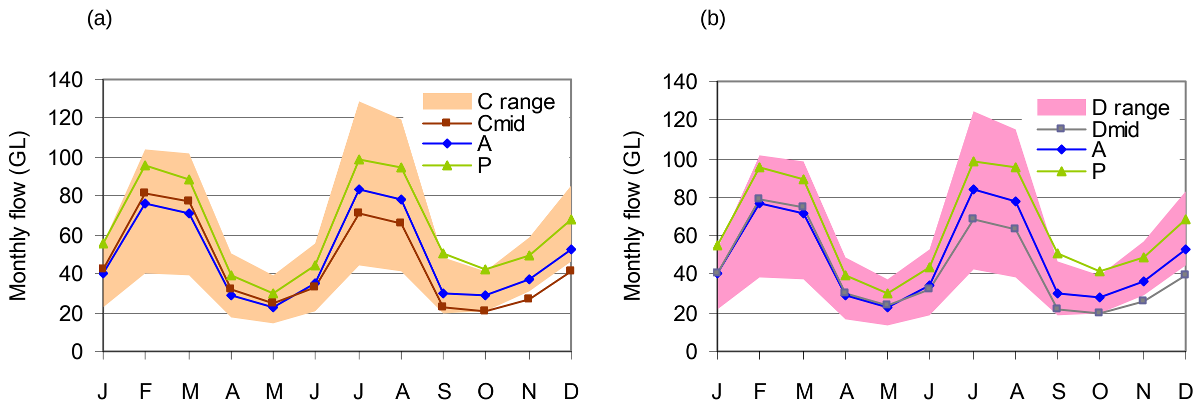


Figure 4-17. Seasonal flow curves at Walgett gauge under (a) Scenario C and (b) Scenario D

The percentages of time for which flow occurs for these scenarios are presented in Table 4-16. Cease-to-flow is considered to occur when model flows are less than 1 ML/day.

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

Outflow Name	P	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	percent							
Namoi River at Walgett	95%	87%	93%	86%	81%	92%	84%	83%

4.3.6 Share of available resource

Non-diverted water shares

There are several ways of considering the relative level of impact on non-diverted water and total use. Table 4-17 presents two indicators for relative impact on non-diverted water:

- the average annual non-diverted water as a proportion of the total surface water availability
- as a proportion of the total surface water availability for Scenario A.

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

Relative level of non-diverted water	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Non-diverted water as a percentage of total surface water availability	63%	72%	61%	52%	70%	59%	50%
Non-diverted share relative to Scenario A non-diverted share	100%	160%	92%	58%	155%	89%	57%

Combined water shares

Figure 4-18 combines the results from water availability, total use and non-diverted water into a bar chart. The size of the bar indicates total surface water availability and the subdivision of the bar indicates the non-diverted and total use fractions.

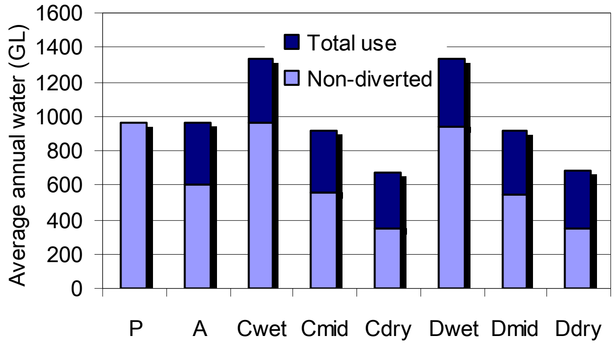


Figure 4-18. Comparison of average annual total use and non-diverted shares of water under scenarios P, A, C and D

4.4 Discussion of key findings

4.4.1 Model configuration

The Peel model is configured to represent a fixed crop area that does not vary as a function of available resources. There are several modelling implications of this type of configuration:

- the irrigation demands fluctuate as a function of climatic conditions.
- crop areas are fixed to match historical usage. This means that modelled usage will not represent the change in usage as a function of a change in the available resources. Usage during resource limited years will higher as a consequence of fixed areas.

There is a significant amount of development in the Mooki River and associated tributaries and Coxs Creek that is currently not modelled. The usage in these systems is inherent in recent historical inflow but is not considered in past inflows. Consequently the inflows into the Namoi River system model will be larger than would be expected with current levels of development. As there is no model available the changes in these inflows for each of the scenarios is not explicitly considered but is partially allowed for as rainfall-runoff models for the Mooki River and Coxs Creek were calibrated to match recent (1985 to 2006) flow characteristics and subsequently adjusted for climate and future development scenarios.

4.4.2 Scenarios

The Namoi model was setup up by DWE to operate over the period 1 October 1892 to 30 June 2006. The results from this study are presented for the common modelling period 1 July 1895 to 30 June 2006. The Upper and Lower Namoi Water Sharing Plan (DIPNR, 2004) results are based on the original modelling period. Results presented in this report may differ from numbers published here due to the different modelling period and revised version of the model. Table 4-7 shows that there is a 1 percent decrease in inflows for the common modelling period compared to what was used to develop the various water sharing plans. Consequently there should not be a substantial difference between results.

Scenario A0 and A results are presented so that the effects of current levels of groundwater extraction at dynamic equilibrium can be considered. Table 4-7 shows a 11.3 GL/year decrease in subcatchment inflows due to groundwater and a 25.4 GL/year increase in loss to groundwater in the river that is offset by a 3.1 GL/year gain elsewhere in the river making the net change 33.6 GL/year loss to groundwater. This groundwater loss reduces diversion by 3 percent and end-of-system flows by 1 percent.

4.4.3 Consumptive use

The Namoi irrigators are modelled to include general security access, supplementary flow access, floodplain harvesting, rainfall harvesting and groundwater use. Not all of these sources of water are calibrated against observed data. However the overall mass balance of farms is calibrated to achieve a realistic water use for the types of crops that are modelled. The proportions of these sources of water for Scenario A (Table 4-7) are general security (191.2 GL/year), supplementary flows (34.6 GL/year), rainfall harvesting (79 GL/year) and groundwater use (36 GL/year). The impact of climate on these different sources of water varies considerably. Surface water resources decrease during dry conditions while groundwater usage increases. This helps to buffer the farm impacts. Note that this groundwater usage is not explicitly considered in groundwater models but is treated by the surface water models as an infinite source of water.

The Namoi River system is managed under a continuous accounting scheme. Traditionally many of the systems operated under annual accounting systems where allocation announcements were made throughout a year that set the proportion of licences available for all general security users. Under continuous accounting each licence holder has an account balance that is limited by their share in the storage that is 200 percent. Users are limited to a maximum of 125 percent of their entitlement in any year. The model accounts for each irrigation node's balance-in-storage and maintains these balances as water inflows and is diverted. Consequently each user will have a different allocation depending on their level of use compared to licensed entitlement. The model provides an allocation output that represents the aggregation of all water users' account balances divided by the licence entitlement. This aggregated allocation is presented in Figure 4-11. Due to the nature of individual balances, actual usage may exceed allocated water as individual irrigators have higher allocations than the average that divert their water. Hence it is possible for diversions to exceed averaged allocations in the reliability figures.

The reduction in general security diversions is less than the reduction in inflow or end of system flows. For the best estimate 2030 climate change scenario inflows reduce by 6 percent, end-of-system flows reduce by 8 percent. Namoi general security usage only reduces by 3 percent which is compensated for by a 1 percent increase in supplementary access, 4 percent increase in floodplain harvesting, 2 percent decrease in rainfall harvesting and a 15 percent increase in groundwater usage. When all of these water sources are considered it is less than a 1 percent impact on the Namoi irrigators. Consequently regulation and the variety of water products available to irrigators help to buffer the impacts of reduced water availability which in turn creates a larger impact on end-of-system flow.

There is no significant impact on high security users as general security allocations are predominantly above zero (Figure 4-11). When there is a general security allocation the high security users will receive their full entitlement. Due to carryover reserve in the resource assessment, sufficient water is reserved so that high security town water supply requirements are met in all but Scenario Ddry when Split Rock and Chaffey dams fall below active storage capacity (Table 4-10 and Figure 4-5). A larger reserve would be required to maintain high security requirements through Scenario Ddry in both the Namoi and Peel systems. A larger reserve would be required in the Namoi system (Split Rock Dam) to ensure Manilla town water supply is met. High security requirements downstream of Keepit Dam are met in all scenarios. Holding larger reserves will reduce the reliability of general security users.

4.4.4 Flow behaviour

The impact on end-of-system flows for the Namoi at Walgett due to climate change are less than the pre-development difference. The cease-to-flow percentile is reasonably well maintained which is due to an end-of-system flow requirement over the June–August period.

4.4.5 Water availability and level of use

There are differences between the water availability and level of use numbers quoted in the Water Sharing Plan (DIPNR, 2004) and this report (Table 4-8 and Table 4-11). The point of maximum water availability is estimated to be a combination of flows at Bugilbone (419021) and Pian (419049) gauges with a value of 888 GL/year under Scenario A (pre-development). However, the point of maximum water availability in the Water Sharing Plan is Narrabri (a combination of gauges 419003 and 419002) with a value of 870 GL/year. In addition to this, the Water Sharing Plan estimate is based on current levels of development while the number in this report is based on pre-development conditions. The latter removes the influence of the larger number as upstream extractions and storage evaporation losses. The modelling period for these two assessments is also different, which due to the exclusion of larger inflows in the 1892 to 1895 period in modelling for this project, reduces water availability by 1 percent.

The allowable level of use is not directly stated in the Water Sharing Plan but is implied to be 27 percent based on the long-term average annual diversion limit for Namoi water use (238 GL/year) and the average water availability (870 GL/year). However, subsequent to the publishing of the Water Sharing Plan the Namoi model has been recalibrated. The revised current average annual water use for the Namoi is estimated to be 251 GL/year (Table 4-8). This gives an estimate of the current average level of use in the Namoi system of 28 percent. The number in Table 4-11 differs from this in that it is based on a different estimate of average surface water availability (965 GL/year), includes the Peel usage (15.9 GL/year), includes the impacts on streamflow of groundwater use and is for a shorter modelling period.

4.5 References

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

DIPNR (2005) Namoi River Valley: IQQM Cap Implementation Summary Report. Department of Infrastructure Planning & Natural Resources, Sydney. ISBN CNR2003.072.

DIPNR (2006) Peel River Valley: IQQM Cap Implementation Summary Report. Department of Infrastructure Planning & Natural Resources, Sydney.

5 Uncertainty in surface water modelling results

The following assessment of uncertainty in the surface water modelling results was conducted to provide an independent comparison of the river modelling results. It has four sections:

- a summary
- an overview of the approach
- presentation and description of results
- 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 the confidence in the results and their appropriate use, are assessed using multiple lines of evidence. This involves comparing: (i) the river model to historical gauged main stem flows and diversions, which are its main points of reference to actual conditions, and (ii) ungauged inferred inflows and losses in the model to independent data on inflows and losses to ascertain if they can be attributed to known processes. These two aspects of model performance were then combined with some other measures to assess how well the model might predict future patterns of flow.

5.1.1 Issues and observations

- Hydrologic data availability in the Namoi region is adequate. The density of the streamflow gauging network is similar to the average for the entire Murray-Darling Basin (MDB). The density of rainfall gauging in the upper catchment is higher than the MDB average.
- Most reaches of the Namoi-Peel system are gaining reaches and only slightly gaining in the lower reaches. There is one strongly losing reach ending at Gunidgera, where the Namoi River overflows into Pian Creek in times of high flow. There are losses to groundwater in the middle reaches.

5.1.2 Key messages

- Overall the river model for the Namoi region is robust and is suitable for the purpose of assessing changes in water availability and assessing the impacts of these changes on water sharing.
- The large proportion of inflows that are ungauged and the narrow range of climate used in model calibration leads to uncertainty in the projected effects of climate change on inflows and thus on the river water balance. However, this uncertainty is considerably less than the uncertainty associated with the climate change predictions.
- There is moderate uncertainty in the river model in the two lowest reaches where natural flow losses are high and out of channel flow is difficult to measure. There is thus greater uncertainty in the assessment of end-of-system flow volumes than there is in assessing flow volumes within the Namoi region.
- River losses to groundwater are important in the middle reaches. These are quantified in this project using groundwater models and the assessed fluxes have been incorporated in the river model.

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

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

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

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

5.2.2 Information sources

Information on the gauging network was obtained from the Water Resources Station Catalogue (www.bom.gov.au/hydro/wrsc) and the Pinneena 8 Database (provided on CDROM by New South Wales Department of Water and Energy (DWE)). The Namoi IQQM Cap implementation report (DIPNR, 2005) and a report on data selection and pre-processing (Ribbons and Burrell, 2005) were provided by New South Wales and the independent cap model audit report (MDBC, 2005) was provided by the Murray-Darling Basin Commission, respectively. 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 sufficient for water accounting for the water years 1990/91 to 2004/05. Water accounts were established for 13 successive reaches. The associated subcatchments are shown in Figure 5-1 and are related to water accounting reaches in Table 5-2.

Table 5-2. Comparison of water accounting reaches with modelling subcatchments

Water accounting reach	Subcatchment code(s)	Description
1	4190201	Manilla @ Brabri
2	4190221	Namoi @ Manilla
3	4190151	Peel @ Piallamore
4	4190241	Peel @ U/S Paradise Weir
5	4190061	Peel @ Carrol Gap
6	4190011	Namoi @ Gunnedah
7	4190121	Namoi @ Boggabri
8	4190031	Narrabri Ck @ Narrabri
9	4190391	Namoi @ Mollee
10	4190591	Namoi @ D/S of Gunidgera
11	4190681	Namoi @ D/S Weeta weir
12	4190211	Namoi @ Bugibone
13	4190261	Namoi @ Goangra
Not assessed		Reason
	4190800	Contributing headwater catchment (to Reach 1)
	4190290, 4190050	Contributing headwater catchment (to Reach 2)
	4190270	Contributing headwater catchment (to Reach 3)
	4190320	Contributing headwater catchment (to Reach 4)
	4190510	Contributing headwater catchment (to Reach 5)
	4190720	Contributing headwater catchment (to Reach 10)
	4190770, 4190360, 4190690	Contributing headwater catchment (to Reach 11)
	4190160	Contributing headwater catchment (to Reach 12)
	4190350	Contributing headwater catchment (to Reach 13)
	4190411	Keepit Dam reservoir at the catchment outlet
	4190662	Does not contribute runoff to the system
	4190491	No inflow streamflow data
	4190911	Insufficient streamflow data

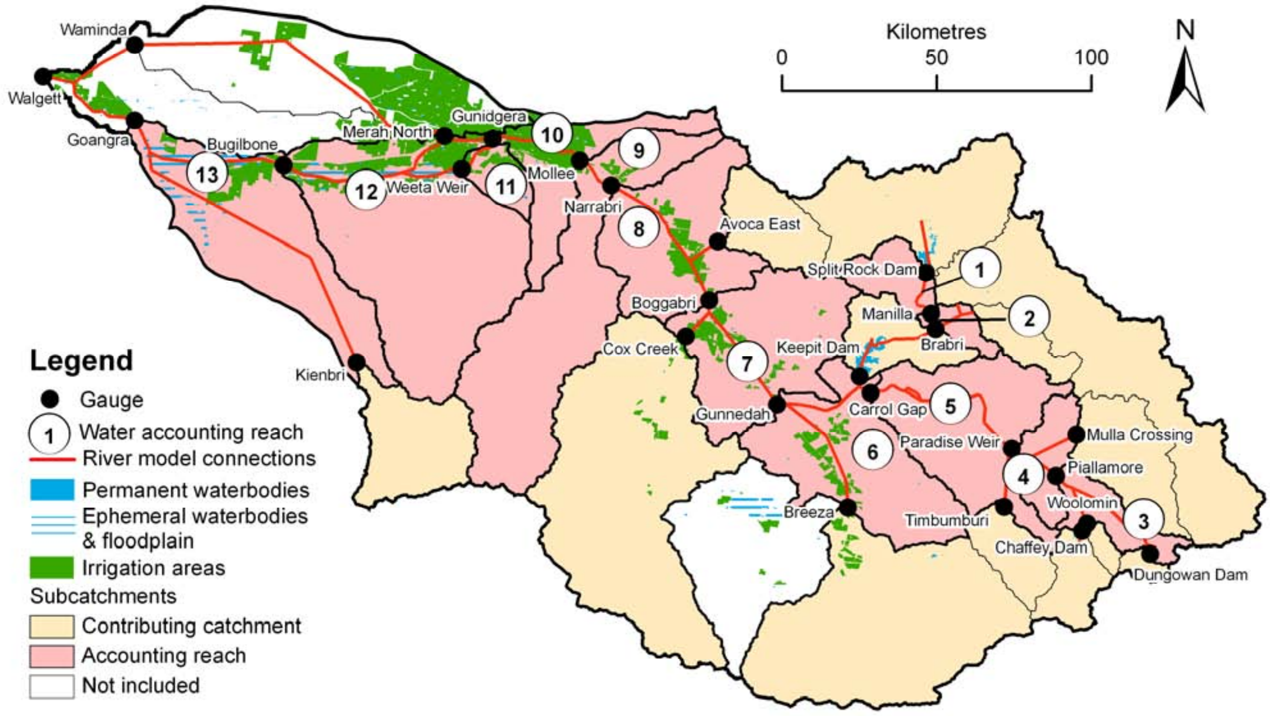


Figure 5-1. Map showing the subcatchments used in modelling, with the reaches for which river water accounts were developed ('accounting reach') and contributing headwater catchments with gauged inflows ('contributing catchment'). Ephemeral waterbodies and floodplain are areas classified as subject to periodic inundation. Black dots and red lines are nodes and links in the river model respectively.

5.2.4 Diversion data

Total annual diversion data covering the water years 1990/91 to 2005/06 and five of the accounting reaches were provided by DWE.

Wetland and irrigation water use

The results of the remote sensing analyses (Chapter 1) are in Figure 5-1. Irrigation areas were identified in the reaches with water accounts. Important wetland areas were identified in water account reaches 4 and 5. Irrigation and wetland areas were also identified in the two westernmost modelled subcatchments where streamflow data were insufficient to establish water accounts.

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. The SIMHYD estimates of local reach inflows required adjustment downwards for most reaches to achieve a reasonable agreement with ungauged apparent gains (Appendix C).

5.2.5 Model uncertainty analysis

The river model results, gauging network, 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. (2007). Calculations were separate for each reach but summary indicators were compared between reaches.

Completeness of hydrological observation network

Statistics on how well all the estimated river gains and losses were gauged – or where ungauged, how well these 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 shown in Appendix C.

Comparison of modelled and accounted reach water balance

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

Climate range

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

Performance of the river model in explaining historical flow patterns

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

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

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

Scenario change-uncertainty ratio

Streamflow patterns simulated for any of the scenarios can be used as an alternative river model. If these scenario flows explain historically observed flows about as well or better than the baseline model, then it may be concluded that the modelled scenario changes are within model 'noise', that is, smaller or similar to model uncertainty.

Conversely, if the agreement between scenario flows and historically observed flows is poor – much poorer than between the baseline model and observations – then the model uncertainty is smaller than the modelled change, and the modelled change can be meaningfully interpreted.

The metric used to test this hypothesis is the change-uncertainty ratio. The definition was modified from Bormann (2005) and calculated as the ratio of the NSME value for the scenario model to that for the baseline (Scenario A) model. A value of around 1.0 or less suggests that the projected scenario change is not significant when compared to river model uncertainty.

A ratio that is considerably greater than 1.0 indicates that the future scenario model is much poorer at producing historical observations than the baseline model, suggesting that the scenario leads to significant changes in flow. The change-uncertainty ratio is calculated for monthly and annual values, in case the baseline model reproduces annual patterns well but not monthly patterns. The same information was plotted as annual time series, monthly flow duration curves and a graphical comparison made of monthly and annual change-uncertainty ratios for each scenario.

5.3 Results

5.3.1 Density of the gauging network

Figure 5-2 shows the location of streamflow, rainfall, and evaporation gauges in the region, and Table 5-3 provides information on the measurement network. The Namoi region has a gauging network that is denser than the average for the MDB (ranked 6th of 18 regions in terms of overall network density). The rainfall gauging network is about twice as dense as the MDB average, and the streamflow and evaporation gauging network is of similar density to the MDB average. Gauging is concentrated in the upper half of the catchment and the Namoi River main stem (Figure 5-2). Uncertainty is associated with the less comprehensive gauging on distributaries in the lower catchment.

Table 5-3. Some characteristics of the gauging network of the Namoi region (39,781 km^2) compared with the entire Murray-Darling Basin (1,062,443 km^2)

Gauging network characteristics	Namoi		Murray-Darling Basin	
	Number	per 1000 km^2	Number	per 1000 km^2
Rainfall				
Total stations	469	11.79	6,232	5.87
Stations active since 1990	245	6.16	3,222	3.03
Average years of record	39		45	
Streamflow				
Total stations	60	1.51	1,090	1.03
Stations active since 1990	54	1.36	881	0.83
Average years of record	21		20	
Evaporation				
Total stations	6	0.15	152	0.14
Stations active since 1990	5	0.13	104	0.10
Average years of record	37		27	

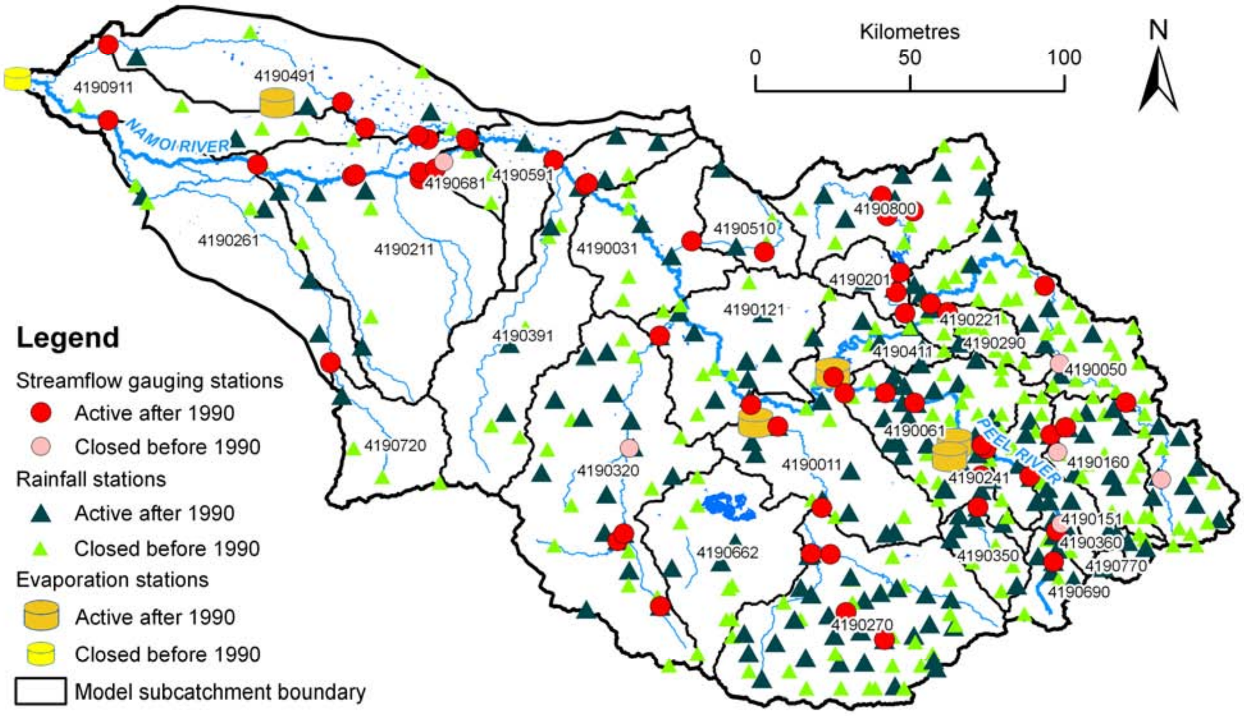


Figure 5-2. Map showing the rainfall, streamflow and evaporation observation network, along with the subcatchments used in modelling

5.3.2 Review of model calibration and evaluation information

Model description

Two IQQM applications were developed to describe the hydrology of the Namoi region:

- the Namoi model that covers the system from the headwaters of Split Rock and Keepit Dams to the confluence with the Baron River at Walgett
- the Peel model that includes some irrigation uses, Dungowan and Chaffey dams and the town of Tamworth.

Modelling reports were provided by New South Wales (DIPNR, 2005; Ribbons and Burrell, 2005) and the Murray-Darling Basin Commission (MDBC, 2005). These reports are reviewed and summarised to assess model concepts, assumptions and calibration. Model performance is also examined according to uncertainty in the scenario results generated by the project.

The model simulates catchment inflows, flow routing, transmission losses and ungauged residual inflows for main stem reaches. The model also simulates: the operation and water balance of Split Rock and Keepit Dams, on-farm storages, Mollee, Gunidgera and Weeta weirs, and other operational flow maintenance rules. On- and off-allocation diversions are simulated by coupling models that simulate farmer cropping decisions, crop water demand, and water resource assessments and ensuing allocations. The model also simulates high security uses (towns, stock and domestic, industrial), that are estimated to amount to less than 10 GL/year. Although temporary or permanent water trade is not modelled explicitly, the indirect effects of water trading are simulated. Groundwater and surface water are used to meet the demands in the model in priority order. However, groundwater use appears considerably greater in reality (MDBC, 2005).

Data availability

Available data from around ten rainfall stations with good quality (less than 6 percent missing data) and long-term data (100 to 126 years) were selected. Evaporation data from six stations was used as input for the model. Available streamflow data were used for the following purposes (Table 5-4):

- thirteen stations were used for calibration of reaches of the Manilla and Namoi Rivers as well as Gunidgera and Pian Creeks.
- seven stations recorded tributary inflows. None of the stations recorded for the entire period from 1892 onwards. Therefore, records were extended via rainfall-runoff models and correlation to other gauges.
- Inflows into Keepit and Split Rock dams were inferred from storage level data after allowing for recorded dam releases, spills and net rainfall onto the dam area.

Information on the quality of these streamflow data was limited but two gauges were excluded due to questionable data quality. Data from a third gauge (417072, Baradine Creek at Kienbri) was used but questioned due to the sandy bed of the creek.

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

Station	Location
Reach calibration	
419043	Manilla River @ Tarpoly
419020	Manilla River @ Brabri
419022	Namoi River @ Manilla railway bridge
419007	Namoi River @ Keepit
419001	Namoi River @ Gunnedah
419012	Namoi River @ Boggabri
419039	Namoi River @ Mollee
419059	Namoi River @ Gunidgera weir
419068	Namoi River @ Weeta weir
419021	Namoi River @ Bugilbone
419026	Namoi River @ Goangra
419061	Gunidgera Creek @ regulator
419079	Gunidgera Creek @ Knights
Inflows	
419005	Namoi River @ North Cuerindi
419029	Halls Creek @ Ukolan
419006	Peel River @ Carrol Gap
419027	Mooki River @ Breeza
419051	Maules Creek @ Avoca East
419032	Cox's Creek @ Boggabri
417072	Baradine Creek @ Kienbri

Crop area data were compiled from different sources including annual surveys by field staff and area information from industry organisations. Numbers could vary by more than a factor of two (MDBC, 2005) so 'best estimates' were derived. Records of the historical capacity of on-farm storages and installed pump capacity were derived from surveys and estimates. Uncertainty is expected to have decreased over time. Comparison by MDBC (2005) suggested different estimates generally agree within ~10 percent.

Model calibration and validation procedures

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

- Flow calibration reproduced the observed flow hydrographs at key locations given observed storage releases, tributary inflows and water extractions. Routing parameters, transmission losses and ungauged inflows were calibrated during this step. The calibration period varied between reaches but was generally from 1988 to 1997.
- Diversion calibration reproduced observed irrigation extractions given observed crop areas and the crop mix. Crop factors and irrigation efficiency were calibrated. The calibration period was 1988 to 1995.
- The area planting decision step involved calibrating an irrigator's decision making process in reproducing observed planted crop areas. Maximum and minimum area, the crop mix and farmers planting decision process were calibrated. The calibration period was 1988 to 1995.
- Storage calibration reproduced observed volumes in the major storages and involved calibrating irrigation ordering and river operation processes. Simulated data instead of observed data for other variables are used in this stage except for crop areas and mixes and off-allocation extractions. The calibration period was 1989 to 1995.

Overall model calibration – putting all component models together – was performed for the period 1997 to 2000. The principal data constraint in the Namoi River was related to irrigation data (diversions, areas and crop mixes). The priority of calibration was to reproduce average behaviour first then temporal patterns.

No independent model validation was attempted. The performance of the model in explaining observed data during the calibration periods was considered as a measure of model performance instead. A standardised quality assessment guideline was adopted with five confidence levels: very high (simulated value within 5 percent of observed value), high (5 to 10 percent), moderate (10 to 15 percent), low (15 to 20 percent) and very low (>20 percent).

Model performance

Overall assessment of the model's performance in reproducing streamflow patterns is summarised below. Overall performance was good,and low-flow performance was moderate.

Table 5-5. Gauges used for main stem model calibration and calibration quality assessment

Station	Location	Total flows	Low range	Mid range	High range	Daily values	Annual totals
419001	Namoi River @ Gunnedah	very high	high	very high	very high	high	high
419039	Namoi River @ Mollee	very high	moderate	very high	very high	high	high
419026	Namoi River@ Goangra	very high	very high	very high	very high	high	high
Overall		very high	moderate	high	very High	high	high

Comparison of annual diversions for the calibration period (1989 to 1995) suggested that on-allocation diversions are generally simulated well but off-allocation diversions are simulated poorly. The simple flow threshold relationships assumed to initiate off-allocation diversions cannot adequately represent historical access to off-allocation water. This was particularly the case for the dry 1993/94 year when it was assumed that a more lenient management regime prevailed (MDBC, 2005). There was insufficient data to allow formal calibration of the planted crop area component of the model and therefore a quantitative performance assessment was not possible. The performance of the model in simulating storage behaviour over the 1988 to 1995 calibration period was very high for both the Keepit and Split Rock dams. The overall model performance was rated as very high taking into account the simulation of general security irrigation, end-of-system flows, combined storage volumes, and flow at Mollee (DIPNR, 2005).

Identified areas of weakness

Additional analysis reported by MDBC (2005) indicated that the above model performance assessment was generally sound but noted that:

- There was a shortage of accurate data and consequent lack of understanding of irrigator and off-allocation behaviour.
- The model had particular difficulty in simulating observed behaviour in dry years.
- The model was not able to accurately predict planted area due to factors other than simply water availability (MDBC, 2005). Performance seems to be lower in winter when diversions are relatively small (C. Ribbons, pers. comm.). This may lead to important annual deviations but not important uncertainty in long-term average diversions.
- The uncertainty in (maximum) on-farm storage volume was not the greatest source of uncertainty. The greatest uncertainty was lack of knowledge about the timing and access to surplus water.

Important uncertainties can also be inferred from areas of improvement proposed by DIPNR (2005). Apart from some model technical improvements that would not necessarily affect uncertainty, these include:

- Use of water other than on-allocation. Floodplain harvesting and off-allocation water uses. Farmers limited by on-farm storage use off-allocation water to wet the soil profile. Remaining unused allocations at the end of season are used to wet the soil or fill on-farm storages. Floodplain harvesting is poorly metered and understood and therefore associated with considerable uncertainty. MDBC (2005) considered that the model represents average behaviour for the period 1989 to 1995 at best and that considerable deviations are likely to occur outside the calibration period and range.
- Substitution of surface water use with groundwater was identified as important in 1993/94 but could not be quantified. Deficiencies were recognised in the description of the influence of groundwater availability and extraction on surface flows but insufficient data were available for any improvement.
- Necessarily the model does not address the influence of market variability and change, changes in farm practice, the need to rotate land, etc.
- Unregulated diversions. There are major unregulated irrigation developments on the Mooki River that are not yet addressed by the model. Pumping from pools in the Pian and Gunidgera creeks is not well simulated.
- Insufficient data for calibration. Spatial variability in rainfall may address unexplained variations in irrigation applications. Runoff from the Pilliga region has only recently been gauged. Large and ungauged volumes of water may have come out of this region during floods.
- Transmission losses are simulated using empirical, average functions and this affects performance during wetter or drier than average periods. During persistently wet periods real losses will be lesser than simulated and greater than simulated during dry periods.

5.3.3 Model uncertainty analysis

The calculated indicators of calibration climate range were discussed in the previous section. All other indicators and results are listed by reach in Appendix C. This section provides a summary of those assessments.

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:

- Most of the gains are well gauged: in most reaches it appears more than 80 percent of inflows into successive reaches are gauged. The first reach (Peel River) is the only exception where less than 50 percent of apparent gains are gauged. These are associated with ungauged tributary inflows.
- Most losses are also reasonably well to well gauged and most reaches have more than 80 percent of the losses gauged. The main exception was the reach to Gunidgera (Reach 10) where the Namoi River overflows into Pian Creek in times of high flow. Generally more than 80 percent of the water balance was gauged.

- Attribution of gains and losses using SIMHYD estimates of local runoff, diversion data and remote sensing helped to explain ungauged gains and losses in most reaches. The poorest results were obtained in the first reach, in Reach 3 where there are ungauged tributary inflows, and in Reach 12, where there were large unaccounted losses.

The hydrological system is considered to be reasonably well instrumented and understood.

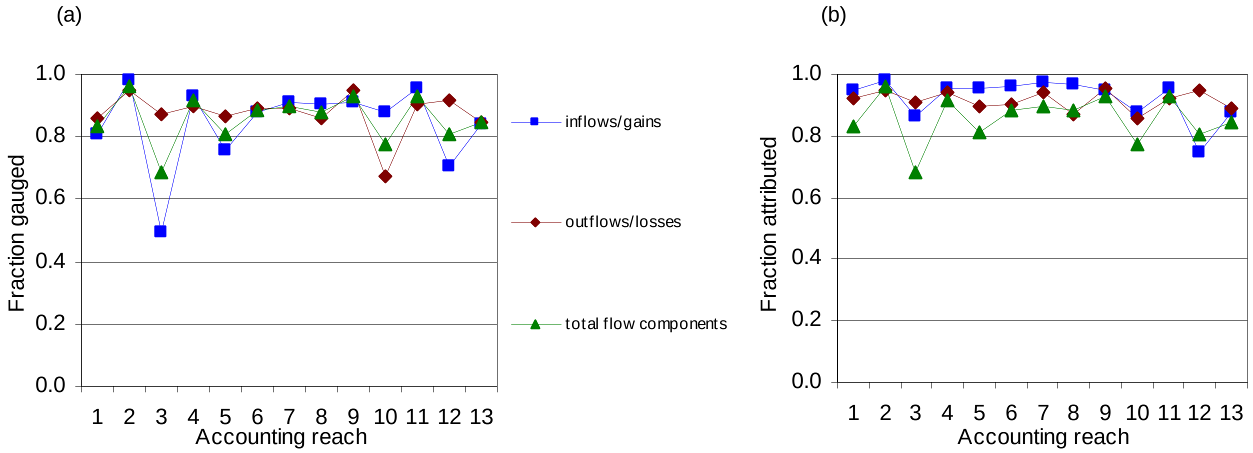


Figure 5-3. The fraction of inflows/gains, outflows/losses and the total of water balance components that is (a) gauged or (b) could be attributed in the water accounts

Comparison of modelled and accounted reach water balance

A summary of the reach by reach water balance 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 5-6. In both cases, numbers are averages for the period 1990 to 2006 to allow direct comparison. Interpretation follows:

- Most reaches of the Namoi-Peel system are gaining reaches, although slightly gaining in the lower reaches (Appendix C). One reach ending at Gunidgera where the Namoi River overflows into Pian Creek in times of high flow is strongly losing (Appendix C).
- Groundwater exchange was not estimated in water accounting due to the lack of direct data. It was estimated at 25 GL/year by the model.
- Combined modelled main stem and tributary inflows are 15 GL/year (2 percent) smaller than gauged inflows. Some of the discrepancies between component inflow terms (main stem and tributary, respectively) may include differences in definition between the model and accounts, or differences in baseline simulated and actual dam releases.
- Modelled local inflows (1133 GL/year) were considerably greater (by 388 GL/year or 52 percent) than the sum of local inflows that could be accounted for with SIMHYD estimates and unattributed gains (745 GL/year, but most likely including measurement error as well). This was compensated by 483 GL/year of unspecified losses.
- Gauged water balance terms (including diversions) represented 52 percent of the total water balance (including measurement noise), whereas another 13 percent could be attributed using SIMHYD estimates and remote sensing estimates of wetland and floodplain losses.
- For the entire accounted system unattributed gains (including measurement noise) represent 436 GL/year or 31 percent of total apparent gains, whereas unattributed losses (including measurement noise) represent 558 GL/year or 40 percent of total apparent losses. Their sum represents 35 percent of the total water balance.

- End-of-system outflow (Namoi River at Goangra) simulated by the model was 216 GL/year (42 percent) higher than observed streamflow. These discrepancies can be ascribed to local inflows on reach upstream (Reach 12, Bugilbone at Weeta weir) that appear to have been overestimated by the model during high flows events in 1996, 1998 and late 2000 by up to about 1000 GL/month. Observed average flows for the main stem gauges upstream were also overestimated, by 2 GL/year to 92 GL/year, or 0.4 percent to 39 percent (Appendix C).
- Simulated and recorded diversions for the accounting period agreed very well for the Namoi as a whole (within 4 percent or 6 GL/year) and for reaches above Mollee Weir (within 7 GL/year). Differences for lower reaches were larger (up to 69 GL/year or 47 percent). This may well be related to differences in the attributed diversion records and diversion simulation nodes to different reaches (Appendix C). It is noted that diversions have increased rapidly during the water accounting period. This influences the comparison between historical data that have been influenced by this and the baseline scenario model, which assumes a stationary level of development during this period.
- The sum of modelled river and floodplain losses and distributary outflows (376 GL/year) was larger than accounted accounting terms (175 GL/year). Both the model and the accounting were unable to explain relatively large losses (483 GL/year and 558 GL/year, respectively). Part of these may represent measurement noise or error.
- Unspecified model-simulated losses of up to 258 GL/year occur in all reaches, and in several cases appear to compensate for higher local runoff estimates than accounted. This has implications for the current study (Section 5.4.3).

Table 5-6. 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
Main stem inflows	128	94	34	36%
Tributary inflows	520	569	-49	-9%
Local inflows	1133	308	824	267%
Subtotal gains	**1781**	**972**	**810**	**83%**
Unattributed gains and noise	–	465	-4656	-100%
End of system outflows	729	513	216	42%
Distributary outflows	363	126	237	188%
Net diversions	168	162	6	4%
River flux to groundwater	25	–	25	n/a
River and floodplain losses	13	110	-98	-74%
Unspecified losses	483	–	483	n/a
Subtotal losses	**1781**	**912**	**870**	**95%**
Unattributed losses and noise	–	525	-525	-100%

Climate range

The calibration period used for the whole Namoi model was from 1997 to 2000 due to data availability. Individual components of the model were calibrated for different periods typically spanning most of the period 1988 to 1997.

The number of years in the entire 111-year record used in modelling that were drier than those included in the calibration period was 65 (or four when the period 1988 to 1997 is included), whereas two years were wetter (in both cases). The region-average rainfall range in the calibration period was 670 to 943 mm/year for the four-year period and 375 to 943 mm/year if the component calibration is included, compared to 354 to 1180 mm/year for the 111-year period. The average rainfall was 8 percent higher than the long-term average for the period 1997 to 2000, and 12 percent higher for the period 1988 to 1997.

The calibration period for the Namoi River model appears to provide a poor representation of long-term climate variability (67 out of 111 years outside the calibration range) when only the four years are considered, but a very good representation (six years outside the calibration range) when the calibration periods for model components are considered.

By comparison, the historical 111-year rainfall record had five years that were drier and no year that was wetter than the extremes during the period of water accounting 1990 to 2006. The water accounting period 1990 to 2006 provides a very good representation of climate variability, and as such provides a further opportunity to assess model performance partially outside its calibrated climate range.

Performance of the river model in explaining historical flow patterns

The better the baseline model simulates streamflow patterns, the greater the likelihood is that it represents the response of river flows to changed climate, land use and regulation changes (notwithstanding the possibility that the model is right for the wrong reasons through compensating errors). In Appendix C, indicators are listed reach by reach of the models 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:

- Reach 8 was used for accounting but no specific model results were available for this reach.
- The model explains observed monthly and annual flows patterns reasonably to very well in all but three reaches (NSME 0.6–0.99). Performance for Reach 1 is reasonable for annual patterns (NSME=0.7), but poor for monthly patterns. This reach is dominated by Split Rock Dam releases and the model does not appear to reproduce the release patterns very well (Appendix C). Performance is poor for the lowest two reaches (reaches 12 and 13) because flows are systematically overestimated by the model, particularly during high flow periods (NSME is better for ranked flows).
- Performance was generally better for annual than for monthly flows.
- The model reproduced the lowest 10 percent of flows poorly. Earlier reports noted difficulty in simulating low flows in the lower reaches during calibration and validation of the model (Section 5.3.2 and Figure 5-4).

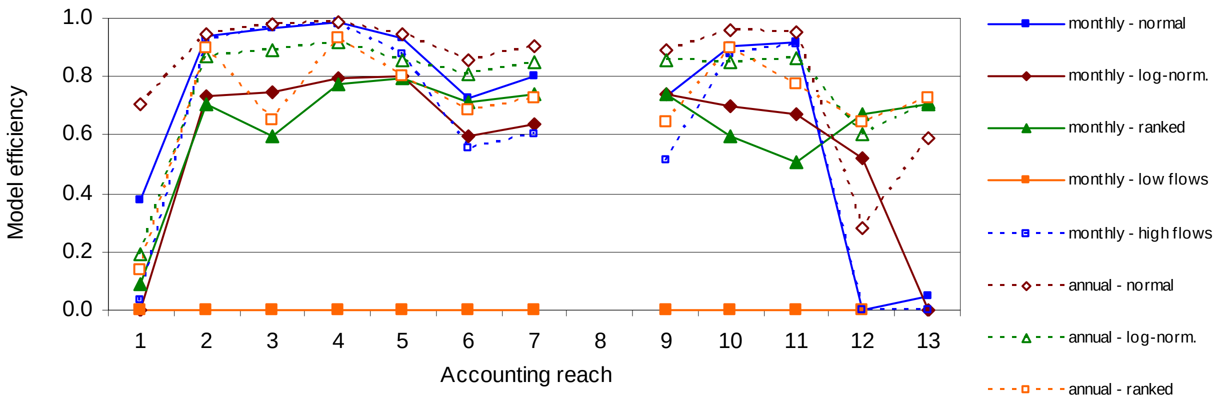


Figure 5-4. Changes in the model efficiency (the relative performance of the river model in explaining observed streamflow patterns) along the length of the river

Scenario change-uncertainty ratio

A high change-uncertainty ratio (CUR) corresponds with a scenario change in flows that is likely to be significant given the uncertainty or noise in the model. A CUR of around 1.0 indicates that the modelled change has a similar magnitude to the uncertainty in the model.

The CUR ratio is shown for each reach for changes in monthly and annual total flows in Figure 5-5 (a) and (b), respectively. The results suggest that:

- The projected changes from pre-development to current flow patterns are generally greater than model uncertainty by a moderate to fair margin (CUR=1.3–6.4). Flow patterns would have been different without development. Low flows would have been lower in the Namoi above Mollee Weir whereas overall flows would have been higher below the weir.
- The projected change in Scenario Cwet is generally greater than model uncertainty by a fair to very high margin (CUR > 2.1) in all reaches except Reach 11 (where the margin is moderate) for annual flow and monthly patterns. The projected changes in Scenario Cdry are greater than model uncertainty in all reaches except the two downstream reaches (12 and 13). The projected changes are greater than model uncertainty for reaches 1 and 6 by margins that vary from weak for the monthly pattern to fair for annual patterns. The margins for other reaches vary from moderate to very high for both monthly and annual patterns. The projected changes in Scenario Cmid are greater than model uncertainty by margins that vary from moderate to fair for reaches 1–5, 10 and 11. The projected Scenario Cmid changes in other reaches are similar to or less than model uncertainty. This can be attributed to the models tendency to overestimate streamflow in the main stem. The extreme wet and dry future scenarios lead to the greater certainty in the projected changes.
- The development scenarios show little projected change over and above the climate change scenarios in most of the upper reaches except those immediately below the dams, where outflows will be influenced by development water demands. The development scenarios show changed flow regimes over and above those of the climate change scenarios in the downstream reaches where the major diversions occur (and hence where development will have the greatest impact). The differences between development and climate change flow regimes appear modest relative to the uncertainty in most reaches and the greatest and most certain difference is in reaches 10 and 11 where the highest level of diversions occur.

The magnitude of projected changes in flow under future scenarios is generally greater than the uncertainty in the model predictions for the wet and dry climate scenarios in most reaches. It ranges from less than to greater than model uncertainty for the mid scenarios.

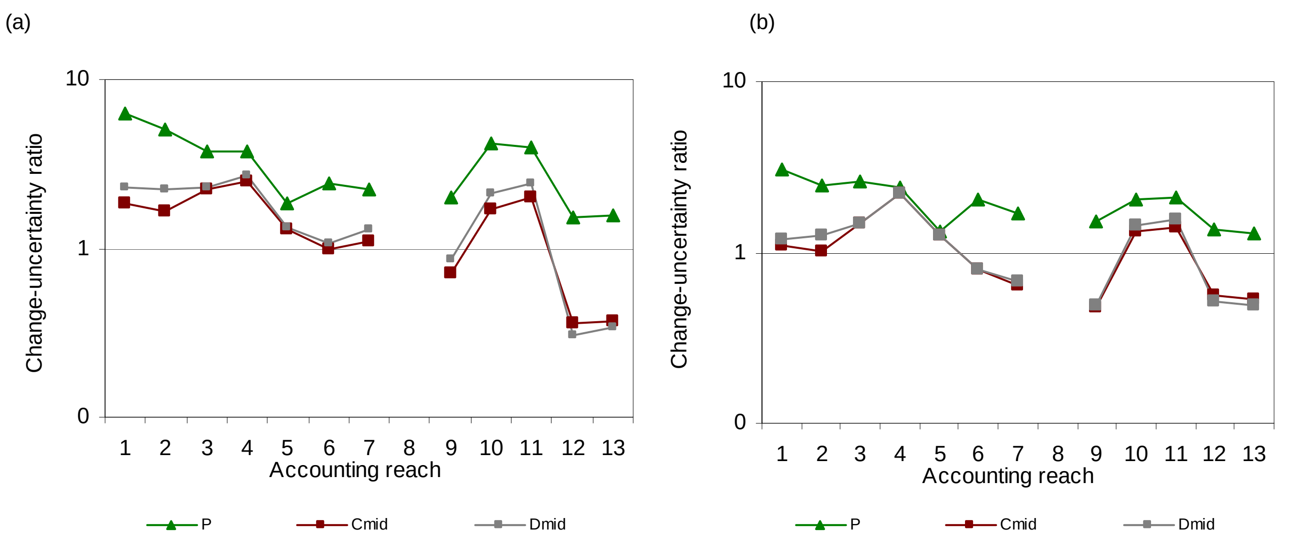


Figure 5-5. Pattern along the river of the ratio of the projected change over the river model uncertainty for the different scenarios modelled for (a) annual and (b) monthly flows

5.4 Discussion of key findings

5.4.1 Completeness of the gauging network

The spatial density of streamflow gauging in the Namoi region is similar to the MDB average and the density of rainfall gauges is about twice the MDB average in the upper part of the region (Section 5.3.1). The main uncertainty in gauging arises from ungauged losses in the lowest reaches. Floodplain harvesting diversions are also not metered.

5.4.2 Conceptual understanding of regional surface hydrology

The conceptual understanding of the current hydrology of the Namoi surface water system appears reasonable. About 65 percent of combined gains and losses were attributed through water accounting (Section 5.3.3). The greatest uncertainty is associated with the estimation of local inflows and ungauged losses in the lower part of the system (Section 5.3.3). The model performance assessment also suggested that the greatest uncertainties arose in these lower reaches but the upper reach that is dominated by releases from Split Rock Dam is also modelled less well (Section 5.3.3). Overall patterns in streamflow, storage levels and diversions are simulated well by the model. This gives greater confidence that the system is well understood (Section 5.3.2). Planted areas are not always well modelled and may lead to some uncertainty in predictions of annual diversions (Section 5.3.2).

The quantitative knowledge of runoff generation in the Namoi region is relatively poor. The ungauged inflows simulated by the river model represented 63 percent of total inflows. The ungauged inflows were more than three times higher than could be accounted for with SIMHYD estimates yet 52 percent more than accounted inflows assuming that all unattributed gains are indeed inflows (assuming there are no measurement errors in gauging). This is partially compensated by large losses that are not attributed by the model (483 GL/year). It indicates the possibility of compensating errors in estimation of local inflows and creates uncertainty in the projected changes as the impact of climate and development on runoff generation was applied by scaling inflows only according to relative changes in SIMHYD estimates. It can lead to an artificial enhancement of any runoff generation reductions and weakening of runoff increases in the river model. The simulated losses typically have a constant component and a component that is proportional to flow. Low flows are affected most by this model uncertainty as a consequence and high flows are least affected. Impacts on averages are expected to be limited (Chapter 4).

The river system loses water to the groundwater in the middle reaches (Chapter 6). The river model results suggest that less than 2 percent of reach streamflow is lost to the groundwater system under the baseline scenario and totals 25 GL/year for the accounted reaches (Appendix C). Over twice the loss to groundwater results from future groundwater development (Chapter 6). River, floodplain and unattributed losses in the reaches with groundwater losses (4, 5, 6, 7, 9, and 10) are considerable (>600 GL/year). Groundwater interactions may play a role and were identified as a source of model uncertainty in years when there is substitution of groundwater for surface water (Section 5.3.2).

5.4.3 Performance and uncertainty in aspects of the river model

Review of a prior model performance assessment suggested that performance was very high (Section 5.3.2). Comparison with observations and water accounts largely confirmed this, although bias in average flows appeared to exist with the model overestimating flows by about 30 percent during the accounting period (1990 to 2006). Low flows were reproduced less well in all reaches. The climate range for the calibration period of the Namoi model as a whole is poor but good when the calibration period for individual components is considered. The water accounting period also provided a good opportunity to evaluate the model outside of its calibration range.

The model generally overestimates runoff and consequently streamflow in the main stem. This is especially true for Reach 12.

5.4.4 Implications for use of the results of this project

The model is able to assess the direction of change under the pre-development, climate change and development scenarios. The estimated uncertainty in climate change is generally of greater magnitude than the internal uncertainty of the model. The estimated impacts of development are small compared to internal uncertainty.

The model overestimates flows at various locations in the system during the accounting period and there are indications that the simulated inflows are higher than those that occur in reality. The model probably provides reasonable estimates of the proportional flow changes under the climate and development scenarios but the absolute magnitude of the flows may not be correct.

5.5 References

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6 Groundwater assessment

This chapter describes the groundwater assessments for the Namoi region. It has eight sections:

- a summary
- a description of the groundwater management units in the region, including their hydrogeological context
- a description of surface–groundwater connectivity
- 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 twelve groundwater management units (GMUs) that cover the entire Namoi region.

Three existing numerical groundwater models underpin the assessments for the Upper Namoi Alluvium and Lower Namoi Alluvium GMUs. Simpler water balance analyses were conducted for the remaining GMUs and a part of the Upper Namoi Alluvium GMU.

6.1.2 Key messages

Groundwater extraction in the Namoi Region for 2004/05 is estimated at 254.8 GL. This represents 15.2 percent of groundwater use in the Murray-Darling Basin (MDB) (excluding confined aquifers of the Great Artesian Basin). About 39 percent of this extraction was from the Upper Namoi Alluvium GMU and about 35 percent was from the Lower Namoi Alluvium GMU.

Groundwater use represents 49 percent of current total water use on average, and 78 percent of total water use in years of lowest flow.

Historical groundwater extraction has impacted, and will continue to impact, on streamflow in the tributaries of the Namoi River. The total average impact on tributary streamflow by 2010 will be a loss to groundwater of 19 GL/year compared to that included in the current river planning models while the eventual impact will be a loss to groundwater of 36 GL/year.

The estimated average groundwater extraction for the region by 2030 is 450 GL/year. This is an increase of 77 percent over current levels. Most of the increase in groundwater extraction is expected to occur in the New England Fold Belt, Gunnedah Basin and Oxley Basin GMUs. The total eventual impact of groundwater extraction at projected 2030 levels would be an average streamflow reduction of 113 GL/year; of this, 76 GL/year is caused by the projected increases in groundwater extraction.

The streamflow reduction is a combination of tributary inflow reductions and increased leakage to groundwater in alluvial reaches. Because the tributary inflow reductions would be distributed across multiple subcatchments, some of the smaller reductions would be difficult to measure. Thus only the larger inflow reductions at a subcatchment level were included in the river modelling. As a result, 71 GL/year (the total estimate impact of 113 GL/year) is included in the river modelling.

Management responses under future scenarios have not been included in the groundwater modelling.

Groundwater modelling indicates that for the Lower Namoi Alluvium GMU:

- Extraction from the Lower Namoi Alluvium GMU currently exceeds the long-term average extraction limit (LTAEL) due to supplementary licences with entitlements that decrease to zero by 2015 when the existing Water Sharing Plan ends. (The reduction in entitlements to the LTAEL level is funded by the New South Wales and Australian governments under the 'Achieving Sustainable Groundwater Entitlements' program).
- The LTAEL for the Lower Namoi Alluvium GMU exceeds total long-term groundwater recharge from all sources and exceeds annual recharge in most years. Extraction at this level, given the current spatial pattern of pumping bores, is not sustainable. Responses will be required from both groundwater users and resource managers as groundwater levels fall. These responses would reduce extraction in areas of falling groundwater levels.
- The lower Namoi River has changed from a river which gained water from groundwater prior to development to a river which now loses considerable streamflow volumes to groundwater.
- The impact of the best estimate (median) 2030 climate on surface–groundwater exchanges would be minimal. Under either the dry or the wet extreme 2030 climate the changes in recharge would be partially offset by changes in river losses; the net result however, would be a change in groundwater storage expressed as changed groundwater levels.

Groundwater modelling indicates that for the six major zones of the Upper Namoi Alluvium GMU:

- The long-term average extraction limit represents 95 percent of recharge from all sources including 24 GL/year of recharge from streamflow. This is a very high level of development and can only be sustained through induced streamflow losses. The New South Wales water sharing process has indicated this should be a maximum permitted streamflow loss.
- Surface–groundwater connections vary along the Upper Namoi and its tributaries. In some reaches the river gains water from groundwater, in other reaches the river loses water to groundwater.
- About 85 percent of any change in groundwater recharge or extraction is offset by a change in water flux from the river.

Water balance analysis indicates that for the Miscellaneous Alluvium of the Barwon region GMU:

- The current level of extraction exceeds rainfall recharge by 15 percent. This is a very high level of development. However, recharge from sources other than rainfall (for example, streamflow and lateral flow) is likely that may sustain the resource.
- Under the best estimate 2030 climate, current extraction would exceed rainfall recharge by 30 percent.
- For the estimated future level of groundwater extraction and under the best estimate 2030 climate, extraction would exceed rainfall recharge by nearly 130 percent. This is a very high level of development. Determining whether these levels of development are sustainable requires greater supporting information – particularly of non-rainfall recharge sources – than is currently available.

Water balance analysis indicates that for the Peel River Alluvium GMU:

- The current level of extraction represents about 55 percent of rainfall recharge. This is a moderate level of extraction. However, recharge from other sources is likely, particularly from streamflow.
- For the estimated future level of groundwater extraction and under the best estimate 2030 climate, extraction exceed rainfall recharge by about 10 percent. This represents a very high level of development. Determining whether these levels of development are sustainable requires greater supporting information – particularly of non-rainfall recharge sources – than is currently available.

6.1.3 Uncertainty

A ranking has been done for both the priority of the GMU in the context of the overall project and also of the analysis method. Ideally the ranking of the analysis method would match that of the priority so that those GMUs which are likely to influence MDB-wide outcomes have greater reliability in terms of groundwater availability and level of development.

The modelling approach used in 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 in order to over the first 111 years bring the groundwater system to a 'dynamic equilibrium' and then for the second 111 years to run in sequence with surface water models to provide input to groundwater-surface water interactions. In some cases, dynamic equilibrium is not reached within 111 years.

The most likely cause is that extraction exceeds recharge from all sources for the model area or for some components of the model area and the water tables gradually fall. This suggests that the modelled spatial pattern of extraction is not sustainable.

In such cases, the modelling results will have implications for beyond the project and in particular for the sustainable extraction limit. Thus, it is important that in the ranking of the assessment methodology, that it provides some information on the reliability of such information. For assessing water availability at the larger scale, a model may be fit for purpose for this project but less than adequate for addressing local management issues.

The ranking criteria in the first instance is based on the approach: 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 water-groundwater connectivity and (vi) level of independent peer review. Since at least three of these criteria are based on availability or quality of data, a good calibration fit in line with the best modelling guidelines may still not rank well. Also, the more mature a model, the more opportunities there are for obtaining a higher ranking because of data availability and peer review. A very thorough model should provide very good reliability in addressing issues of groundwater balance and hence extraction limits.

For the Namoi, none of the models have a steady-state pre-development calibration. The Lower and Upper Namoi models have been used to prepare groundwater sharing plans and so have had a high level of prior scrutiny. Good monitoring and extraction data exist for both models. Lateral flows represent 5 percent in Upper Namoi, 9 percent in Lower Namoi and 30 percent in Zone 8 of the Mooki model. The Lower Namoi model is based on a coarse grid. Both models have been assessed as thorough, while the Zone 8 model has been assessed moderate. Thus, all models are adequate for providing information on water availability in the context of this project, but barely more. The Lower Namoi did not reach a dynamic equilibrium and the Upper Namoi is reliant on stream losses to maintain water table levels. For both models, the level of reliability of predictions could be improved to very thorough given the importance of these GMUs as a groundwater resource.

The level of analysis against each of the GMUs is at an acceptable level, except in one case – the Upper Namoi Alluvium GMU.

The Lower Namoi model is a well-calibrated and verified model. The Upper Namoi and Mooki (Zone 8) models are less well calibrated. Neither model was able to successfully simulate pre-development conditions. It is also less than ideal that the whole of the Upper Namoi GMU has not been incorporated into one model platform. Future work is warranted in the Upper Namoi to simulate the pre-development condition in a stable manner.

There is considerable uncertainty in the future projections of groundwater development outside of the Lower and Upper Namoi GMUs but the estimates do show the importance of development in these areas. The projections of groundwater extraction are considered to generally represent the upper limit of groundwater development as it can be constrained by pumping rules, groundwater quality and land suitability. However, the estimates of development impacts are dependent on the use of connectivity estimates based on conservative 'best guess' analysis.

In the water balance approach the extraction to rainfall recharge signals aquifer where extraction is high compared to the rainfall recharge. There may be other forms of recharge including from streams and a high to very high signals that further work is required to support this level of development.

6.2 Groundwater management units

6.2.1 Location

The aquifers within the Namoi region are divided into 12 GMUs for management purposes (Table 6-1). The GMUs are three-dimensional because of the layered nature of geological formations at different depths. Different GMUs cover the entire region. Extraction from each GMU varies considerably from areas of intensive extraction for irrigation to areas of broad-scale stock and domestic use.

6.2.2 Ranking

Table 6-1 shows the GMU priority ranking and the assessment ranking for this project. The priority ranking focuses efforts on the GMUs that affect the overall groundwater or surface water resource in the MDB. The ranking ranges from ‘very low’ to ‘very high’ in the context of this project and is based on the level of groundwater use, potential for growth in use and the potential for groundwater to impact on streamflow.

The groundwater assessments vary for different GMUs reflecting the availability of data and analysis tools as well as the priority of the GMU. Assessment rankings range from minimal to very thorough. For the GMUs in the Namoi, a ranking of simple denotes a water balance approach while thorough denotes a well-calibrated and conceptualised numerical groundwater model (for the purpose of this project) with a good underlying dataset. The assessment and priority rankings are consistent for all of the GMUs listed in Table 6-1 except for the Upper Namoi Alluvium GMU. While these assessments are generally appropriate with the constraints and for the terms of reference of this project, additional work may be required for local management of groundwater resources.

Table 6-1. Categorisation of groundwater management units in the Namoi region together with estimated current and future extraction, and extraction limits for each unit

Code	Name	Priority ranking	Assessment ranking	Entitlement	Current extraction 2004/05*	Long-term average extraction limit**	Maximum likely extraction without plan revision
					GL/y		
N01	Lower Namoi Alluvium	high	thorough	89.3	89.04	86 (plus basic landholder rights)	86 (plus basic landholder rights)
N04	Upper Namoi Alluvium	very high	thorough	119.24	100.3	122.1 (plus basic landholder rights)	122.1 (plus basic landholder rights)
N05	Peel Valley Alluvium	low	simple	51.35	10.32	14.1	21.6
N23	Miscellaneous Alluvium of the Barwon Region	low	simple	7.16	4.06	1.74	7.16
N63	GAB Alluvial	very low	simple	0.39	0.33	9.92	5.95
N601	GAB Intake Beds	very low	simple	3.85	0.83	4.06	4.06
N604	Gunnedah Basin	low	simple	6.66	5.62	87.19	61.03
N608	Oxley Basin	low	simple	12.58	9.24	77.21	46.33
N805	New England Fold Belt	low	simple	10.79	7.55	113.23	67.94
N813	Warrumbungle Tertiary Basalt	very low	simple	0.01	0.01	0.53	0.26
N814	Liverpool Ranges Basalt	low	simple	3.66	2.48	23.74	11.87
N819	Peel Valley Fractured Rock	low	simple	35.75	25.06	70.48	35.75

* Current groundwater extraction for Macro Groundwater Sharing Plan areas is based on metered and estimated data provided by New South Wales Department of Water and Energy (DWE). The Sharing Plan is scheduled to be operational in 2009. Data quality is variable depending on the location of bores and the frequency of meter reading. Where indicated the recharge volume does not include the volume of groundwater available for basic rights, which is an additional volume.
**For Macro Groundwater Sharing Plan areas these limits are draft, as plans for these areas are not yet gazetted.

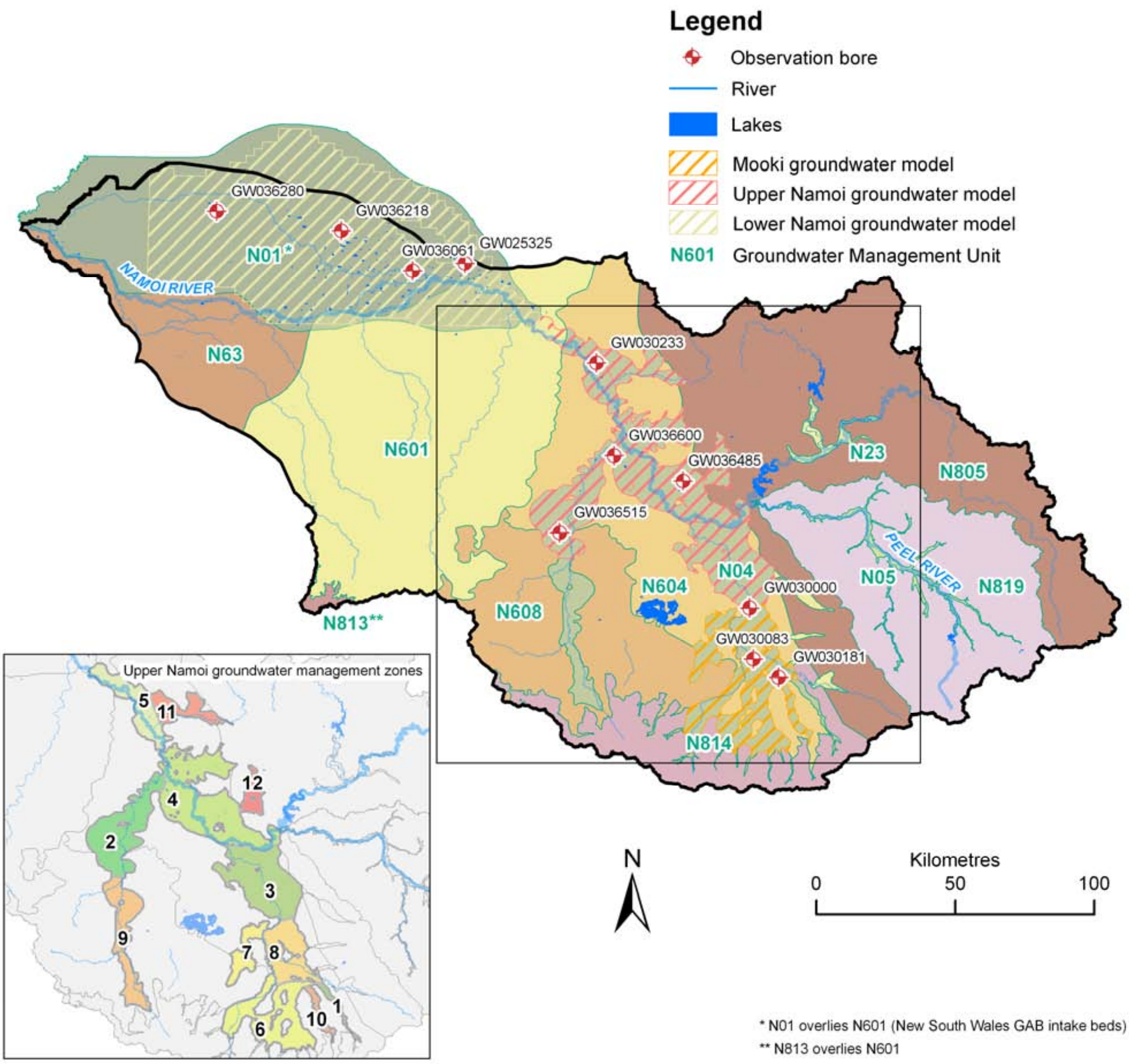

Figure 6-1. Map of groundwater management units in the Namoi region with inset showing Upper Namoi groundwater management zones (Table 6-4)

6.2.3 Hydrogeological context

Groundwater resources in the Namoi region are the most intensively developed in New South Wales and lie in a hydrogeologically complex region. Most groundwater is extracted for irrigation, stock, domestic and town water from alluvial aquifers associated with the main rivers and prior channels including the coarse-grained Gunnedah Formation and the underlying Cubbaroo Formation.

The Peel River Alluvium is highly connected to the river and more than 80 percent of the groundwater extracted is ultimately drawn from the river. Connectivity between the alluvial aquifers and the river decreases in the downstream direction with limited connection between the river and the Lower Namoi aquifer.

The region is underlain by the consolidated sandstones, shales and mudstones that form the multi-layered aquifers of the GAB.

The groundwater resources within GAB aquifers are not considered in this assessment except where intake-beds for the GAB outcrop within the region. Groundwater in these areas has the potential to be connected to surface water systems.

Upper Namoi hydrogeology

The description of the Upper Namoi hydrogeology is based on information in DLWC (2000a) and URS (2006).

The aquifer system of the Upper Namoi Valley comprises the unconsolidated sediments associated with the Namoi and Mooki Rivers and Coxs Creek. The alluvial sediments consist mainly of sand and gravel. The total area of alluvium approximates 3000 km^2 and is up to 170 m thick. A palaeochannel in the central valley area represents the deepest parts of the aquifer.

Good quality groundwater is found in high-yielding aquifers across wide areas of the alluvial plain. The most productive aquifer is the main palaeochannel. The coarseness of the palaeochannel sediments supports high groundwater extraction rates.

Other aquifers of the Upper Namoi Valley consist of a variety of different fractured rock types of Palaeozoic and Mesozoic age. Rock types include sedimentary and metamorphic rocks, basalts and granites. Other important aquifers in the region include unconsolidated highland alluvium deposited in valley floors. Regional groundwater flows are from east to west; however the groundwater flow systems within all of these aquifers are generally ‘local’ to ‘intermediate’ in scale.

Fractured rock and granite aquifers are recharged where soils are thin on mid- to upper-slopes and discharge to adjacent streams, valley floors and at breaks in slope. The basalts are highly porous, well flushed and are recharged extensively. Alluvium deposited in valley floors is also recharged throughout the landscape. The recharge volume depends on the nature of soils and weathered rock above the watertable and the frequency of flooding.

Groundwater discharges typically to drainage lines and at local changes in soil texture, break-of-slope and the base of terraces within the highland alluvial systems. Salt storage in the finer-grained units of these systems is high and groundwater salinity is variable from fresh to saline. Lower salinity levels characterise the coarser sediments. These systems respond rapidly to a change in the water balance.

Lower Namoi hydrogeology

The description of the Lower Namoi hydrogeology is based on information in DLWC (2000b) and URS (2006).

The aquifer system of the Lower Namoi Valley comprises the unconsolidated sediments of inter-bedded clays, sands and gravels associated with the Namoi River and its tributaries. They accumulated for more than 15 million years within a broad valley of the old Namoi River, to a maximum depth of about 120 m and an area of about 5100 km^2. The Namoi River alluvium joins the alluvium associated with the Barwon and Gwydir rivers to the north-west. It is bounded by colluvium associated with weathered GAB sediments and basalt flows in the north-east and south. The Namoi River alluvium joins the alluvium associated with the Barwon and Castlereagh rivers to the south-west.

There are two alluvial aquifer systems identified with most areas of the Lower Namoi: the shallow Narrabri Formation and the deeper Gunnedah Formation. An aquifer called the Cubbaroo Formation underlies the Gunnedah Formation. There is no difference discernible between the aquifer systems and they act as a single aquifer in some areas to the east. The Gunnedah Formation extends over most of the area and generally occurs between 40 and 90 m depth. The Cubbaroo Formation occurs 90 m below the ground surface and is restricted to a palaeochannel.

Recharge to the fractured rock systems flows through the fractures to discharge into adjacent streams and valley floors within the highland areas of the region. The rivers of the highland valleys tend to be gaining in nature.

All streams in the western parts of the region on the alluvial plain run across the top of the Narrabri Formation. The rivers are in direct hydraulic contact with the watertable at the eastern margin of the plain. An unsaturated zone develops further west where the watertable falls well below the streams and surface water leaks to the underlying aquifer. Watertables are closer to the surface and saturated conditions are re-established at the far western edge of the alluvial plain. The Gunnedah Formation is recharged via infiltration from the overlying Narrabri Formation. Recharge to the groundwater system on the alluvial plain is primarily via leakage from the stream channel under normal flows, leakage from overbank flooding and infiltration from rainfall. There is a downward movement of groundwater from the Narrabri to the Gunnedah Formation in the eastern parts of the plain and the direction is reversed at the western margin.

6.2.4 The ‘Achieving Sustainable Groundwater Entitlements’ structural adjustment program

The ‘Achieving Sustainable Groundwater Entitlements’ structural adjustment program announced in June 2005, reduced entitlements in the Upper and Lower Namoi, Lower Macquarie, Lower Lachlan, Lower Murray, Lower Gwydir and Lower Murrumbidgee groundwater sources. The New South Wales and Australian governments jointly invested $110 million in this program to improve long-term sustainability of the six major groundwater systems in New South Wales. In June 2007, the Australian Government provided an additional $25 million to the program, bringing the Australian Government contribution to $80 million and total funding to $135 million.

The level of entitlements in the groundwater systems of these areas was reduced to equal the long-term average extraction limit (LTAEL) within the Water Sharing Plans. The available extraction from each system will be gradually reduced from current levels to the LTAEL over the ten years of the Water Sharing Plan.

The LTAEL forms the assumed levels of extraction under Scenario D, and in nearly all cases, under Scenario A. These values are used for scenarios A and D for the Lower Namoi and for those zones covered by the Upper Namoi model as well as Zone 8. In most of the other zones in the Upper Namoi, current use is lower than entitlements and in these areas Scenario A assumes current use while Scenario D assumes the LTAEL.

6.3 Surface–groundwater connectivity

The surface–groundwater connectivity mapping aims to (i) provide a catchment context for surface–groundwater interactions, (ii) constrain the surface water balance and (iii) constrain groundwater balances. The main output is a map of the magnitude and direction of groundwater fluxes adjacent to the main streams.

The approach uses Darcy’s Law and hence estimates the hydraulic conductivity and groundwater gradients surrounding the streams. The method is dependent on the availability of appropriate groundwater monitoring data and on reported estimates of hydraulic conductivity.

River levels and groundwater levels were compared at a single point in time to provide a snapshot of the direction and magnitude of the flow between surface water and groundwater. The date selected for production of the flux map and associated calculations was June 2006, as this was the most recent date with both a large quantity of available bore and river elevation data. The selected date represents a historical low flow period with an average depth of 0.6 m at Namoi River Stream gauging station 419012. This compares with a depth range of 0.3 to 3.8 m over the period of record (1982 to 2007). Testing shows that spatial patterns are preserved even though absolute values will generally be much higher than at this exceptionally dry time.

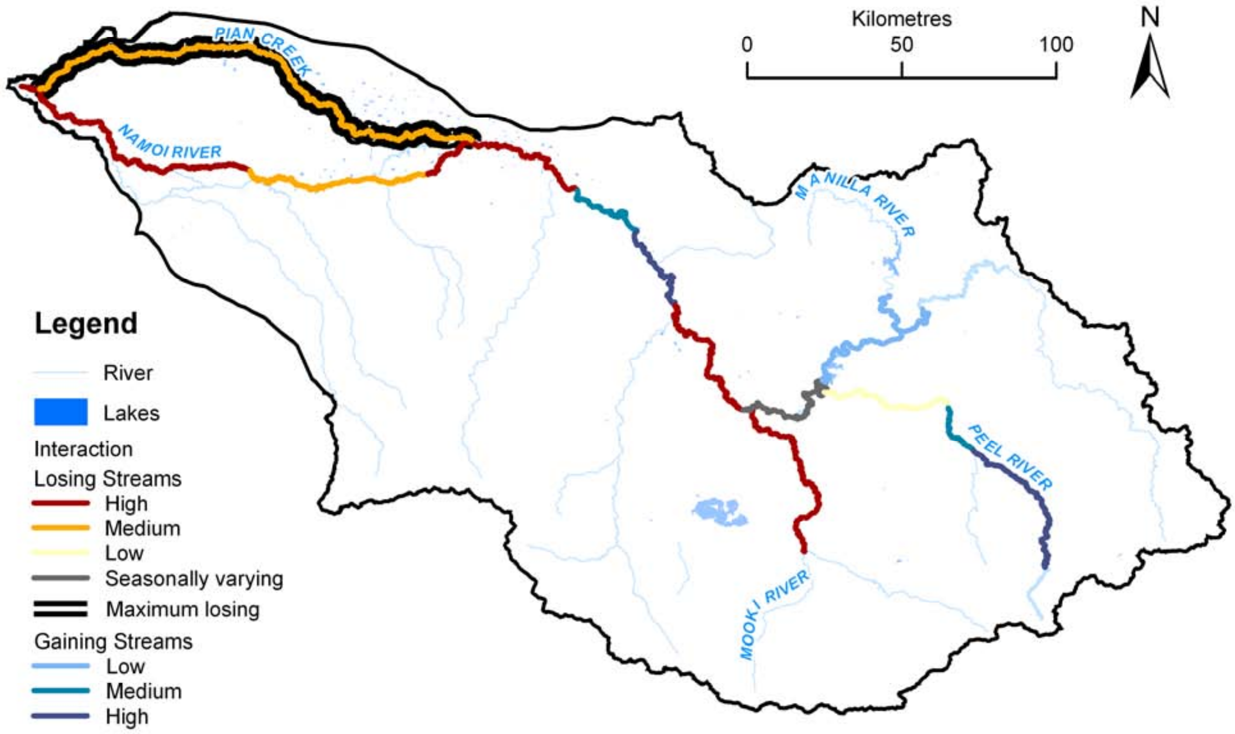

Figure 6-2. Map of surface–groundwater connectivity showing gaining rivers in upper reaches, varied conditions for mid-catchment and losing rivers in the lower catchment

Figure 6-2 provides the surface–groundwater connectivity results from the flux assessment that shows the lower Namoi reaches of the Namoi River and Pian Creek are losing. The river changes from losing to gaining and back to losing in the mid to upper Namoi reaches, including the Mooki River and Coxs Creek. The reaches are predominantly gaining in the highlands areas of the Peel, and Manilla rivers and losing in lower parts of the Peel. This result is generally consistent with previous hydrogeological interpretations of the region.

An average aquifer thickness of 25 m was used for all river reaches in the flux calculations. An average hydraulic conductivity of 30 m/day was used for the upper Narrabri formation. The Peel River and lower Manilla River intersect the carboniferous metasediments that generally have lower conductivities of between 1 and 2 m/day. Most of Pian Creek is a disconnected system with depths to watertable of over 20 m. A vertical conductivity of 0.1 m/day with an assumed gradient of 1 was applied to the Pian Creek reaches.

The results of the flux assessment are only for a single point in time (June 2006). Comparisons between river levels at two gauging stations and adjacent groundwater levels indicate how fluxes change with time. Figure 6-3 is an example of a high losing reach of the Mooki River, with river levels recorded at the Breeza stream gauge (419027) and groundwater levels taken from a bore situated approximately 300 m from the river (GW030000). As the gauge is located approximately 2.5 km upstream of the bore the modelled river elevation was used to estimate an appropriate shift such that the river elevation was representative of the river height at the bore. An upstream shift of 5 m was applied to the bore.

The hydrograph in Figure 6-3 indicates that the losing nature of the Mooki River at the time of assessment is representative of the last ten years for this river reach. Prior to 1995 the river reach is shown to be gaining. Groundwater levels dropped significantly since 2002 due likely to significant groundwater extraction and decreased rainfall recharge. Some recovery is evident in 2004/05 when river flows were higher than those experienced in 2002 and 2003. This recovery in groundwater levels further illustrates the losing nature of the stream and the level of connection between the river and watertable.

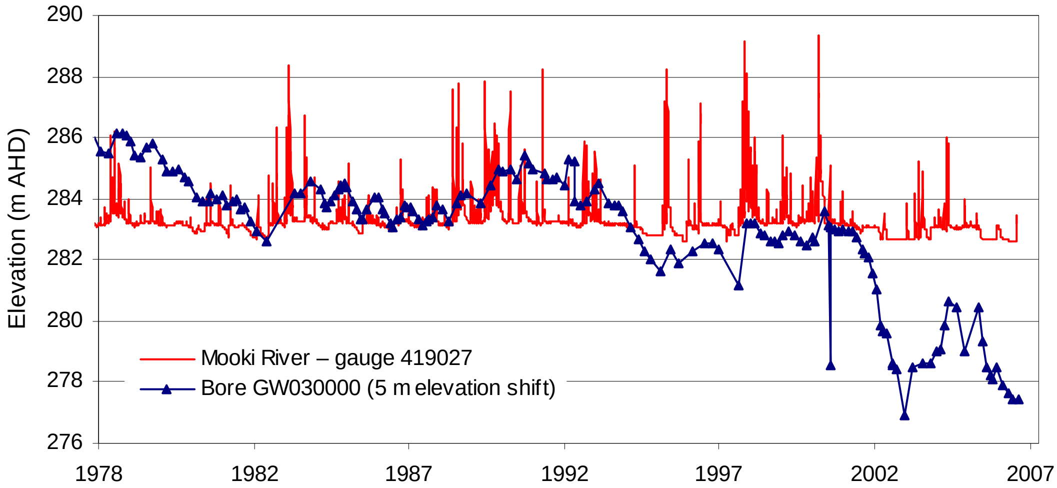

Figure 6-3. Comparison of groundwater levels with river stage for the Mooki River at Breeza showing increasingly losing conditions over the ten-year period 1997 to 2007

6.4 Groundwater modelling

About 74 percent of the current groundwater extraction in the Namoi region occurs in the Lower and Upper Namoi Alluvium GMUs. These GMUs were assessed using three numerical groundwater models: the Lower Namoi model (Merrick, 2001a), the Upper Namoi model (McNeilage, 2006), and the Mooki model (Merrick, 2001b) that were developed previously by or for the New South Wales Government. The Lower Namoi model covers most of the GMU, while the other two models cover parts of the Upper Namoi Alluvium GMU. The original groundwater models were modified to model scenarios for this project.

6.4.1 Modelling approach – Lower Namoi

The Lower Namoi groundwater model analyses a groundwater system towards the lower end of the Namoi region as shown in Figure 6-1 and covers most of the Lower Namoi Alluvium GMU.

The Lower Namoi groundwater model developed in stages from 1986. The latest version of the model (Merrick, 2001a) is used here. The model was calibrated against measured groundwater hydrographs over the period 1980 to 1998.

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

- Layer 1 is the uppermost model layer or Narrabri Formation that commonly outcrops. It comprises leveed stream type deposits from 10 to 40 m thick
- Layer 2 or Gunnedah Formation consisting of fluvio-lacustrine sediments up to 80m thick.
- Layer 3 or Cubbaroo Formation is a palaeochannel passing to the north-west through Narrabri. The channel is in-filled with fluviatile sediments up to 60 m thick.

The model cell size is 2500 m by 2500 m.

The model includes boundary conditions that define the interaction between the rivers and the groundwater system (river boundary cells), and allow water to enter or leave the model domain through its external boundaries (both general head and constant head boundary conditions). The river boundary cell conductance terms (used to regulate flow at the boundary) are variable both temporally and spatially, with an assumed fining of river bed sediments in the downstream direction. Temporal variation in river boundary cell conductance values allows for enhanced fluxes entering the aquifer during periods of flood inundation. General head boundary cells included in Layer 2 of the model were included to allow for interaction with the underlying aquifers of the GAB.

Recharge associated with downward percolation of water from the surface that is from rainfall, irrigation accessions and flood inundation is applied to Layer 1 of the model. The recharge flux is set at a fixed percentage of rainfall (0.1 percent of measured rainfall in the north and 0.5 percent of measured rainfall in the south) for much of the model with a region of enhanced recharge flux used to represent the impacts of inundation during flood events. The distribution of recharge zones to account for flood inundation is complex and is derived from an analysis of flooded area and river flows measured during historical flooding events. Increased recharge due to irrigated accessions was not included in the model. Evapotranspiration fluxes from the watertable are also not included.

6.4.2 Modelling approach – Upper Namoi

The Upper Namoi groundwater model was developed by and is documented in McNeilage (2006). The latest version of the model was made available for this project.

The Upper Namoi groundwater model sits at the lower end of the Upper Namoi valley. It includes zones 2, 3, 4, 5, 11 and 12 of the Upper Namoi Alluvium GMU. The geology of the modelled area consists of unconsolidated sediments of the Namoi River valley overlying low permeability bedrock. The model incorporates the two aquifer layers of the basal Gunnedah Formation and the surficial Narrabri Formation. The Gunnedah Formation reaches a maximum thickness of 115 m and consists of sands and gravels with interbedded clays. It is conceptualised as a high-yielding aquifer with good quality, low salinity water. The overlying Narrabri Formation reaches a maximum thickness of 70 m and is conceptualised as a lower-yielding aquifer composed generally of clays with some sand and gravel.

Recharge to the aquifers occurs via six mechanisms: direct rainfall recharge, irrigation, river leakage, flood inundation, inflow from surrounding aquifers, and hillslope ‘run-on’ from outcropping bedrock at the aquifer margins. Direct rainfall recharge is modelled at 3 percent of rainfall with an adjustment for evapotranspiration. The Upper Namoi valley experienced average annual rainfall of 660 mm/year over the period 1985 to 2001; higher than the long-term average. Pan evaporation over the same period was approximately 1700 mm/year.

Stream–aquifer interaction is an important part of the hydrological cycle in the Upper Namoi valley and the Namoi River has good hydraulic connection to the shallow aquifer. Traditionally the Namoi River was a losing stream upstream and a gaining stream downstream of Boggabri. Lower groundwater levels in recent times (post-2000) have produced increasing losses to groundwater.

Groundwater discharges are largely restricted to pumping, river interaction and lateral groundwater flow to the Lower Namoi. Groundwater pumping has increased significantly since the 1980s and now approximately 70 GL/year is extracted. Watertables in the Namoi Valley are typically deeper than 2 m and consequently direct groundwater evapotranspiration is not a significant part of the water balance.

The model cell size is 1000 m by 1000 m.

The model includes boundary conditions that define the interaction between the rivers and the groundwater system (river boundary cells), and that allow water to enter or leave the model domain through its external boundaries (both general head and constant head boundary conditions).

The river boundary cell conductance terms (used to regulate flow at the boundary) are variable both temporally and spatially. Spatial variation in this term is to account for the assumed fining of river bed sediments in the downstream direction. Temporal variation in river boundary cell conductance values is included to allow for enhanced fluxes entering the aquifer during periods of flooding inundation.

Recharge associated with downward percolation of water from the surface that is from rainfall, irrigation accessions and flood inundation is applied to Layer 1 of the model. Recharge input is adopted from the original Department of Natural Resources model.

Groundwater extractions were set as an annual time series repeated for the 111 years of the simulation. The same groundwater extractions were used for scenarios A and C. These replicated observed pumping from the 2004/05 irrigation season.

6.4.3 Modelling approach – Mooki

The GMU for the Upper Namoi alluvium is divided into 12 management zones. Zones 2, 3, 4, 5, 11 and 12 are a part of the ‘Upper Namoi groundwater model’. Merrick (2001b) describes the ‘Zone 8’ groundwater model that was developed for Upper Namoi management zones 6, 7, 8 and 10 within the alluvium on the Mooki River. This model is active in these four management zones but only considered to be calibrated in Zone 8, hence the model’s name. The whole groundwater model will be referred to as the Mooki groundwater model and references to inputs and outputs to Zone 8 within the model will be referred to as Zone 8 fluxes.

The alluvial plains of the upper Mooki River and its tributaries are modelled in two layers (Narrabri and Gunnedah formations) that overlie the fractured rock basement. Layer 1 is considered to be an unconfined aquifer and Layer 2 a semi-confined or confined aquifer.

Merrick (2001b) discusses the response of groundwater bores to a flood event on the Mooki River and Quirindi Creek in June and July 1998. The observed rise in groundwater level of 1 m is too small to try and account for in this model. Hence the possible effects of flooding on the groundwater system are not represented.

Rainfall recharge is an important groundwater balance component and is modelled as a percentage of rainfall. The percentages used appear to allow for run-on to the alluvial areas from the adjacent hill slopes and for areas of intensive irrigation.

Merrick (2001b) presents groundwater extraction volumes for the period 1979 to 2000 over the whole area of the Mooki groundwater model. Usage peaks in 1994/95 at 31 GL/year but averages 15.5 GL/year over this period. Records suggest usage was about 16 GL/year since the 1980s within Zone 8 alone.

6.4.4 Scenario implementation

The objective of the numerical modelling is to assess groundwater and surface water impacts under a range of scenarios of groundwater extraction from the Lower and Upper Namoi Alluvium GMUs. The groundwater impacts are characterised by resource condition indicators and the surface water impacts are characterised by river losses to groundwater. Groundwater extraction was set at 86 GL/year for all scenarios in the Lower Namoi model, consistent with the Long-Term Average Extraction Limit defined in the Lower Namoi Groundwater Source Water Sharing Plan (DIPNR, 2003). Similarly, groundwater extraction was set at 69.5 GL/year for the Upper Namoi model and 13.5 GL/year for Zone 8 in the Mooki model.

Climate can affect the groundwater balance in a number of ways. It 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 Recharge Scaling Factor (RSF). The method used to estimate the RSF is described in the section below.

The river and groundwater models are run in a sequence to simulate the effect of climate on surface–groundwater exchange fluxes and both groundwater and surface water balances (Chapter 1). The IQQM river model as implemented for the Water Sharing Plan would implicitly include groundwater–surface water exchanges within the unattributed losses and gains. The calibration periods for the groundwater model broadly coincide with the latter part of the surface water model calibration (generally 1983 to 1997). Hence the change in groundwater–surface water exchange fluxes in the MODFLOW outputs from the calibration period is assumed to be the same as the change in groundwater gains and losses from that included in the unattributed gains and losses. In all cases, extraction rates were assumed to be constant.

The various scenarios were run for periods of 222 years. This was implemented by using a 111-year climate series for two consecutive runs. The second run uses the final condition from the first as its initial condition. The second run of 111 years provided 'dynamic equilibrium' conditions and most of the results are drawn from this second 111-year period. The rationale for this modelling approach is to provide input to surface water-groundwater interactions in conjunction with surface water models. This requires the modelled groundwater system to be in a dynamic equilibrium. The first period is referred to as the 'warm-up' period and the second the 'dynamic equilibrium' run.

Climatic stresses including rainfall recharge and flooding inundation (where it was appropriate to the model) were obtained from recorded climatic and river flow data over the period 1895 to 2006. River stage is obtained from an interpolation of stage heights obtained from the IQQM run over the same time frame with the same assumed climatic conditions. Flood inundation was assumed to have the same recharge signature as that included in the calibration model during the flooding event of 1998. Flooding inundation and associated enhancement of river cell conductance occurs for the Lower Namoi model over a two-month period when and immediately after river levels (estimated by the IQQM) exceed a trigger level of 200 m Australian Height Datum (AHD) at gauge 419039 (Mollee).

River stage and riverbed conductance values for all river boundary cells are calculated using the IQQM predicted stages at key nodes for all three models.

Scenario D includes the same assumptions and input data as Scenario C except that the assumed groundwater extraction is close to the LTAEL for the aquifer. This is effectively the same as current levels of extraction in the Lower and Upper Namoi models. The extraction for Zone 8 was set to between 15.5 and 16 GL/year in the Mooki model. Dry, medium and wet climate scenarios are defined for Scenario D using the same climatic assumptions as those used in Scenario C. River stage, recharge, inundation recharge and river bed conductance enhancement are all calculated separately for these models given the climatic and river flow modelling results.

A pre-development steady state model generated initial heads for all scenarios for the Lower Namoi model. The Upper Namoi model had some instability when run for the pre-development scenario and therefore, results for this are unavailable. The models were run with no groundwater pumping and with annual average rainfall and river level assumptions.

6.4.5 Recharge modelling

RSFs are applied in the groundwater modelling described in the previous section and in the simple water balance analyses described later. Values of diffuse dryland recharge were used to calibrate the original implementation of the groundwater model and for management of the other GMUs within the Namoi. 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. For other climate scenarios RSFs would be expected to be close to 1.0. 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.

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

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

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

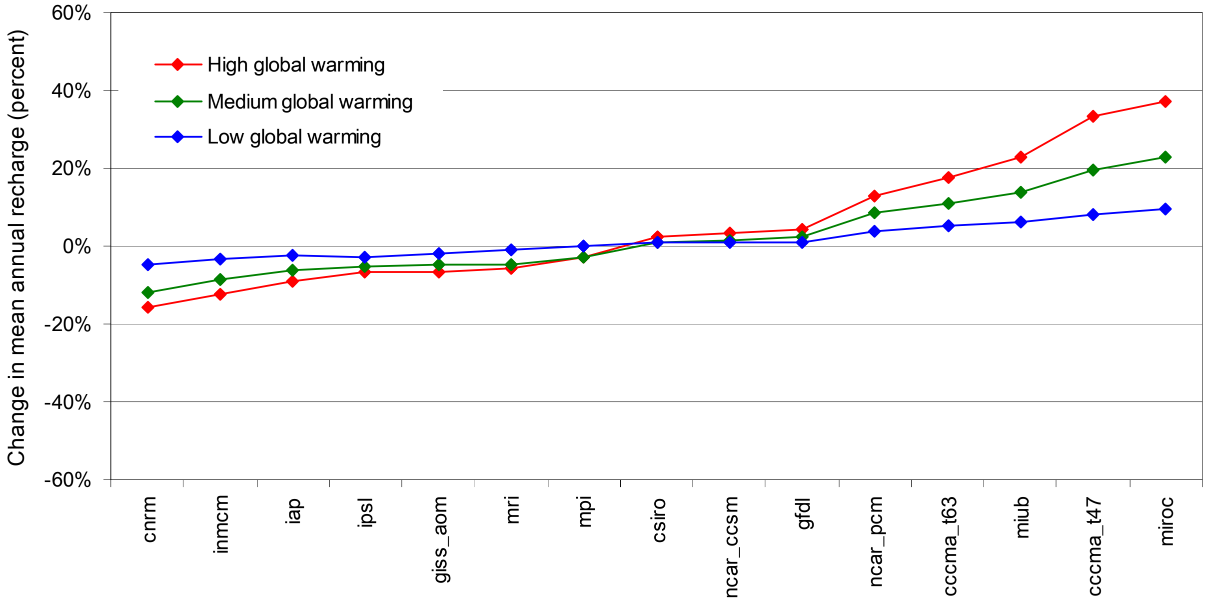

Figure 6-4. Percentage change in mean annual recharge from the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A recharge

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 were selected for further modelling.

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Recharge	GCM	Rainfall	Recharge	GCM	Rainfall	Recharge
cnrm	-10%	-16%	cnrm	-6%	-12%	cnrm	-3%	-5%
inmcm	-7%	-12%	inmcm	-4%	-8%	inmcm	-2%	-3%
iap	-3%	-9%	iap	-2%	-6%	ipsl	-1%	-3%
ipsl	-3%	-7%	ipsl	-2%	-5%	iap	-1%	-2%
giss_aom	**-10%**	**-7%**	giss_aom	-6%	-5%	giss_aom	-3%	-2%
mri	-3%	-6%	mri	-2%	-5%	mri	-1%	-1%
mpi	-6%	-3%	mpi	-4%	-3%	mpi	-2%	0%
csiro	-3%	2%	**csiro**	**-2%**	**1%**	ncar_ccsm	1%	1%
ncar_ccsm	2%	3%	ncar_ccsm	2%	2%	gfdl	-1%	1%
gfdl	-4%	4%	gfdl	-3%	2%	csiro	-1%	1%
ncar_pcm	5%	13%	ncar_pcm	3%	8%	ncar_pcm	1%	4%
cccma_t63	5%	18%	cccma_t63	4%	11%	cccma_t63	2%	5%
miub	8%	23%	miub	5%	14%	miub	2%	6%
cccma_t47	**13%**	**33%**	cccma_t47	8%	19%	cccma_t47	4%	8%
miroc	12%	37%	miroc	8%	23%	miroc	3%	10%

Figure 6-4 shows the percentage change in the modelled mean annual recharge averaged over the Namoi 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 variability between the GCMs and scenarios regarding climate change in the Namoi with just under half the scenarios predicting less or equal recharge and the remainder predicting more recharge. The high global warming scenario predicts both the highest and lowest change in recharge for the Namoi region.

Only the 'dry', 'mid' and 'wet' Scenario C variants are shown in subsequent reporting of modelling results. These variants are based-on the runoff modelling and are emboldened in Table 6-2. The choice of GCMs for surface runoff is comparable to those that would be chosen if recharge formed the basis of choice with the second highest, second lowest and median in surface run-off being respectively the second highest, sixth lowest and the 45th percentile for RSF.

The large variability in RSFs is related to the large variability in rainfall produced by the various GCMs. Rainfall and RSFs are correlated, although not perfectly. Some GCMs that indicate reductions in rainfall lead to RSFs greater than 1.0. This is due to the more extreme events being more frequent, in spite of a reduction in mean rainfall. Changes in mean annual recharge for GMUs and management zones are shown in Table 6-3 and Table 6-4 respectively.

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

Code	GMU	Cdry	Cmid	Cwet
		percent change relative to Scenario A		
N01	Lower Namoi Alluvium	-2%	-4%	37%
N04	Upper Namoi Alluvium	-1%	2%	36%
N05	Peel Valley Alluvium	-3%	1%	32%
N23	Miscellaneous Alluvium of Barwon Region	-4%	-10%	43%
N601	Great Artesian Basin Intake Beds	-2%	-1%	32%
N604	Gunnedah Basin	-2%	-1%	33%
N608	Oxley Basin	-2%	-1%	34%
N63	GAB Alluvial	-3%	2%	32%
N805	New England Fold Belt	-3%	-6%	32%
N814	Liverpool Ranges Basalt	-2%	-2%	37%
N819	Peel Valley Fractured Rock	-3%	3%	33%

Table 6-4. Change in recharge applied to model scenarios for management zones under Scenario C

Management zone	Cdry	Cmid	Cwet
	percent change relative to Scenario A		
Lower Namoi	1%	0%	43%
Upper Namoi			
Zone 1	-1%	1%	43%
Zone 2	-1%	2%	37%
Zone 3	-1%	1%	38%
Zone 4	-1%	2%	36%
Zone 5	-2%	2%	44%
Zone 6	-2%	1%	43%
Zone 7	-1%	1%	27%
Zone 8	-1%	2%	43%
Zone 9	-1%	2%	32%
Zone 10	-3%	-2%	35%
Zone 11	-2%	2%	35%
Zone 12	-5%	1%	47%

6.5 Modelling results

6.5.1 Groundwater levels – Lower Namoi

The predicted water levels for parts of the aquifer are still falling at the end of the scenario run. Dynamic equilibrium had not been reached despite the inclusion of a 111-year warm-up period.

The results suggest that the level of groundwater extraction included in the model is not sustainable over the long term. In reality groundwater management rules would cause an intervention in the groundwater pumping regime as water levels fell past pre-determined trigger levels. Similarly the saturated thickness of the aquifer diminishes the rate at which water can be extracted from production bores which also decrease and hence the level of groundwater extraction is self-limiting.

The impacts of the various climate scenarios are best represented by frequency-distribution curves of water levels over time at a bore. These median levels can be used as a guide to the level of drawdown experienced in an aquifer under the various climate scenarios. Table 6-5 suggests that the differences between the groundwater levels at the various reporting points do not vary appreciably between the scenarios. The results show that the lowest heads are generally predicted under Scenario Cdry, and the highest are predicted under Scenario Cwet.

Table 6-5. Lower Namoi groundwater model: median groundwater levels in key indicator bores under Scenario A, and difference in median groundwater level under scenarios C and D relative to Scenario A

Key indicator bore	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A					
GW036280_1	128.8	-0.2	0.0	0.5	0.2	-0.1	0.5
GW036280_2	129.1	-0.3	-0.1	0.5	0.1	-0.2	0.4
GW036280_3	128.1	-0.3	-0.1	0.5	0.1	-0.1	0.4
GW025325_1	180.2	-6.3	-1.0	3.1	-6.8	-2.1	2.2
GW025325_2	180.2	-5.8	-0.9	2.8	-6.5	-1.9	2.0
GW025325_3	180.5	-5.8	-0.9	2.6	-6.5	-2.0	1.9
GW036061_1	173.8	-5.8	-1.0	2.9	-3.7	-1.9	2.0
GW036061_2	171.6	-5.9	-0.9	3.1	-3.7	-1.8	2.2
GW036218_1	138.7	-0.9	-0.2	0.6	0.2	-0.4	0.5
GW036218_2	137.0	-0.7	-0.1	0.3	0.2	-0.2	0.3

6.5.2 Groundwater levels – Upper Namoi

Groundwater levels in parts of the valley continue to fall through the model runs, despite the 111-year warm-up period. This is most prominent in management Zones 2 and 4.

Floods are a significant source of aquifer recharge. These are represented in the hydrographs as sharp increases in water level of up to 2 m. The aquifers undergo consistent depletion in between flood events and it is typically only during flood events when recharge exceeds extractions. Thus the number of floods under each climate scenario has a significant impact on long-term drawdowns and depletion of the aquifer resource over time.

As for the Lower Namoi, the median groundwater levels for the Upper Namoi were derived and are given in Table 6-6. Under the 'Dry' scenarios, the water levels are 1.5 to 2.5 m below those under Scenario A. Conversely, under the 'Wet' scenarios groundwater levels are 2 to 6 m higher. Groundwater levels under the 'Mid' climate scenarios are similar to that of Scenario A. These results are directly linked to the changes in rainfall recharge, hillslope run-on and in particular the increase or decrease in the number of flood inundation periods.

Table 6-6. Upper Namoi groundwater model: median groundwater level in key indicator bores under Scenario A and difference in median groundwater level under scenarios C and D relative to Scenario A

Key indicator bore	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A					
GW036600_2	232.3	-1.5	-0.4	2.4	-1.8	-0.5	2.2
GW036600_1	234.0	-1.5	-0.4	2.4	-1.8	-0.5	2.3
GW036515_3	249.0	-2.7	-0.4	5.7	-3.1	-0.4	5.6
GW036515_1	252.0	-2.8	-0.5	6.0	-3.2	-0.5	5.8
GW036485_2	232.3	-1.5	-0.2	4.4	-1.7	-0.3	4.2
GW036485_1	233.3	-1.7	-0.2	4.8	-1.8	-0.3	4.7
GW030233_3	215.4	-1.6	-0.5	3.0	-1.8	-0.6	2.8
GW030233_2	217.6	-1.7	-0.5	3.3	-2.0	-0.7	3.1

6.5.3 Groundwater levels – Mooki

As for the Lower Namoi, the median groundwater levels for the Mooki model area were derived and are given in Table 6-7 for the second 111-year simulation period. The data shows the difference in median groundwater levels under scenarios C and D relative to Scenario A.

Modelled groundwater levels show a distinction between the lower, more conductive Gunnedah Formation and the surface Narrabri formation layer in Management Zone 8 of the Upper Namoi alluvial area. Nearly all of the groundwater extraction occurs in Layer 2 (~ 98 percent) and levels in Layer 2 are on average 4 m below the levels in Layer 1. The two key groundwater bores selected in this zone (GW030083 and GW030181) show that there are large seasonal variations in groundwater levels in Layer 2 in response to groundwater extraction. Within Zone 8 about 7 percent of the model cells in Layer 1 became dry during the 222 years of simulation (all in one area at the upstream and southern end of Zone 8).

Table 6-7. Upper Namoi Zone 8 groundwater model: median groundwater level* in key indicator bores under Scenario A and difference in median groundwater level under scenarios C and D relative to Scenario A

Key indicator bore	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD	m AHD relative to Scenario A					
Layer 1	310.4	-0.8	-0.3	3.8	-0.9	-0.9	1.8
Layer 2	306.3	-2.5	-0.4	5.3	-6.3	-5.0	-1.2
GW030083_1	308.3	-0.4	-0.1	1.2	-0.7	-0.6	-0.7
GW030083_2	300.3	-2.0	-0.4	4.2	-6.5	-5.3	-6.5
GW030181_1	312.5	-1.1	-0.5	6.5	-1.1	-1.1	4.2
GW030181_2	312.3	-3.0	-0.5	6.4	-6.0	-4.8	4.1

* Medians extracted from modelled groundwater levels in the second 111-year period

6.5.4 Groundwater balance – Lower Namoi

The mass balance components under all scenarios for the Lower Namoi model are summarised in Table 6-8. The inputs to the mass balance for all scenarios consist of areally distributed recharge associated with percolation of rainfall and irrigation, losses of water from rivers and inflows from surrounding aquifers (including upflow from the GAB). The outflow includes groundwater discharge to rivers and groundwater fluxes out of the model domain to surrounding aquifers. The dominant mass outflow from all development models is the extraction of water from wells. On average, the outputs from the groundwater system are greater than the inputs. Note that extraction falls below the planned 86 GL/year as some production bores run dry in the model.

Table 6-8. Average annual fluxes into (recharge) and out of (discharge) the groundwater system (second 111 years) in the Lower Namoi under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (gains)							
Rainfall and irrigation	41	27	38	55	24	35	50
River system	32	37	34	28	44	35	31
Lateral flow	8	9	8	8	9	8	8
Sub-total	**81**	**73**	**80**	**91**	**77**	**78**	**89**
Discharge (losses)							
Extraction	83	83	83	85	83	83	84
To rivers	6	3	5	10	4	5	9
Lateral flow	9	8	9	9	8	8	9
Sub-total	**98**	**94**	**97**	**104**	**95**	**96**	**102**
Change in storage	-17	-21	-17	-13	-18	-18	-13

Figure 6-5 shows a comparison between the combined annual recharge included in the Scenario A model and the groundwater pumping flux. For most years the extractions exceed recharge and during these years water levels fall. Peaks in the combined recharge plot are caused by the increased recharge assumed to occur during periods of flood inundation.

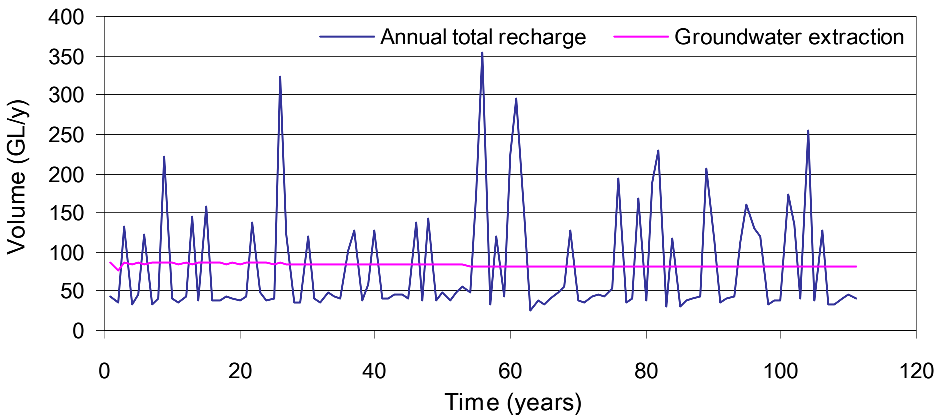

Figure 6-5. Total recharge compared to groundwater extraction in the Lower Namoi under Scenario A

Table 6-9 provides an estimate of the proportion of time when the total groundwater recharge exceeds groundwater pumping. In the pre-development case there is no groundwater pumping and hence recharge exceeds pumping all of the time. For the various development scenarios considered in this project recharge exceeds extraction between 14 and 38 percent of the time. Table 6-9 also presents the average flux of water predicted to flow from the river to the aquifer. The results suggest river losses of between 30 and 45 GL/year depending on the scenario. The highest levels of river loss are predicted for Scenario D reflecting the consequences of low groundwater levels on the river–groundwater interaction. Table 6-9 indicates that for the development scenarios total average recharge varies from almost 70 to 90 GL/year which is substantially higher than the 50 GL/year predicted for the pre-development scenario. Total recharge includes both input-controlled recharge processes – that is, areally distributed rainfall recharge, enhanced recharge during flooding and inundation – and head dependent processes such as the predicted leakage from rivers and inflows from general head and constant head boundary cells. Recharge components depend not only on the specified input parameters but also on groundwater levels beneath and near the river boundary cells. Recharge from the river represents a significant proportion of total recharge entering all scenario models. The predicted increase in total recharge for all scenarios compared to the no-development scenario indicates the relative importance of head dependent recharge processes. The recharge from rivers is highest during dry scenarios (both absolutely and as a proportion), reflecting the greater potential for river leakage when watertable levels are low.

This latter process occurs despite the model allowing for the simulation of flux limited conditions when the watertable falls substantially below the river bed and the two water sources become ‘disconnected’.

Table 6-9. Annual average combined recharge and net loss of river flow in the Lower Namoi under no development and scenarios A, C and D

Scenario	Total recharge	Recharge from river	Percent of years recharge exceeds pumping
	GL/y		percent
Pre-development*	50.6	-5.0	100%
A	81.4	32.0	32%
Cdry	72.8	36.7	17%
Cmid	80.0	33.6	29%
Cwet	90.9	28.5	38%
Ddry	76.8	44.1	14%
Dmid	78.5	34.7	25%
Dwet	88.9	31.1	36%

* There is a net flux of groundwater to the river in the pre-development model

Figure 6-6 shows the exceedance curves for annual recharge for all scenarios. Variability in total recharge between the various scenarios arises from:

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

The dominant factor is the variability of the frequency of flooding inundation included in the scenarios. Inundation recharge is applied to the models at the times when the modelled river stage height exceeds a trigger level of 200 m AHD at gauge 419039 (Mollee).

The current level of extraction of 86 GL/year represents a 14 to 38 percent chance of being achieved in any year under the different scenarios. Total recharge is predicted to exceed 150 GL/year under all scenarios in 10 percent of years.

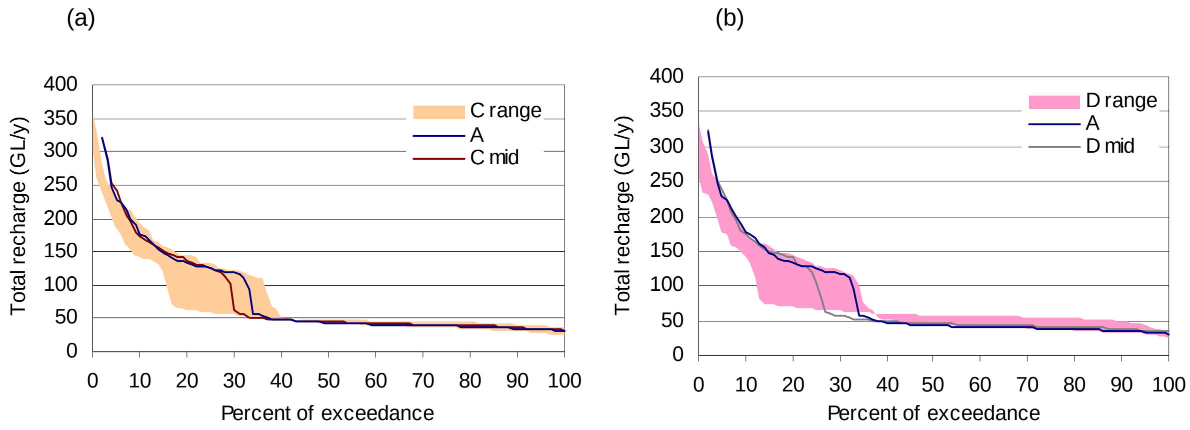

Figure 6-6. Distribution of annual total recharge in the Lower Namoi model over the second 111-year model period under (a) Scenario C and (b) Scenario D

6.5.5 Groundwater balance – Upper Namoi

Average annual groundwater fluxes are presented in Table 6-10. The dominant groundwater recharge processes in the Upper Namoi model area are dryland rainfall recharge, irrigation recharge and river interactions. The dominant groundwater discharge mechanism is groundwater pumping since the region's groundwater resources were developed. Lateral groundwater flow to surrounding aquifers and groundwater discharge to the river currently represent minor components of the overall water balance. River discharge is more responsive to groundwater level reduction than lateral groundwater flow (approximately three times more responsive) when the water balance outputs of the climate scenarios are compared. Any change to the groundwater extraction regime would have significant and direct implications for groundwater–surface water interactions. The water balances also show that there is a less than 10 percent change in the total inputs when the wet climate scenarios are compared with Scenario A. There is essentially no change to the balance when the dry climate scenarios are compared to Scenario A. The impacts of any future climate change will be subordinate to the changes already in place within the groundwater system.

Table 6-10. Average annual fluxes into (recharge) and out of (discharge) the groundwater system (second 111 years) in the Upper Namoi under scenarios A, C and D

Groundwater Balance	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (inflows)							
Dryland rainfall recharge	21.2	19.8	21.2	27.9	19.9	21.2	28.1
Flood recharge	4.5	2.3	3.6	8.6	1.8	3.6	8.1
Irrigation recharge	16.9	16.9	16.9	16.9	16.9	16.9	16.9
River recharge to groundwater	23.9	26.0	24.4	17.8	26.1	24.3	17.7
Lateral groundwater flow in	3.9	4.2	4.0	3.4	4.2	4.0	3.4
Hillslope run-on	2.5	2.3	2.4	3.4	2.3	2.4	3.4
Total inflows	**72.9**	**71.5**	**72.5**	**78.0**	**71.2**	**72.4**	**77.6**
Discharge (outflows)							
Groundwater pumping	69.6	69.5	69.6	69.7	69.5	69.6	69.7
Lateral groundwater flow out	1.7	1.6	1.7	2.2	1.5	1.7	2.2
River discharge	2.4	1.5	2.2	6.1	1.4	2.1	5.9
Total outflows	**73.7**	**72.5**	**73.4**	**78.0**	**72.4**	**73.3**	**77.7**
Total river losses to groundwater*	21.5	24.5	22.2	11.7	24.7	22.2	11.8

* Calculated as river recharge minus river discharge

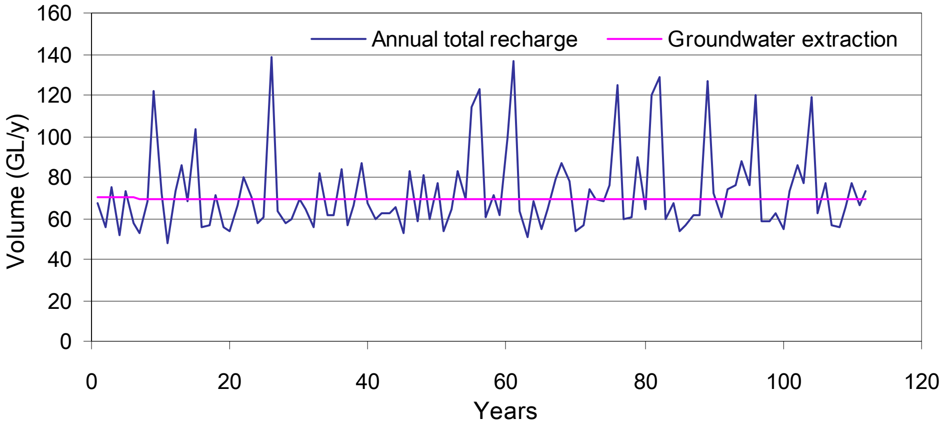

Figure 6-7. Total recharge compared to groundwater extraction in the Upper Namoi under Scenario A

The drier climate scenarios will exacerbate the river losses to groundwater. The cause of this is highlighted in Figure 6-8 (also summarised in Table 6-11) that shows exceedence curves of annual total recharge.

Recharge only exceeds extractions in 42 percent of years under Scenario A. This figure remains at 42 percent despite the reduction in rainfall recharge and flood inundation under Scenarios Cmid and Cdry. This result may seem counter-intuitive; however the recharge reductions are compensated for by an increase in river leakage and water drawn-in from surrounding aquifers. This effect is most notable in average to dry years. The enhanced rainfall recharge and flood inundation become far more dominant recharge processes reducing the river losses to groundwater in wetter years.

Table 6-11 also indicates that during the driest 25 percent of years the wet scenario has the lowest total recharge. This results from the higher groundwater levels that persist throughout the wet scenarios that decrease the net losses from the river.

The issue of total aquifer recharge only exceeding extractions in 42 percent of years correlates with the consistent drawdown observed in hydrographs between flood events. Even under Scenario Cwet, recharge only exceeds groundwater extractions in 47 percent of years. It is difficult to distinguish between recharge under scenarios C and D due to the minimal changes between their respective model runs.

Table 6-11. Comparison of recharge sources and groundwater pumping volumes (second 111 years) in the Upper Namoi under scenarios A, C and D

Volumes	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Total land recharge*	45.1	41.2	44.1	56.8	40.8	44.1	56.5
River-derived recharge	23.9	26.0	24.4	17.8	26.1	24.3	17.7
Groundwater pumping	69.6	69.5	69.6	69.7	69.5	69.6	69.7
	percent						
Percent of time total recharge exceeds pumping	42%	42%	42%	47%	42%	42%	47%

*Total land recharge includes rainfall, irrigation, flood inundation and hillslope run-on

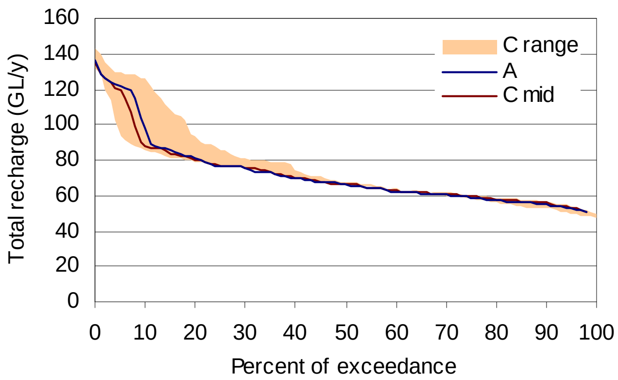

Figure 6-8. Distribution of annual total recharge in the Upper Namoi model over the second 111 year model period under Scenario C. No significant discrepancies were observed between scenarios C and D; only Scenario C results are shown.

The exceedence curves for annual recharge under the different scenarios are shown in Figure 6-8. The data shows that all scenarios have similar annual recharge for the driest half of years, but diverge markedly for the wettest half of years. Recharge varies between about 85 GL/year up to about 130 GL/year for the wettest 10 percent of years.

6.5.6 Groundwater balance – Mooki

The total annual groundwater recharge was calculated as the sum of rainfall recharge, lateral groundwater flow into the model and flow of water from rivers to groundwater. Figure 6-9 shows total recharge and groundwater extraction for the second 111 years in Scenario A. Both totals are provided for Zone 8 only, however groundwater extraction also occurs elsewhere in the model.

Extraction never exceeds recharge in the model period. The lateral inflow of groundwater to Zone 8 is nearly always matched by lateral groundwater flow out of the zone and there is also a significant loss of water to rivers which results in little long-term change in groundwater levels (Table 6-12).

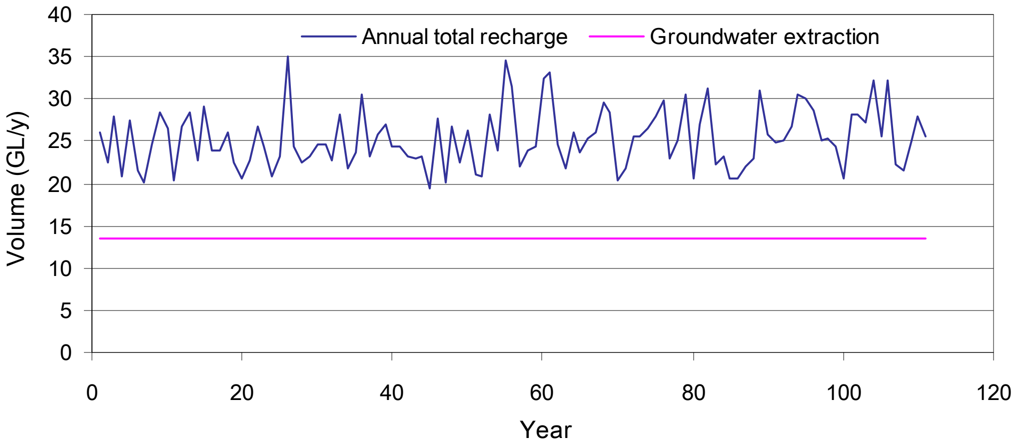

Figure 6-9. Total recharge compared to groundwater extraction in the Mooki under Scenario A

Table 6-12 shows the average annual groundwater fluxes into and out of Zone 8 over the second 111-year modelling period. Over this model period there is no significant net loss or gain of water from the groundwater system and therefore watertables are not rising or falling across the model area. One of the major differences in fluxes between scenarios is the greater rainfall recharge under scenarios Cwet and Dwet, relative to Scenario A.

The lateral groundwater fluxes are balanced by the lateral groundwater fluxes out of Zone 8. Flow to and from rivers occurs, with a net loss from rivers as discussed further below.

Table 6-12. Average annual fluxes into (recharge) and out of (discharge) the groundwater system (second 111 years) in Zone 8 under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (gains)							
Rainfall and irrigation	9	8	9	13	8	9	13
River system	8	8	8	6	9	9	6
Lateral flow	9	8	9	10	9	9	10
Sub-total	**26**	**24**	**26**	**29**	**26**	**27**	**29**
Discharge (losses)							
Extraction	14	14	14	14	16	16	16
To rivers	3	2	3	5	2	2	4
Lateral flow	9	9	9	10	9	9	10
Sub-total	**26**	**25**	**26**	**29**	**27**	**27**	**30**
Change in Storage	0	-1	0	0	-1	0	-1

Figure 6-10 shows the distributions of annual total recharge under scenarios A, C and D. Scenario D outputs differ from the corresponding Scenario C outputs in that the groundwater extraction is about 10 percent larger and flow in the Mooki River is reduced. The additional groundwater extraction appears to increase total recharge primarily through increased net loss from the river and this occurs when annual total recharge is smallest (compare Dmid and Cmid, Figure 6-10). Increased net loss from rivers is caused by lower groundwater levels due to pumping increasing flow from rivers to groundwater and reducing the flow from groundwater to rivers.

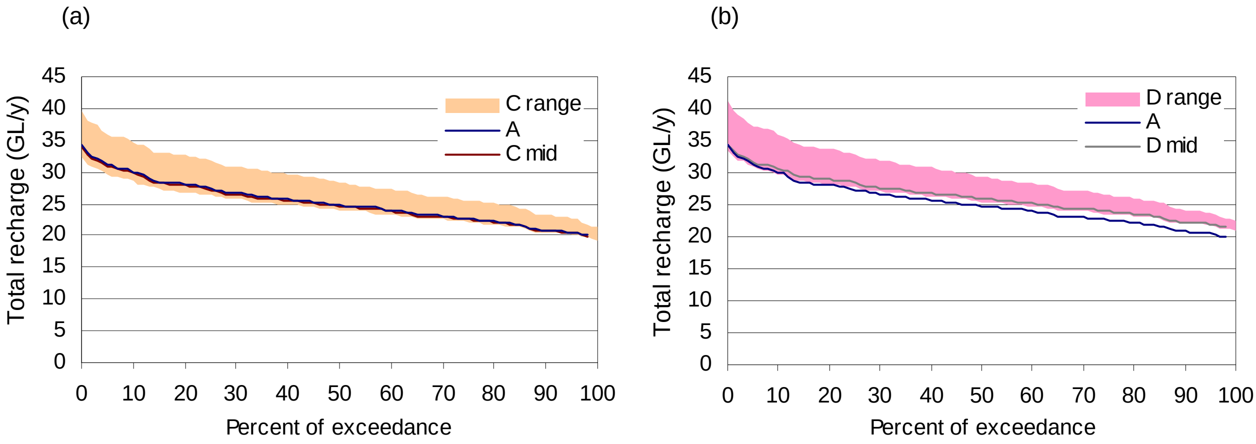

Figure 6-10. Distribution of annual total recharge in the Mooki model over the second 111-year model period under scenarios (a) C and (b) D

6.5.7 Surface–groundwater interactions – Lower Namoi

The rivers are predominantly losing features under Scenario A in the Lower Namoi and for most of the scenario duration groundwater recharge as leakage from the river exceeds groundwater discharge to the river bed (baseflow). The model predicts that in the undisturbed, pre-development condition the complete Lower Namoi river system is, on balance, gaining and as such would have received significant levels of baseflow fluxes from the aquifer. No allowance is made for the impacts of changing land use on recharge (eg deforestation and land clearing leading up to current vegetative cover) in the pre-development scenario. The total effect of groundwater–river interaction is given by the difference between Scenario A results and the pre-development scenario results and this difference is presented in Figure 6-11.

Figure 6-11 presents the additional river flow that would have been measured had there been no groundwater extraction over the duration of Scenario A. This figure shows the warm-up period as well as the 'dynamic equilibrium' period, together take about 100 years for Scenario A. The impacts of groundwater development as indicated by a loss of river flow appears to reach a dynamic equilibrium of about 42 GL/year with additional peaks (associated with flooding events) superimposed on this level.

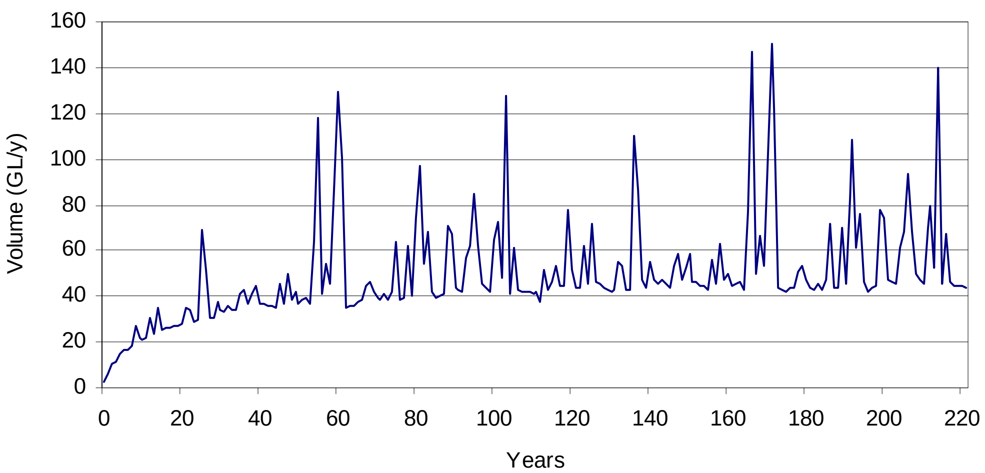

Figure 6-11. Net annual river loss to groundwater in the Lower Namoi model under Scenario A

The above time response needs to be coupled with extraction history in order to assess the historical impact on streams. There was very little development in the Namoi Valley prior to the commencement of cotton growing in the Lower Namoi.

The early 1960s, using Californian expertise, and more efficient bore construction technology, coupled with the 1965 drought provided a major stimulant for irrigation development. By the 1980/81 season groundwater accounted for over half of the irrigation development in the Namoi Valley (DLWC, 2000a). Due to concerns about declining water levels in the early 1980s drought, an embargo on issuing high yield licences was introduced in January 1983, and a volumetric conversion process was introduced the same year on a zone-by-zone basis throughout the Lower Namoi Alluvium GMU (DLWC, 2000b). By 1984/85, the groundwater extraction was estimated to be approximately 60 GL/year. Thus, much of the impact of extraction on streams may have occurred by the late 1980s.

The calibration period of the groundwater model (1980 to 1998) was used as a reference for assessing the so-called 'double accounting' terms. The calibration of the river models would have included some of the groundwater–surface water interchange. Using this as a reference would provide a perspective during a period for which the IQQM was calibrated. The overall change from the calibration run to the Scenario A run is a 2.2 GL/year gain along the IQQM reaches to Mollee, Gunidgera, Bugilbone, Goangra and Pian.

The discrepancy between the 46 GL/year loss with the pre-development run as the reference, and the 2.2 GL/year gain with the calibration period as the reference, can be attributed to:

- much of the response (~30GL/year) having occurred by the late 1980s (~38 GL/year by the mid-1990s)
- some of the captured discharge occurring downstream of Pian Creek
- lack of evapotranspiration in the model and not appropriately accounting for evapotranspiration that occurred prior to the 1980s.

6.5.8 Surface–groundwater interactions – Upper Namoi

The importance of stream–aquifer interactions in the Upper Namoi has already been highlighted. The volume of water lost to groundwater increases due to the lowering of the watertable in conjunction with the continued high levels of pumping despite lower river levels in the dry scenarios. Despite the rivers remaining as predominantly losing streams, there is a shift for the wet scenarios in the volume of water lost from surface water flows.

This is a result of the increased ability of rainfall recharge and flood inundation to meet the groundwater pumping demands. This process is illustrated in Figure 6-12 under Scenario A. The data shows a cycling of river losses over the full time period. The increasing river loss cycle is during a period of lower recharge, whereas the decreasing river loss cycle is during a period of substantially higher recharge (probably due to a higher frequency of flooding). Higher recharge meets the groundwater extraction needs and is also able to increase watertables to the point where river leakage decreases. Loss from the rivers generally lies between about 15 and 25 GL/year, with infrequent peaks between 5 and 35 GL/year. The nature of the river loss plot for the Upper Namoi model area is slightly different from that for the Lower Namoi in that there is no pre-development scenario available for the Upper Namoi, and hence no ability to take into account the difference in river loss between the two scenarios.

The calibration period was used as a reference to assess the double accounting term. The change in river losses from the calibration period to Scenario A is 18.7 GL/year. The calibration period (1985 to 2001) is later than most of the earlier development which ran parallel to the Lower Namoi. By 1985/86, estimated use was about 70 GL/year. During the 1990s, use was closer to 90 GL/year apart from some high-use years of 1992 to 1994 and 2002 to 2004. The calibration period for the IQQM is for these stretches of river between 1983 and 1997 and represents most of the calibration period of the groundwater model.

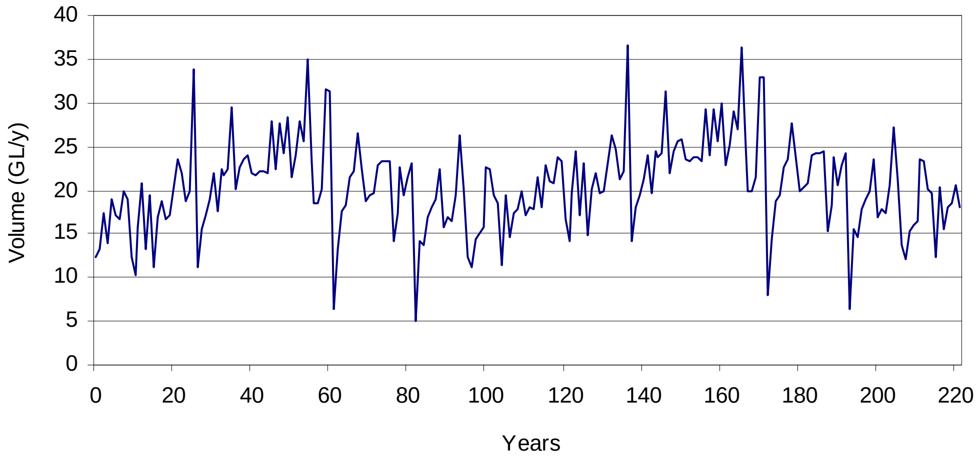

Figure 6-12. Modelled average annual net river loss to groundwater in the Upper Namoi under Scenario A

6.5.9 Surface–groundwater interactions – Mooki

The model seems to take about 15 years to reach a dynamic equilibrium with a continuing low rate of change in net river losses thereafter. This time to equilibrium may be model warm-up or it could be truly groundwater responses. The long-term loss rate appears to be between 4 and 6 GL/year.

The groundwater model represents flow into and out of rivers:

- In areas where the groundwater level around the river is in general higher than the river, the dry scenarios will have less flow into the river than the wet because there is less rainfall recharge in the dry scenarios and the watertable is lower as a result.
- In areas where the groundwater level is in general within the depth of the water column in the river and net flow is perhaps away from the river, the dry scenarios are likely to have greater loss from the river in the long term than the wet scenarios because the watertable is lower.
- In areas where the groundwater level is always below the base of the river in the model, the wet scenarios have the greatest loss of water from the river because the higher river water levels in the wet provide more gradient for water loss than the dry scenarios.

The calibration run (1979 to 1996) was used as a reference. Groundwater use in Zone 8 in 1985/86 was close to 16 GL/year. The difference between this reference and Scenario A is a 2 GL/year loss from the rivers.

6.5.10 Groundwater indicators

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

Table 6-13. Definition of groundwater indicators

Groundwater Indicators	
Groundwater security indicator	Percentage of years in which extraction is less than the average recharge over the previous ten-year period. Values less than 100 percent 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 draw-down under each scenario.

Lower Namoi

Groundwater security indicators are low to moderate under all scenarios. The wet scenarios have the highest values where about 50 percent of the time extraction is equal to or less than the previous ten-year average recharge. The dry scenarios have security indicators where this criterion is met only about 30 percent of the time. This indicator is particularly relevant when considering ten-year management plan cycles and the setting of extraction limits.

The Environmental indicator shows derived values of close to 1.0 under all scenarios. This indicates that all available recharge is required to balance groundwater extraction.

The Drought indicator shows that maximum drawdown levels are essentially the same under all scenarios. The numbers in need to be seen as a fluctuation below median water level for that scenario plus a difference in median water levels between scenarios. Where there is a variation between scenarios (e.g. GW025325), there is a corresponding difference between median water levels. The dry scenarios show the largest drawdown from the average condition, as expected.

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

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Groundwater security indicator	46%	31%	43%	58%	32%	36%	56%
Environmental indicator				ratio			
	1.0	1.1	1.0	0.9	1.1	1.1	1.0
Drought indicator							
Observation bore				m			
GW036280_1	-0.8	-1.1	-0.8	-0.1	-0.6	-0.9	-0.2
GW036280_3	-7.8	-8.1	-7.9	-7.2	-7.6	-7.9	-7.3
GW036280_2	-8.2	-8.4	-8.2	-7.9	-8.1	-8.3	-7.9
GW036218_2	-3.1	-3.1	-3.1	-2.8	-2.8	-3.1	-2.9
GW036218_1	-2.0	-2.2	-2.0	-1.5	-1.7	-2.0	-1.6
GW036061_2	-3.8	-10.4	-5.0	-1.8	-7.8	-5.9	-2.3
GW036061_1	-2.9	-9.3	-4.1	-0.9	-6.4	-4.9	-1.5
GW025325_3	-4.3	-10.5	-5.6	-2.0	-11.5	-6.5	-2.6
GW025325_2	-4.5	-10.8	-5.8	-2.2	-11.8	-6.7	-2.7
GW025325_1	-3.2	-9.9	-4.7	-0.9	-10.8	-5.6	-1.4

Upper Namoi

Groundwater security statistics indicate that even under wet conditions the volume of groundwater pumping exceeds recharge. Total recharge exceeds groundwater extractions under the wet scenario 89 percent of the time (based on a ten-year rolling average). However the groundwater security falls to 63 percent and 64 percent under scenarios Cdry and Ddry respectively. This indicator is particularly relevant when considering ten-year management plan cycles and the setting of extraction limits.

The Environmental indicator shows derived values of between 0.9 and 1.0 for all scenarios, which indicates that virtually all recharge is required to balance groundwater extraction.

The Drought indicator shows that maximum drawdown levels vary through a small range, with wet scenarios showing a rise in water levels. The dry scenarios show the largest drawdown from the average condition, as expected. The range of water level changes does not appear to be excessive.

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

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Groundwater security indicator	68%	63%	69%	89%	64%	67%	89%
Environmental indicator				ratio			
	1.0	1.0	1.0	0.9	1.0	1.0	0.9
Drought indicator							
Observation bore				m			
GW036600_2	-2.1	-3.1	-2.3	0.3	-3.3	-2.4	0.2
GW036600_1	-1.8	-2.8	-2.0	0.6	-3.0	-2.2	0.5
GW036515_3	-2.6	-5.4	-3.1	3.4	-5.8	-3.1	3.2
GW036515_2	-1.5	-4.0	-2.0	4.1	-4.3	-2.0	4.0
GW036515_1	-1.5	-4.0	-2.0	4.1	-4.3	-2.0	4.0
GW036485_2	-2.0	-3.3	-2.2	1.8	-3.4	-2.3	1.8
GW036485_1	-1.5	-2.8	-1.7	2.6	-2.9	-1.8	2.5
GW030233_3	-2.6	-3.7	-2.9	-0.2	-3.8	-3.0	-0.2
GW030233_2	-2.4	-3.4	-2.6	0.3	-3.6	-2.7	0.3
GW030233_1	-2.6	-3.7	-2.9	-0.2	-3.8	-3.0	-0.2

Mooki

Groundwater security indicators are all 100 percent, showing that total groundwater recharge always exceeds extraction. The Environmental Indicator shows that between 0.5 and 0.6 of the recharge is required to balance groundwater extraction. The drought indicators show that there may be some significant lowering of watertables in Scenario D where groundwater extraction is greatest.

Table 6-16. Groundwater indicators for Mooki under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Groundwater security indicator	100%	100%	100%	100%	100%	100%	100%
Environmental indicator				ratio			
	0.5	0.6	0.5	0.5	0.6	0.6	0.5
Drought indicator							
Observation Bore				m			
GW030083_1	-0.4	-0.7	-0.5	0.5	-1.0	-0.9	-1.0
GW030083_2	-2.1	-3.7	-2.3	-0.1	-8.3	-7.1	-8.3
GW030181_1	-1.2	-1.3	-1.2	3.6	-1.3	-1.3	1.3
GW030181_2	-2.1	-4.4	-2.6	3.5	-7.9	-6.5	1.1

6.6 Water balances for lower priority groundwater management units

There are several other GMUs in the Namoi region apart from the Lower and Upper Namoi Alluvium GMUs (Table 6-1). Simple water balance analyses were undertaken for each of these lower ranked GMUs. Two indicators are reported. The first indicator is the ratio of extraction to rainfall recharge (E/R). The level of development for a GMU is categorised in terms of E/R values as follows: low (0.0–0.3); medium (0.3–0.7); high (0.7–1.0); and very high (>1.0). A significant fraction of recharge to alluvial aquifers may come from streams either directly from channels or during floods. Extraction may be maintained at E/R values greater than 1.0 in these cases, although with impacts on streamflow. E/R is not used as an indicator for confined aquifers. The second indicator is the average volumetric impact of groundwater extraction on streamflow.

6.6.1 Groundwater extraction

Estimated current and future groundwater extraction from low priority GMUs within the Namoi region is shown in Table 6-17. The estimates for areas controlled by macro groundwater plans for current use are based on metered data. This is on a proportion of access licence entitlement and on an average extraction estimate of 1.5 ML/year for each stock and domestic bore (DWE, pers. comm.).

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

Table 6-17. Estimated current and future groundwater extraction for lower priority groundwater management units the Namoi region

Code	Name	Current extraction 2004/05	Entitlement	Maximum likely extraction without plan revision
			GL/y	
N05	Peel Valley Alluvium	10.3	51.4	21.6*
N23	Miscellaneous Alluvium of the Barwon Region	4.1	7.2	7.2
N63	GAB Alluvial	0.3	0.4	6.0
N601	GAB Intake Beds	0.8	3.9	4.1
N604	Gunnedah Basin	5.6	6.7	61.0
N608	Oxley Basin	9.2	12.6	46.3
N805	New England Fold Belt	7.6	10.8	67.9
N813	Warrumbungle Tertiary Basalt	0.0	0.0	0.3
N814	Liverpool Ranges Basalt	2.5	3.7	11.9
N819	Peel Valley Fractured Rock	25.1	35.8	35.8
	Total	**65.5**	**132.2**	**262.0**

***** Peel Valley Alluvium volume provided by New South Wales DWE. This may differ from the draft Macro Groundwater Sharing Plan.

Groundwater extraction within the Namoi region is forecast to grow in the future. Estimates of the likely maximum extraction were provided for each GMU by DWE. The rate of growth to the estimated maximum is not determined but it is assumed here that full growth will be achieved by 2030.

The 'maximum likely extraction' is based on the historical development of irrigation, urban and stock and domestic water supply works in New South Wales. The estimated growth rate within a region is based on the rate of historical growth. It is assumed that all new domestic and stock water supply works will be drilled and constructed on separate properties. An average size for each property was calculated. The total additional stock and domestic requirement was then calculated based on assumed usage rates for domestic bores of 2.25 ML/year and for stock bores of 0.0088 ML/ha/year.

6.6.2 Estimates of rainfall recharge

Rainfall recharge is the largest component of the water balance and is therefore the focus of this assessment. The following data were provided by DWE.

The effect of different stresses on various components of the hydrologic cycle was analysed using the RSFs (Section 6.4). The RSFs were calculated from one-dimensional modelling to produce point estimates of root zone drainage from which to transform recharge figures. Scaling factors for Scenario D are identical to Scenario C with the addition of groundwater management rules and future levels of development.

Scenario D is designed to estimate the change in recharge assuming the 2030 climate change scenario, and models the effects of changes in land and groundwater use. The results of applying the RSFs are shown in Table 6-18.

Table 6-18. Recharge estimates for the lower priority groundwater management units in the Namoi region under scenarios A and C

Code	Name	Recharge estimate	Scaled recharge		
		A	Cdry	Cmid	Cwet
			GL/y		
N05	Peel Valley Alluvium	20.1	19.6	20.3	26.5
N23	Miscellaneous Alluvium of the Barwon Region	3.5	3.3	3.1	5.0
N63	GAB Alluvial	16.5	16.0	16.9	21.8
N601	GAB Intake Beds	189.8	185.3	188.3	251.1
N604	Gunnedah Basin	124.6	122.0	123.4	165.2
N608	Oxley Basin	110.3	108.2	109.4	148.0
N805	New England Fold Belt	226.5	220.3	213.3	298.1
N813	Warrumbungle Tertiary Basalt	1.1	1.0	1.0	1.5
N814	Liverpool Ranges Basalt	47.5	46.4	46.3	65.1
N819	Peel Valley Fractured Rock	141.0	137.2	145.2	187.1
	Total	**880.8**	**859.3**	**867.3**	**1169.2**
	Percent change		**-2%**	**-2%**	**+33%**

Note – RSF for Scenario D is no different for Scenario C and is not reported

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

The overall trend observed in these ratios is that groundwater extraction is relatively insignificant for most of the aquifers but is major in the Peel Valley Alluvium and the Miscellaneous Alluvium of the Barwon region GMUs. Current extraction is far greater than the available rainfall recharge in both of these regions. A drier climate results in a large imbalance between extraction and rainfall recharge leading to a worsening of the ratio between extraction and recharge in these aquifers. Both of these GMUs are highly connected with their associated river systems and as such, receive additional river recharge not accounted for in this process. As a result, their E/R value would be lower, but issues surrounding double accounting of water resources will become more important.

Table 6-19. Comparison of groundwater extraction with scaled rainfall recharge for lower priority groundwater management units in the Namoi region under scenarios A and C

Code	Name	Current extraction 2004/05	E/R	Scaled E/R		
			A	Cdry	Cmid	Cwet
		GL/y		ratio		
N05	Peel Valley Alluvium	10.3	0.5	0.5	0.5	0.4
N23	Miscellaneous Alluvium of the Barwon Region	4.1	1.2	1.2	1.3	0.8
N63	GAB Alluvial	0.3	<0.1	<0.1	<0.1	<0.1
N601	Great Artesian Basin Intake Beds	0.8	<0.1	<0.1	<0.1	<0.1
N604	Gunnedah Basin	5.6	0.1	0.1	0.1	<0.1
N608	Oxley Basin	9.3	0.1	0.1	0.1	0.1
N805	New England Fold Belt	7.6	<0.1	<0.1	<0.1	<0.1
N813	Warrumbungle Tertiary Basalt	<0.1	<0.1	<0.1	<0.1	<0.1
N814	Liverpool Ranges Basalt	2.5	0.1	0.1	0.1	<0.1
N819	Peel Valley Fractured Rock	25.1	0.2	0.2	0.2	0.1

Examination of the results shows that planned changes to groundwater entitlement within the Peel Valley Alluvium will result in a rising extraction to recharge ratio, bringing it to a very high level of development.

The Miscellaneous Alluvium of the Barwon region E/R ratios will increase to greater than 2.0. The GMUs should be considered in their landscape setting to better understand these results.

Table 6-20. Comparison of groundwater extraction with scaled rainfall recharge for lower priority groundwater management units in the Namoi region under Scenario D

Code	Name	Future groundwater extraction	Scaled E/R		
			Ddry	Dmid	Dwet
		GL/y	ratio		
N05	Peel Valley Alluvium	21.6	1.1	1.1	0.8
N23	Miscellaneous Alluvium of the Barwon Region	7.2	2.2	2.3	1.4
N63	GAB Alluvial	6.0	0.4	0.4	0.3
N601	GAB Intake Beds	4.1	<0.1	<0.1	<0.1
N604	Gunnedah Basin	61.0	0.5	0.5	0.4
N608	Oxley Basin	46.3	0.4	0.4	0.3
N805	New England Fold Belt	67.9	0.3	0.3	0.2
N813	Warrumbungle Tertiary Basalt	0.3	0.3	0.3	0.2
N814	Liverpool Ranges Basalt	11.9	0.3	0.3	0.2
N819	Peel Valley Fractured Rock	35.8	0.3	0.3	0.2

Peel Valley Alluvium GMU

The Peel Valley Alluvium is located in a steep-sided valley with the alluvium deposited in the base of the valley in direct hydraulic contact with the Peel River. The alluvium deposits are long in proportion to their width and thickness and extend down the valley. Development in the Peel Valley Alluvium GMU is concentrated along the river valley. This is a limited area from which to draw groundwater and the proximity of the bores to the river indicates that there will be significant impacts on surface water flows and that the response to changes will be rapid. Rivers in this region are connected and highly losing streams.

These features support an estimate that up to 83 percent of the volume of groundwater extracted from the aquifer is derived from streamflow. The value is derived from a preliminary water balance, partial GMU flow modelling and limited groundwater monitoring. This volume would otherwise contribute to flows further down the catchment. Groundwater extraction is predicted to grow in this GMU and contributions to groundwater extraction from streamflow will increase.

Due to the relative density of bores within the alluvium, their proximity to the river and the high degree of hydraulic connection within the alluvium, any impact will occur rapidly, from one to ten years.

The results of the scenario analysis for the Peel Valley Alluvium under the current extraction scenario indicate that groundwater is being extracted at almost half the amount of rainfall recharge entering the system.

Peel Valley Fractured Rock GMU

The Peel Valley Fractured Rock aquifer is a highland aquifer composed of fractured sedimentary rocks. Groundwater recharges via infiltration through fractures within the rocks and because of the spatial distribution of these fractures, its movement is less predictable than within porous aquifers.

Bores within the Peel Valley Fractured Rock GMU are more widely spaced than within the Peel Valley Alluvium, however, groundwater extraction is expected to increase in this GMU. This fractured rock aquifer accounts for a significant volume of groundwater recharge and under increased extraction this recharge will no longer be delivered to streams. This will impact on surface water flows. Approximately 32 percent of groundwater extraction comes from surface water flows with an estimated time of between ten to 50 years for a response.

The results of the scenario analysis for the Peel Valley Fractured Rock under the current extraction scenario show that because the GMU has a large area receiving recharge, extraction is well below rainfall recharge for all scenarios.

The impacts of groundwater extraction on surface water are more substantial than the effects on the availability of groundwater as a result of climate change.

GAB Intake Beds GMU

Development in the GAB Intake Beds GMU is relatively widely spaced and the intensity of development is not an issue. The introduction of the GAB Groundwater Management Plan will limit development within this GMU. Extraction is predicted to decrease as the component share of the Eastern Recharge Zone of the GAB WSP is gradually reduced over time.

The GAB Intake Beds are assigned a zero connectivity rate in New South Wales. This connectivity rate is assumed within the very low recharge rates assigned to the Intake Beds (about 0.5 percent of rainfall). The low recharge rates are influenced by "recharge (is) often rejected back to the surface for stream baseflow" (M. Williams, pers comm.). The low connectivity applies to the Intake Beds only after the recharge is rejected as this is the more robust estimate of long-term recharge to the GAB confined aquifers. The recharge rates referred to above were estimated for management of the regional confined GAB aquifers. These deeper confined GAB aquifers are not connected to the surface water systems of the MDB. Rejected recharge returns to streams as baseflow indicating that there are small local groundwater flow systems operating at the top of the intake beds. These local systems are highly connected to the surface water system. Any groundwater extraction in the Intake Beds that disrupts the water balance of the local flow systems will also have an influence on the volume of rejected recharge that is returned to the rivers and streams. Any storage deficit that occurs in the aquifer due to groundwater pumping will draw on water that would have previously been reported as streamflow. It is also likely that the initial recharge rates to the Intake Beds is much higher than the quoted 0.5 percent rate allowing for the volume of recharge that is rejected.

The results of the scenario analyses for the GAB GMU show only minor variations in volume due to climate change. The level of impact within this GMU remains small and consistent as the area and hence the volume of rainfall recharge is relatively large if current extraction rates are maintained in the future. Future extractions within the GAB are predicted to decrease and as such impacts from groundwater pumping in these units will decrease.

Miscellaneous Alluvium of the Barwon Region GMU

The Miscellaneous Alluvium of the Barwon region is located in a similar geomorphic setting to the Peel Valley Alluvium. Steep sided valleys contain the alluvium in the valley bottom which is incised by the river and is in direct hydraulic contact. Groundwater extraction would impact on the volumes of water available for surface water flows.

Extraction from the Miscellaneous Alluvium of the Barwon Region GMU is likely to impact rapidly (within one to ten years) because of the intense scale of development within a very narrow zone. This alluvium is located along the base of highland valleys and provides fresh water for irrigation. The estimated degree of connection is 52 percent based on a preliminary water balance, partial GMU flow modelling and limited groundwater monitoring. Groundwater extraction is predicted to decrease in the future easing pressures on flows from this region. However, there is an estimated delay of between 10 and 50 years until the full impact of changes to groundwater extraction on streamflow are realised (MDBC, 2007).

Groundwater use represents a large proportion of the rainfall recharge under Scenario A. If extraction rates continue into the future the relative volume of extraction will only increase as climate becomes drier since the amount of rainfall recharge will decrease. This leads to relatively modest rises in E/R values in scenarios Cmid and Cdry.

Groundwater extraction is expected to rise. The decrease in recharge coupled with increasing extractions creates a situation in Scenario Ddry where the resource is being extracted at the same rate as rainfall is recharging the system.

6.6.3 Impact of extraction on streamflow

The following analyses some lower priority GMUs from a surface water–groundwater impacts perspective that builds upon the E/R ratios from previous sections and the connectivity values in Table 6-21.

Both current and future stream impacts of groundwater extraction are estimated in two related and different ways. Both use a connectivity factor that is assigned to each GMU to relate changes of groundwater extraction to changes in stream impact.

A value of 1.0 is indicative of close connection between the aquifer being pumped and the relevant stream so that the extraction of a volume of water leads to an equivalent volume leaving the stream in some reasonable time. A value of zero implies a very poorly connected system where the extraction leads to a change in groundwater storage (lower watertables), less evapotranspiration or less recharge from other sources, but no recharge from the streamflow source.

The impact of groundwater extraction on streamflow is estimated by multiplying the connectivity factor by the extraction in the first of the two methods to be used. The estimates for current and future extraction are shown in Table 6-21. The area in the Upper Namoi GMU outside of the Upper Namoi groundwater models (zones 1, 6, 7, 9 and 10) is included. The connectivity factors were previously supplied by New South Wales (MDBC, 2007), except for the Upper Namoi. The numerical modelling above suggests connectivity factors of up to 0.85 for the Upper Namoi region. The zone considered in this analysis includes more upland alluvial areas and hence a connectivity factor of 0.3 is used.

Two issues arise in using these values. The first is the time lag between the extraction beginning and the full impact being realised in the stream. The time lags depend on groundwater characteristics and the distance of extraction from the stream. Some estimates are given for each GMU in Table 6-21. These are used to estimate the current extraction impact through a time lag factor.

The second issue is the need to compare to a reference. The Namoi IQQM has implicitly included groundwater fluxes into the calibration conducted for many of the river reaches over the period 1983 to 1997. There is a need to estimate the impacts relative to this calibration period so that allowance can be made for impacts not included in the current implementation of the IQQM. A reference is estimated for the impacts of extraction on surface water at the time of the calibration. The Scenario A (2010) estimate is then obtained by multiplying the time lag factor by the difference between the full impacts of current extraction relative to the reference. The scenario A and D full impacts are obtained by taking the difference between full impacts of current and projected extractions respectively, and the reference. The results of this are in Table 6-21 and show a 2010 impact of 8.2 GL/year and a future impact of 17.7 and 87.9 GL/year for current and projected extractions, respectively.

Table 6-21. Estimate of the impacts of current and future groundwater extraction on streamflow outside of the Lower and Upper Namoi groundwater management units

Code	Name	Connectivity**	Full impact of current extraction	Full impact of future extraction	Reference	Time lags*	Scenario A 2010 impacts	Scenario A impact	Scenario D impact
		percent		GL/y		years		GL/y	
N05	Peel Valley Alluvium	83%	8.6	17.9	8.6	1–10	0.0	0.0	9.4
N23	Misc. Alluvium of the Barwon Region	52%	2.1	3.7	0.7	1–10	1.4	1.4	3.0
N63	GAB Alluvial	17%	0.1	1.0	0.1	10–50	0.0	0.0	1.0
N601	GAB Intake Beds	0%	0.0	0.0	0.0	NA	0.0	0.0	0.0
N604	Gunnedah Basin	26%	1.5	15.9	0.5	10–50	0.3	1.0	15.4
N608	Oxley Basin	31%	2.9	14.4	0.4	10–50	0.7	2.5	14.0
N805	New England Fold Belt	32%	2.4	21.7	0.4	50–100	0.2	2.0	21.3
N813	Warrumbungle Tertiary Basalt	31%	0.0	0.1	0.0	1–10	0.0	0.0	0.1
N814	Liverpool Ranges Basalt	32%	0.8	3.8	0.2	1–10	0.6	0.6	3.6
N819	Peel Valley Fractured Rock	32%	8.0	11.4	0.5	10–50	2.3	7.5	10.9
	Upper Namoi (unmodelled)	30%	4.2	10.7	1.5	1–10	2.7	2.7	9.2
	Total		**30.5**	**100.7**	**12.8**		**8.2**	**17.7**	**87.9**

*A timelag factor (1.0 for 1–10 years, 0.3 for 10–50 years, 0 for 50–100 years) is used to estimate current impact
**Connectivity factors were obtained from MDBC (2007), except Upper Namoi.
NA – not available

The maximum likely extractions without plan revision represent an upper limit on projected extractions. While the underlying assumptions are reasonable, the extraction may not be realised for reasons of water quality, extraction rules or for land suitability. This represents the best estimate of the impacts of those projections and is dependent on the connectivity factor which should be considered a 'best guess'. The estimates appear to be conservative.

A second more conservative estimate was made for inclusion in the river modelling. The above data were not available and the extraction use data outside of the Upper Namoi and Peel River Alluvium GMUs were likely to be underestimates of current extraction when the river modelling was undertaken. The current entitlements were used instead of current extraction rates. These second more conservative estimates were distributed across either the subcatchments that supply inflows to the reaches modelled by IQQM or to reaches of IQQM where gains or losses may need to be modified. The process for doing this is described in Rassam et al. (2007). Stations with impacts less than 2 GL/year are ignored as and likely to be indistinguishable from errors associated with gauging. The application of the assumption led to further reductions in the estimates providing an even more conservative estimate of groundwater impacts on river flow within the river modelling. The results are shown in Table 6-22.

Table 6-22. Impacts of groundwater extraction on streamflow by subcatchment under scenarios A and D

Station Identifier	Station Name	Scenario A	Scenario Dmid
		GL/y	
4190050	Namoi @ Nth Cuerindi		6.2
4190061	Peel @ Carrol Gap	4.1	6.2
4190241	Peel @ U/S Paradise Weir	1.9	2.5
4190270	Mooki @ Breeza	8.7	15.8
4190320	Coxs Ck @ Boggabri	2.7	15.2
4190800	Manilla @ Split Rock Dam storage		4.1
Total		**17.5**	**50.1**

The estimated losses in each subcatchment were used to modify daily flow duration curves (Figure 6-13), and thus modify the Scenario D inflows for the relevant subcatchments in the river model (Chapter 4). Figure 6-13 shows the flow duration curves for the Cmid, Dmid and Dmid modified scenarios. The Dmid scenario is the impact before groundwater extraction is included, while Dmid modified is that including extraction. The difference between Cmid and Dmid can be largely attributed to farm dams. Thus, the effect of groundwater extraction can be compared to that of farm dams by comparing the difference between Dmid and Cmid and Dmid-modified and Dmid respectively. Groundwater extraction leads to the percentage of low flows being decreased by up to 50 percent in the affected subcatchments, where as the impact of farm dams is spread more broadly across the flow regime. These reductions in base flow would make flow in these streams even more ephemeral, affecting near-river ecosystems and flow in the main channel.

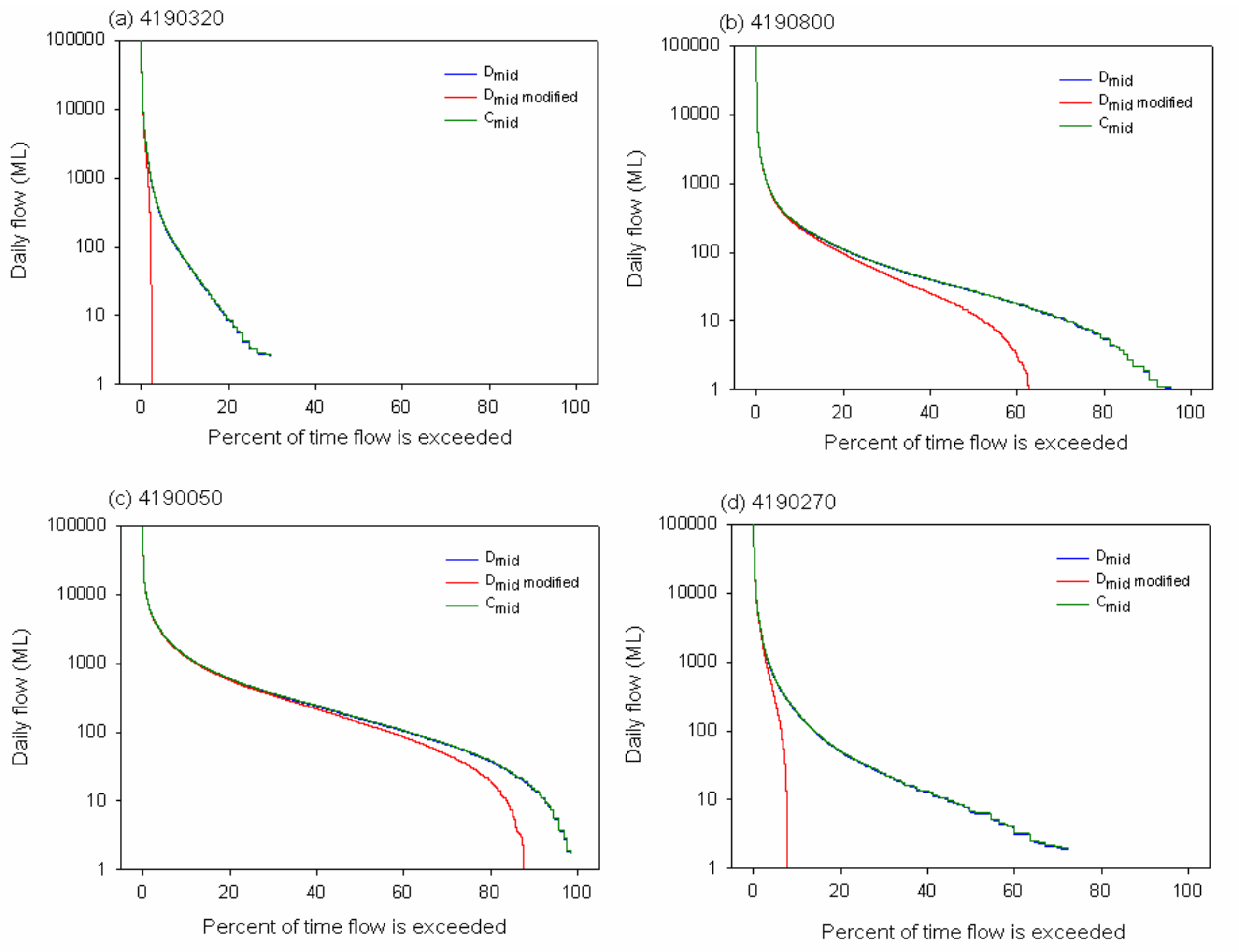

Figure 6-13 Daily flow duration curves for gauges (a) 4190320, (b) 4190800, (c) 4190050 and (d) 4190270. The scenarios shown are Cmid (current level of development), Dmid (current groundwater development and future farm dam impacts) and Dmid-modified (future farm dams and future groundwater extraction impacts)

Combination of the results from the assessment of lower priority GMUs and the results from the MODFLOW models will help explain total stream impacts of groundwater extraction. The first column in Table 6-23 gives the impacts of current extraction on streamflow at 2010 and shows that 19.2 GL/year is unaccounted for in the current IQQM model.

The second column shows the full impact of current extraction being 36.2 GL/year, recognising that this may be realised over coming decades. The estimate of 112.6 GL/year is for the full impact of projected extraction. A more conservative estimate is used in the river modelling. This together with the logistics of incorporating these estimates in the river modelling has led to a much reduced estimate of 71.2 GL/year.

Table 6-23. Estimates of impacts of groundwater extraction on streamflow in the Namoi region

Model	Scenario A 2010 impacts relative to reference	Scenario A full impacts relative to reference	Scenario Dmid full impacts relative to reference	River modelling Scenario A full impacts	River modelling Scenario Dmid full impacts
	GL/y				
Upper Namoi	9	18.7	19.4	18.0	19.4
Upper Namoi Zone 8	2	2	3.6		
Lower Namoi	0	-2.2	1.7	-2.2	1.7
Lower priority GMU	8.2	17.7	87.9	17.5	50.1
Total	**19.2**	**36.2**	**112.6**	**33.3**	**71.2**

6.7 Conjunctive water use indicators

Groundwater can provide a secure water source during drier periods. Irrigators may elect to change from surface water to groundwater during years of low flow where such 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 6-24 shows these ratios for years of lowest surface water diversions up to a year with average flow.

Groundwater can be from 49 to 78 percent of total diversions in the Namoi region under current conditions. This does not change much for Cmid (49 to 77 percent), but does for Cdry (53 to 85 percent) and Cwet (46 to 60 percent).

There is expected to be an almost four-fold expansion in groundwater extractions under Scenario D mainly for stock and domestic use in the fractured rock areas. This leads to a decrease in river flows as described above, but the exchange is not one for one. Some of the water that is extracted would have otherwise been used for plant transpiration or would have perhaps moved to another groundwater system and this is expressed as a connectivity factor of less than one. The proportion changes to 66 to 94 percent for best estimates under Scenario D, 71 to 97 percent for the dry extreme and 63 to 81 percent for the wet extreme. Conservative impacts of groundwater extraction were used in river modelling and there may be a further 13 GL/year impact under scenarios A to C and a further 53 GL/year impact under Scenario D.

These results show that groundwater forms a minor source of water for the region as a whole under average flow years but is important in drier years, occasionally being the dominant source of water. It is not surprising to see this significance increase under the drier future conditions. It becomes a major source of water for low flow years in general. The increased significance represents a trend in the way groundwater is used in the region toward stock and domestic.

Table 6-24. Conjunctive water use indicator: ratio of groundwater to total water diversion in the Namoi region in 1-year, 3-year and 5-year periods of lowest surface water diversions and the average year under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Dry	Dmid	Dwet
Lowest 1-year period	78%	85%	77%	60%	97%	94%	81%
Lowest 3-year period	66%	77%	65%	56%	93%	84%	74%
Lowest 5-year period	59%	70%	61%	53%	87%	79%	70%
Average	49%	53%	49%	46%	71%	66%	63%

6.8 Discussion of key findings

6.8.1 Connectivity

The key features of the connectivity analysis are:

- The lower reaches of the Namoi River and Pian Creek are losing, and in parts ‘disconnected’ from the river.
- The river changes from losing to gaining, with some seasonal or spatial variability, in the mid to upper Namoi reaches including the Mooki River and Coxs Creek.
- The reaches are predominantly gaining in the highland areas of the Peel, Namoi and Manilla rivers.

The evaluation was done during a dry period, so while values will change over time, the assessment suggests that the patterns are robust. The patterns and values are consistent with the numerical model, where the numerical model overlaps with the river. They are also broadly consistent with other regions.

6.8.2 Lower Namoi

Groundwater modelling has demonstrated that current levels of groundwater extraction (approximately 87 GL/year) are not sustainable. Dynamic equilibrium conditions for this level of pumping are not attained until water levels fall below the base of the Narrabri and Gunnedah formations in places, resulting in the drying of the aquifer and eventual loss of production potential from parts of the aquifer. Groundwater management intervention and natural loss of productivity as the aquifers are dewatered will prevent the aquifers from drying out completely in practice.

Modelling has indicated that dynamic equilibrium conditions (quasi steady state conditions) take many decades of continuous pumping to be realised. In fact dynamic equilibrium conditions are not attained within the 111 years of warm-up modelling prior to the start of the predictive scenarios. The regions that are heavily drawn on for groundwater production are the slowest to reach equilibrium. Indeed dynamic equilibrium conditions are never reached in the scenarios as the drying of parts of the aquifer and associated reduction in groundwater pumping prevent groundwater levels from stabilising during the model runs.

Groundwater recharge exceeds groundwater extraction (assumed to be 87 GL/year) in 14 to 38 percent of the modelled years depending on the climate scenario assumed. Total combined average groundwater recharge amounts to between 73 and 91 GL/year for the development scenarios considered in this project and this level of groundwater extraction may be sustainable in the long term.

Modelling has indicated that extraction has modified stream from gaining stream to a losing stream. The same effect may also be achieved through river regulation and the need to sustain flows for longer periods.

6.8.3 Upper Namoi

Two numerical models and a simple water balance for unmodelled areas were used to analyse the Upper Namoi Alluvium GMU. The first modelled were zones 2, 3, 4, 5, 11 and 12, while the second modelled were zones 6, 7, 8 and 10 within the alluvium on the Mooki River. Results from Zone 8 only were used in this analysis. The first model shows good connection to the river and that any change in flux is offset by changes in fluxes from the river with about 85 percent connectivity. The connectivity is greater than 50 percent for Zone 8.

There is a 16.3 GL/year impact of groundwater extraction on streamflow at 2010 under Scenario A relative to a reference period used in calibration and a 25.6 GL/year impact eventually from current extraction. This may climb to 32.5 GL/year under Scenario D. Groundwater levels continue to fall slowly throughout the model run.

6.8.4 Stream impacts of groundwater extraction

The impact that groundwater extraction will have on streams is yet to be fully realised even for current levels of development with 36 GL/year compared to the surface water models used as the basis of water sharing plans and the potential for another 76 GL/year under Scenario Dmid. This is based on assumptions that may overestimate the growth and assumptions that underestimate the impact of this growth.

The impact on baseflow of some subcatchments could lead to a reduction of the number of effective no-flow days by as much as 50 percent of the total time. The timelag for groundwater–surface water exchanges to equilibrate varies from 15 years for Zone 8 in the Mooki to 50 years for the Lower Namoi. It was not possible to define the similar timelag for the Upper Namoi model. There is potential for further groundwater extraction in the Peel Alluvium – which would equilibrate quickly – and in some of the hard-rock areas of the catchment which would have a longer equilibration time (>50 years).

6.9 References

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7 Environment

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

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

7.1 Summary

7.1.1 Issues and observations

- The Namoi region contains one wetland of national importance – Lake Goran (NSW005; Environment Australia, 2001) which is adjacent to the Liverpool plains. The lake is the terminus of an internal drainage basin that does not connect to the Namoi River. This area is not explicitly represented in the river models for the Namoi region and so could not be assessed in this project.
- The Namoi River system provides a wide range of aquatic habitats and is ecologically important. The floodplain downstream of Narrabri contains large areas of anabranches and billabongs. When flooded these areas are considered to be important and work on similar rivers has established that they provide large amounts of organic carbon, which is essential to aquatic ecosystem functioning.
- The environmental assessments undertaken within this project for the region are limited to a partial analysis of potential changes in the hydrologic regime affecting the anabranches and billabongs associated with the Namoi River.
- Further contextual information on river-related environmental assets and values is provided in Chapter 2.

7.1.2 Key messages

- As a result of water resource development there has been an increase in the average period between flooding of the Namoi River billabongs and wetlands of about 27 percent. The maximum period between flood events has increased by nearly 50 percent. The size of events has decreased somewhat, such that the average annual flooding volume is now 28 percent (or 150 GL) lower. This level of hydrologic change is likely to have affected ecological processes and aspects of the ecological character of these ecosystems.
- Under the best estimate 2030 climate the hydrology of the Namoi River billabongs and wetlands would not change greatly from current conditions. Under the dry extreme 2030 climate there would be a 36 percent increase in the average period between events and a 46 percent reduction in the average annual flooding volume. These changes would considerably alter the connectivity between the river and the billabongs and wetlands, which would be likely to alter nutrient transfer processes with consequences for the aquatic fauna of the river and the billabongs and wetlands. Under the wet extreme 2030 climate the average and maximum period between events would return to pre-development values and the average annual flooding volume would exceed the pre-development value.
- The impacts of future development (additional farm dams and increased groundwater use) alone would be similar to the impacts of the best estimate 2030 climate. The combined effect would be to increase the average period between flood events by 14 percent (from 3.8 to 4.3 months) and to decrease the average annual flooding volume by 13 percent. These combined effects would be likely to cause additional ecological change over and above the changes already caused by water resource development.
- The minimum flow rule in the water sharing plan is met under all modelled scenarios. Minimum flows would be lowest under the dry extreme 2030 climate. Under the best estimate 2030 climate minimum flows would be similar to current conditions.

7.1.3 Uncertainty

The main uncertainties involving analysis and reporting include:

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

7.2 Approach

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

7.2.1 A summary of environmental flow rules

The Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources section on environmental water (DIPNR, 2004a) provides:

- a limit on the total annual amount of water extracted from the water sources over the long term. This limit is equal to the amount of water that could be extracted under 1999/2000 levels of water resource development and the management rules in the water sharing plan (currently estimated to average 238 GL/year over the long term). This rule reserves about 73 percent of the average annual flow over the longterm for the environment
- a minimum flow rule which passes 75 percent of the natural 95th percentile daily flow to the end-of-system at Walgett
- for access licences to be committed for environmental purposes
- limits on extraction of supplementary flow events.

The supplementary extraction limits and minimum flow rules are both for environmental outcomes for the Namoi River and to meet requirements of the Interim Unregulated Flow Management Plan for the North West. There are also environmental flow rules for Phillips Creek, Mooki River, and Quirindi and Warrah creeks (DIPNR, 2004b).

7.2.2 Environmental assets and indicators

The only wetland of national importance in the Namoi region is Lake Goran (NSW005; Environment Australia, 2001) which is adjacent to the Liverpool plains (Figure 7-1). The lake is the terminus of an internal drainage basin that does not connect to the Namoi River (Environment Australia, 2001). This area is not explicitly represented in the Namoi river models and so could not be assessed in this project.

The Namoi River and its associated billabongs and wetlands are also important environmental assets. A study carried out on the Macintyre River showed billabongs and wetlands are important for providing the river with dissolved organic matter (Thoms et al., 2005). Foster (2004) mapped all billabongs and wetlands along the Namoi River from Keepit Dam to Walgett and assessed their flow connections with the Namoi River. He estimated that flows in the range 4 to 5 GL/day at the Duncans Junction gauging station flood nearly 1000 km of billabongs and wetlands along the river system. This flow threshold is therefore used as the hydrologic indicator of relevance to these billabongs and wetlands; it assesses the supplementary access rules. Additionally, the minimum flow rule of the water sharing plan, the percentage of the pre-development scenario 95th percentile daily flow which passes Walgett, is assessed.

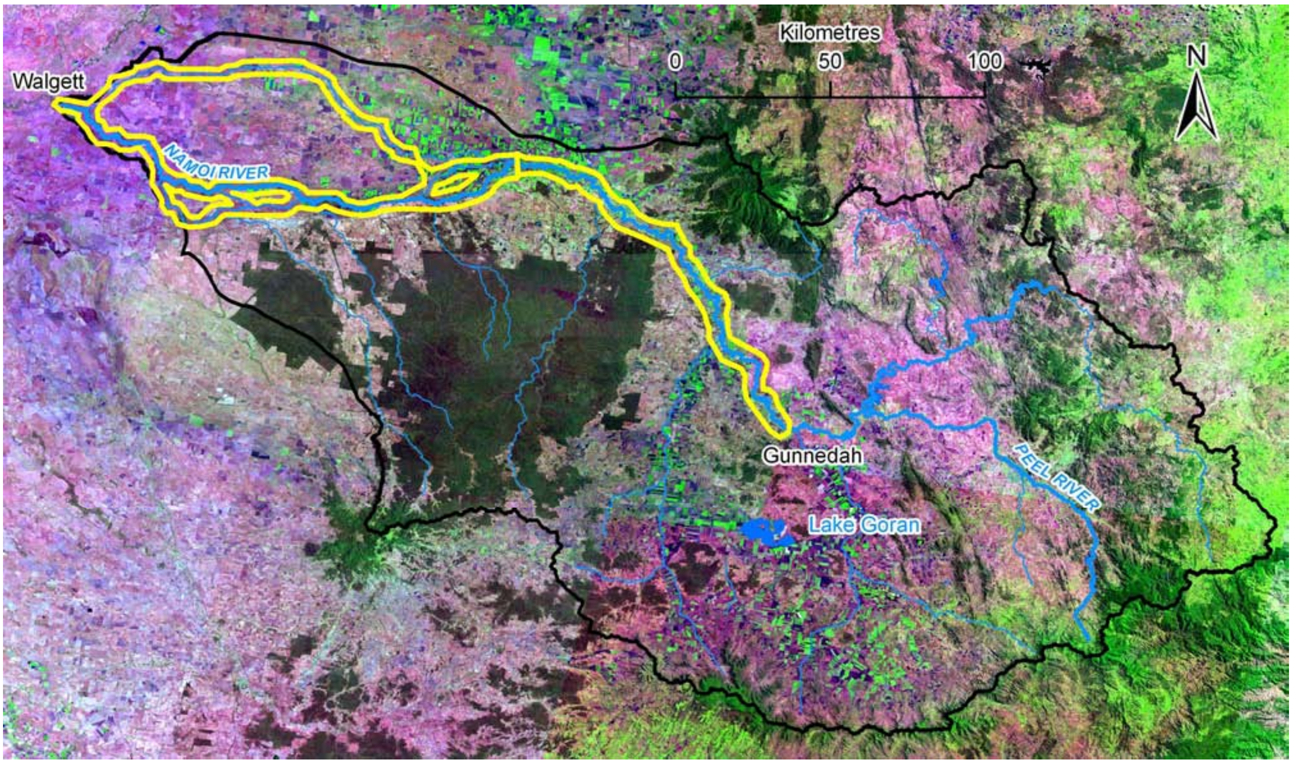

Figure 7-1. Satellite image of the Namoi region (2002). Yellow polygon indicates location of billabongs and wetlands along the Namoi River and Pian Creek.

Table 7-1. Definition of environmental indicators

Namoi River indicators	Description
River-floodplain connecting flows	
Average period between events	Average period (months) between events above 4 GL/day at Duncans Junction gauge
Maximum period between events	Maximum period (months) between events above 4 GL/day at Duncans Junction gauge
Average flooding volume per event	Average volume (GL) per event above 4 GL/day Duncans Junction gauge
Average flooding volume per year	Average volume (GL) per year above 4 GL/day Duncans Junction gauge
Minimum flows	
Minimum flow rule indicator	Percentage of the pre-development 95th percentile daily flow passing Walgett

7.3 Results

The projected changes in the environmental indicators for the various scenarios (including pre-development – Scenario P) are listed in Table 7-2. These were assessed using scenario outputs for the Duncans Junction and Walgett gauges from the Namoi River system model (Chapter 4).

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

	P	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	months		percent change from Scenario A					
Average period between events	3	3.8	36%	6%	-21%	50%	14%	-15%
Maximum period between events	25.2	37.2	5%	0%	-31%	29%	0%	-31%
	GL							
Average flooding volume per event	154	140	-28%	-3%	31%	-25%	-2%	35%
Average flooding volume per year	545	395	-46%	-8%	63%	-49%	-13%	57%
	percent of pre-development 95th percentile daily flow							
Minimum flow rule indicator	95%	87.5%	81.4%	85.6%	93.2%	82.7%	84.2%	91.9%

7.4 Discussion of key findings

As a result of water resource development there has been an increase in the average period between flooding of the Namoi River billabongs and wetlands of about 27 percent or one month. The maximum period between flood events has increased by nearly 50 percent or 12 months. The size of these events has decreased somewhat, such that the average annual flooding volume is now 150 GL lower. This level of hydrologic change is likely to have affected ecological processes and aspects of the ecological character of these ecosystems.

Under the best estimate 2030 climate the hydrology of the Namoi River billabongs and wetlands would not change greatly from current conditions. However, under the dry extreme 2030 climate there would be a 36 percent increase in the average period between events and a 5 percent increase in the maximum period between events. The average flooding volume would reduce by 28 percent leading to a 46 percent reduction in the average annual volume above the event threshold. These changes would considerably alter the connectivity between the river and the billabongs and wetlands, which would be likely to alter nutrient transfer processes with consequences for the aquatic fauna of the river and the billabongs and wetlands. Under the wet extreme 2030 climate the average and maximum period between events would return to pre-development values. The average event volume would increase to be larger than pre-development volumes, so that the average annual flooding volume would exceed the pre-development value.

The impacts of future development (additional farm dams and increased groundwater use) alone would be similar to the impacts of the best estimate 2030 climate. The combined effect would be to increase the average period between flood event by 14 percent (from 3.8 to 4.3 months) and to decrease the average annual flooding volume by 13 percent. These combined effects would be likely to cause additional ecological change over and above the changes already caused by water resource development. Under the extreme 2030 climates, development would mainly have an impact on the average and maximum period between events under the dry extreme: the average period would increase by an additional 14 percent over and above the climate change impact and the maximum period would increase by an additional 24 percent.

The minimum flow rule in the water sharing plan is met under all modelled scenarios. Minimum flows would be lowest under the dry extreme 2030 climate. Under the best estimate 2030 climate minimum flows would be similar to current conditions.

7.5 References

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DIPNR (2004b) Water Sharing Plan for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources 2003. Effective 1 July 2004 and ceases ten years after that date. Department of Infrastructure Planning and Natural Resources, Sydney. NSW Government Gazette.

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Appendix A Rainfall-runoff results for all subcatchments

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

		Scenario A					Scenario Cdry		Scenario Cmid		Scenario Cwet	
Modelling catchment	Area	Rainfall	APET	Runoff	Runoff coefficient	Runoff contribution	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff
	km^2	mm			percent		percent change from Scenario A					
4190011	1846	617	1430	23	4%	4%	-10%	-29%	-2%	-6%	13%	36%
4190031	1649	633	1468	21	3%	4%	-10%	-35%	-2%	-7%	13%	41%
4190050	2522	786	1292	54	7%	14%	-10%	-29%	-1%	-6%	13%	37%
4190061	1760	656	1388	35	5%	6%	-10%	-28%	-1%	-6%	13%	35%
4190121	1820	586	1450	12	2%	2%	-10%	-32%	-2%	-6%	13%	40%
4190151	441	831	1305	77	9%	3%	-10%	-31%	-1%	-7%	13%	39%
4190160	893	808	1286	65	8%	6%	-10%	-32%	-1%	-6%	13%	40%
4190201	405	659	1387	36	5%	1%	-10%	-29%	-2%	-6%	13%	35%
4190211	3584	571	1506	6	1%	2%	-10%	-32%	-2%	-6%	13%	44%
4190221	188	654	1414	32	5%	1%	-10%	-28%	-2%	-6%	13%	35%
4190241	472	690	1366	37	5%	2%	-10%	-29%	-1%	-3%	13%	37%
4190261	2270	502	1524	9	2%	2%	-10%	-32%	-4%	-11%	13%	42%
4190270	3105	691	1369	34	5%	11%	-12%	-29%	-2%	-7%	13%	38%
4190290	357	757	1341	49	6%	2%	-10%	-29%	-1%	-6%	13%	37%
4190320	3800	625	1416	20	3%	8%	-10%	-32%	-2%	-4%	13%	44%
4190350	459	762	1324	45	6%	2%	-10%	-31%	-1%	-7%	13%	39%
4190360	92	980	1279	120	12%	1%	-10%	-30%	-1%	-8%	13%	38%
4190391	2674	627	1465	9	1%	3%	-10%	-35%	-2%	-4%	13%	45%
4190411	603	609	1423	28	5%	2%	-10%	-27%	-2%	-5%	13%	34%
4190491	2553	497	1547	9	2%	2%	-10%	-32%	-3%	-5%	13%	41%
4190510	663	703	1405	30	4%	2%	-10%	-34%	-2%	-8%	13%	42%
4190591	931	601	1510	16	3%	2%	-10%	-36%	-2%	-3%	13%	44%
4190662	1841	608	1419	15	3%	3%	-10%	-31%	-2%	-3%	13%	43%
4190681	295	582	1519	15	3%	0%	-10%	-36%	-2%	-2%	13%	44%
4190690	409	894	1290	80	9%	3%	-11%	-31%	-1%	-8%	13%	41%
4190720	981	660	1429	13	2%	1%	-10%	-36%	-2%	-7%	13%	46%
4190770	95	1021	1251	148	14%	1%	-10%	-31%	-1%	-8%	13%	38%
4190800	1634	703	1378	43	6%	7%	-10%	-30%	-2%	-6%	13%	37%
4190911	1442	470	1547	8	2%	1%	-10%	-32%	-3%	-10%	13%	43%
	39780	**633**	**1431**	**24**	**4%**	**100%**	**-10%**	**-31%**	**-2%**	**-6%**	**13%**	**39%**

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		
4190011	23	0	1004	0.5	-31%	-8%	33%
4190031	21	0	1121	0.7	-37%	-9%	39%
4190050	54	0	1226	0.5	-30%	-7%	36%
4190061	35	0	727	0.4	-29%	-7%	33%
4190121	12	0	1075	0.6	-33%	-8%	37%
4190151	77	0	133	0.3	-32%	-8%	39%
4190160	65	0	401	0.4	-33%	-7%	39%
4190201	36	0	131	0.3	-30%	-7%	34%
4190211	6	0	2364	0.7	-34%	-8%	40%
4190221	32	0	48	0.3	-29%	-7%	34%
4190241	37	0	178	0.4	-31%	-4%	36%
4190261	9	0	863	0.4	-33%	-12%	40%
4190270	34	0	1740	0.6	-30%	-9%	37%
4190290	49	0	118	0.3	-30%	-6%	36%
4190320	20	0	1745	0.5	-33%	-5%	42%
4190350	45	0	120	0.3	-31%	-8%	39%
4190360	120	0	7	0.1	-30%	-8%	38%
4190391	9	0	1481	0.6	-37%	-6%	42%
4190411	28	0	218	0.4	-28%	-7%	32%
4190491	9	0	1148	0.4	-33%	-7%	39%
4190510	30	0	382	0.6	-36%	-10%	40%
4190591	16	0	584	0.6	-38%	-5%	41%
4190662	15	0	949	0.5	-32%	-5%	41%
4190681	15	0	180	0.6	-38%	-4%	42%
4190690	80	0	86	0.2	-31%	-8%	41%
4190720	13	0	338	0.3	-37%	-8%	45%
4190770	148	0	7	0.1	-31%	-8%	38%
4190800	43	0	582	0.4	-31%	-7%	36%
4190911	8	0	499	0.3	-33%	-11%	41%
	24	**0**	**19454**	**0.5**	**-32%**	**-7%**	**38%**

Appendix B River water modelling reach mass balances

Subcatchment 4190911

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	640.6	52%	-8%	-39%	48%	-11%	-42%
Indirectly gauged	11.5	43%	-10%	-32%	42%	-11%	-33%
Effluent return	19.2	35%	-2%	-27%	31%	-5%	-30%
Sub-total	**671.3**	**52%**	**-8%**	**-38%**	**47%**	**-11%**	**-41%**
Diversions							
Licensed private diversions							
Regulated	5.1	16%	-4%	-18%	13%	-7%	-26%
Surplus	3.6	13%	-1%	-13%	10%	-5%	-15%
Floodplain	0.9	27%	5%	-33%	23%	5%	-37%
High security 'other demands'	0.49	0%	-1%	-3%	0%	-1%	-1%
Sub-total	**10.0**	**15%**	**-2%**	**-17%**	**12%**	**-5%**	**-22%**
Outflows							
End-of-catchment flows	583.0	52%	-8%	-39%	48%	-11%	-42%
Net evaporation from river channel	1.6	12%	2%	-3%	9%	-1%	2%
Sub-total	**584.6**	**52%**	**-8%**	**-39%**	**47%**	**-11%**	**-42%**
Unattributed fluxes							
River unattributed loss	76.9	53%	-8%	-39%	48%	-11%	-42%
Mass balance							
Mass balance error (%)	-0.03%	-0.02%	-0.03%	-0.05%	-0.02%	-0.03%	-0.05%

Subcatchment 4190491

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	58.5	17%	-3%	-27%	15%	-7%	-34%
Indirectly gauged	11.2	41%	-5%	-32%	39%	-7%	-33%
River groundwater gains (GL/y not percent change)	0.05	0.02	0.12	0.32	0.00	0.21	0.43
Sub-total	**69.8**	**21%**	**-3%**	**-28%**	**19%**	**-7%**	**-33%**
Diversions							
Licensed private diversions							
Regulated	40.1	11%	-5%	-26%	10%	-9%	-35%
Surplus	1.3	4%	12%	-29%	3%	2%	-33%
Floodplain	0.5	-53%	8%	-30%	-49%	15%	-42%
High security 'other demands'	0.13	-1%	0%	-1%	0%	0%	-1%
Sub-total	**42.1**	**10%**	**-4%**	**-26%**	**9%**	**-8%**	**-35%**
Outflows							
End-of-catchment flows	19.3	35%	-2%	-27%	31%	-5%	-30%
River groundwater loss (GL/y not percent change)	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Net evaporation from river channel	0.4	-11%	14%	35%	-14%	23%	39%
Sub-total	**19.6**	**34%**	**-2%**	**-26%**	**31%**	**-5%**	**-29%**
Unattributed fluxes							
River unattributed loss	8.1	47%	-2%	-37%	45%	-4%	-39%
Mass balance							
Mass balance error (%)	-0.01%	0.00%	0.00%	-0.01%	0.00%	0.00%	-0.01%

Subcatchment 4190261

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	691.2	53%	-7%	-39%	48%	-11%	-42%
Indirectly gauged	40.1	48%	-13%	-35%	46%	-14%	-36%
Sub-total	**731.3**	**53%**	**-8%**	**-39%**	**48%**	**-11%**	**-42%**
Diversions							
Licensed private diversions							
Regulated	5.9	11%	-2%	-17%	9%	-6%	-26%
Surplus	1.9	21%	2%	-16%	14%	-3%	-18%
Floodplain	3.2	35%	1%	-7%	31%	-3%	-12%
High security 'other demands'	0.16	3%	-1%	-2%	2%	-2%	-2%
Sub-total	**11.1**	**19%**	**0%**	**-13%**	**16%**	**-4%**	**-20%**
Outflows							
End-of-catchment flows	640.6	52%	-8%	-39%	48%	-11%	-42%
River groundwater loss (GL/y not percent change)	0.03	0.05	0.03	0.00	0.05	0.02	0.00
Net evaporation from river channel	3.4	3%	5%	6%	3%	5%	7%
Sub-total	**644.0**	**52%**	**-8%**	**-39%**	**47%**	**-11%**	**-42%**
Unattributed fluxes							
River unattributed loss	76.2	61%	-8%	-42%	56%	-12%	-45%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190211

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	384.9	38%	-8%	-32%	33%	-12%	-33%
Indirectly gauged	226.6	44%	-6%	-32%	40%	-8%	-34%
Effluent return	266.6	60%	-5%	-43%	55%	-9%	-48%
River groundwater gains (GL/y not percent change)	2.0	5.0	1.3	0.0	4.1	0.5	0.0
Sub-total	**880.2**	**46%**	**-7%**	**-36%**	**42%**	**-10%**	**-38%**
Diversions							
Licensed private diversions							
Regulated	36.3	9%	-2%	-17%	7%	-6%	-27%
Surplus	11.0	15%	0%	-14%	11%	-4%	-19%
Floodplain	5.2	21%	6%	-20%	22%	4%	-25%
High security 'other demands'	0.26	0%	0%	-1%	0%	0%	0%
Sub-total	**52.7**	**11%**	**-1%**	**-17%**	**10%**	**-5%**	**-25%**
Outflows							
Subcatchment effluent	58.5	17%	-3%	-27%	15%	-7%	-34%
End-of-catchment flows	680.0	53%	-7%	-39%	48%	-11%	-42%
River groundwater loss (GL/y not percent change)	0.0	0.0	0.0	0.6	0.0	0.0	10.3
Net evaporation from river channel	2.7	1%	4%	6%	1%	3%	8%
Sub-total	**741.2**	**50%**	**-7%**	**-38%**	**45%**	**-11%**	**-40%**
Unattributed fluxes							
River unattributed loss	86.2	36%	-7%	-29%	32%	-11%	-31%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190681

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	422.9	37%	-8%	-31%	32%	-12%	-33%
Indirectly gauged	5.6	44%	-2%	-36%	42%	-4%	-38%
River groundwater gains (GL/y not percent change)	0.3	1.2	0.1	0.0	0.8	0.0	1.1
Sub-total	**428.8**	**37%**	**-8%**	**-31%**	**32%**	**-12%**	**-33%**
Diversions							
Licensed private diversions							
Regulated	16.6	14%	-4%	-21%	12%	-7%	-30%
Surplus	4.2	2%	3%	-4%	0%	-1%	-10%
Floodplain	0.3	35%	-5%	-43%	27%	-10%	-54%
High security 'other demands'	0.17	1%	0%	0%	1%	0%	0%
Sub-total	**21.3**	**12%**	**-2%**	**-17%**	**10%**	**-6%**	**-26%**
Outflows							
End-of-catchment flows	384.9	38%	-8%	-32%	33%	-12%	-33%
River groundwater loss (GL/y not percent change)	0.0	0.0	0.0	0.9	0.0	0.1	0.0
Net evaporation from river channel	0.2	0%	5%	11%	0%	5%	11%
Sub-total	**385.1**	**38%**	**-8%**	**-32%**	**33%**	**-12%**	**-33%**
Unattributed fluxes							
River unattributed loss	22.5	49%	-7%	-38%	44%	-11%	-41%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190591

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	759.7	41%	-6%	-33%	37%	-10%	-37%
Indirectly gauged	64.8	44%	-3%	-36%	42%	-5%	-38%
River groundwater gains (GL/y not percent change)	0.0	3.5	0.0	0.0	1.6	0.0	0.0
Sub-total	**824.5**	**42%**	**-6%**	**-33%**	**38%**	**-10%**	**-37%**
Diversions							
Licensed private diversions							
Regulated	64.0	8%	-2%	-17%	7%	-6%	-26%
Surplus	11.6	12%	1%	-7%	7%	-4%	-12%
Floodplain	4.0	29%	6%	-26%	28%	1%	-27%
High security 'other demands'	0.12	0%	0%	0%	0%	0%	0%
Sub-total	**79.8**	**10%**	**-1%**	**-16%**	**8%**	**-5%**	**-24%**
Outflows							
Subcatchment Effluent	266.6	60%	-5%	-43%	55%	-9%	-48%
End-of-catchment flows	422.9	37%	-8%	-31%	32%	-12%	-33%
River groundwater loss (GL/y not percent change)	0.9	0.0	1.9	4.5	0.0	2.6	4.5
Net evaporation from river channel	0.3	-1%	5%	10%	-1%	5%	10%
Sub-total	**690.7**	**46%**	**-7%**	**-35%**	**41%**	**-10%**	**-38%**
Unattributed fluxes							
River unattributed loss	54.1	46%	-7%	-35%	41%	-11%	-38%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190391

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Mollee Weir	-0.01	-47%	6%	-28%	-36%	-2%	-32%
Total change in storage	**-0.01**	**-47%**	**6%**	**-28%**	**-36%**	**-2%**	**-32%**
Inflows							
Subcatchments							
Directly gauged	757.0	40%	-6%	-32%	35%	-11%	-36%
Indirectly gauged	99.4	43%	-6%	-35%	40%	-8%	-37%
River groundwater gains (GL/y not percent change)	0.7	1.4	0.6	0.0	1.2	0.4	0.0
Sub-total	**857.1**	**40%**	**-6%**	**-32%**	**36%**	**-10%**	**-36%**
Diversions							
Licensed private diversions							
Regulated	8.5	9%	-2%	-16%	8%	-6%	-25%
Surplus	0.6	6%	-1%	-6%	3%	-5%	-10%
Floodplain	1.9	41%	1%	-24%	38%	-2%	-28%
High security 'other demands'	0.04	0%	0%	0%	0%	0%	0%
Sub-total	**11.0**	**14%**	**-2%**	**-17%**	**13%**	**-5%**	**-25%**
Outflows							
End-of-catchment flows	759.7	41%	-6%	-33%	37%	-10%	-37%
River groundwater loss (GL/y not percent change)	7.8	5.2	8.1	9.2	5.2	8.1	9.4
Sub-total	**767.4**	**41%**	**-6%**	**-33%**	**36%**	**-10%**	**-36%**
Net evaporation Public storages	0.7	9%	2%	-5%	8%	0%	-9%
Net evaporation from river channel	0.3	-1%	5%	9%	-1%	5%	10%
Unattributed fluxes							
River unattributed loss	78.2	40%	-7%	-33%	35%	-12%	-38%
Mass balance							
Mass balance error (%)	-0.03%	-0.09%	-0.03%	-0.05%	0.01%	0.04%	0.06%

Subcatchment 4190121

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	789.4	40%	-6%	-32%	35%	-11%	-36%
Indirectly gauged	64.9	40%	-6%	-32%	37%	-8%	-33%
Sub-total	**854.3**	**40%**	**-6%**	**-32%**	**36%**	**-10%**	**-36%**
Diversions							
Licensed private diversions							
Regulated	4.6	12%	-4%	-24%	11%	-8%	-32%
Surplus	0.3	26%	-3%	-22%	22%	-7%	-26%
Floodplain	0.5	39%	-6%	-33%	33%	-13%	-35%
Sub-total	**5.4**	**16%**	**-4%**	**-24%**	**14%**	**-8%**	**-32%**
Outflows							
End-of-catchment flows	735.2	40%	-6%	-32%	35%	-11%	-36%
River groundwater loss	7.5	-41%	5%	20%	-40%	6%	23%
Net evaporation from river channel	0.4	-1%	5%	9%	-1%	5%	9%
Sub-total	**743.2**	**39%**	**-6%**	**-31%**	**34%**	**-10%**	**-35%**
Unattributed fluxes							
River unattributed loss	105.6	49%	-6%	-37%	44%	-11%	-41%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190011

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from scenario A					
Inflows							
Subcatchments							
Directly gauged	682.0	40%	-7%	-31%	36%	-11%	-35%
Indirectly gauged	328.5	36%	-6%	-29%	33%	-8%	-31%
River groundwater gains (GL/y not percent change)	0.0	2.0	0.0	0.0	2.0	0.0	0.0
Sub-total	**1010.5**	**39%**	**-7%**	**-31%**	**35%**	**-10%**	**-34%**
Diversions							
Licensed private diversions							
Regulated	3.0	14%	-4%	-22%	12%	-8%	-31%
Surplus	0.1	40%	2%	-28%	35%	-2%	-31%
Sub-total	**3.1**	**15%**	**-3%**	**-22%**	**13%**	**-8%**	**-31%**
Outflows							
End-of-catchment flows	727.3	40%	-6%	-32%	36%	-9%	-35%
River groundwater loss (GL/y not percent change)	3.2	1.9	3.4	4.1	1.9	3.4	4.1
Net evaporation from river channel	3.7	-1%	5%	10%	-1%	5%	10%
Sub-total	**734.1**	**39%**	**-6%**	**-31%**	**36%**	**-9%**	**-34%**
Unattributed fluxes							
River unattributed loss	273.3	37%	-8%	-29%	33%	-11%	-32%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190061

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	215.0	43%	-7%	-33%	42%	-8%	-34%
Indirectly gauged	101.0	35%	-6%	-29%	34%	-7%	-30%
Urban returns	1.6	0%	0%	0%	0%	0%	0%
Sub-total	**317.6**	**40%**	**-7%**	**-32%**	**39%**	**-8%**	**-33%**
Diversions							
Licensed private diversions							
Regulated	3.3	-3%	3%	-3%	-3%	2%	-5%
Surplus	0.6	23%	11%	9%	21%	10%	9%
High security 'other demands'	0.1	0%	0%	0%	0%	0%	0%
Sub-total	**4.0**	**1%**	**4%**	**-1%**	**1%**	**3%**	**-3%**
Outflows							
End-of-catchment flows	250.9	42%	-7%	-33%	40%	-9%	-35%
River groundwater loss	4.1	0%	0%	0%	50%	50%	50%
Net evaporation from river channel	0.9	-1%	5%	10%	-1%	5%	10%
Sub-total	**255.9**	**41%**	**-7%**	**-33%**	**40%**	**-8%**	**-34%**
Unattributed fluxes							
River unattributed loss	57.6	38%	-7%	-31%	36%	-9%	-32%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190241

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	180.7	43%	-7%	-33%	42%	-8%	-33%
Indirectly gauged	32.3	37%	-3%	-29%	36%	-4%	-31%
Sub-total	**213.0**	**42%**	**-7%**	**-32%**	**41%**	**-7%**	**-33%**
Diversions							
Licensed private diversions							
Regulated	0.7	-3%	2%	-3%	-3%	2%	-5%
Surplus	0.05	-22%	26%	110%	-23%	27%	119%
Urban diversions for town water supply	2.6	-24%	25%	95%	-24%	25%	95%
High security 'other demands'	0.1	0%	0%	0%	0%	0%	0%
Sub-total	**3.4**	**-19%**	**20%**	**73%**	**-19%**	**20%**	**73%**
Outflows							
End-of-catchment flows	187.2	43%	-7%	-34%	42%	-8%	-35%
River groundwater loss	1.9	0%	0%	0%	28%	29%	28%
Net evaporation from river channel	0.3	-2%	7%	12%	-2%	6%	12%
Sub-total	**189.4**	**43%**	**-7%**	**-33%**	**42%**	**-8%**	**-34%**
Unattributed fluxes							
River unattributed loss	20.4	44%	-7%	-37%	43%	-8%	-38%
Mass balance							
Mass balance error (%)	-0.1%	-0.1%	-0.2%	-0.2%	-0.1%	-0.2%	-0.2%

Subcatchment 4190151

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Chaffey Dam	-0.1	-103%	104%	241%	-100%	116%	242%
Dungowan Dam	0.0	451%	-138%	-198%	450%	-141%	-198%
Total change in storage	**-0.1**	**-129%**	**116%**	**261%**	**-126%**	**128%**	**263%**
Inflows							
Sub-catchments							
Directly gauged	78.0	40%	-8%	-31%	40%	-8%	-31%
Indirectly gauged	52.1	39%	-7%	-31%	39%	-8%	-32%
Sub-total	**130.1**	**40%**	**-8%**	**-31%**	**39%**	**-8%**	**-31%**
Diversions							
Licensed private diversions							
Regulated	1.5	-4%	3%	-3%	-4%	3%	-4%
Surplus	0.1	-40%	23%	127%	-39%	24%	134%
Urban diversions for town water supply	6.7	11%	-7%	-33%	11%	-7%	-33%
High security 'other demands'	0.1	0%	0%	0%	0%	0%	0%
Sub-total	**8.4**	**8%**	**-5%**	**-25%**	**8%**	**-5%**	**-26%**
Outflows							
End-of-catchment flows	100.0	45%	-8%	-33%	44%	-9%	-34%
Net evaporation public storages	5.2	-2%	4%	5%	-2%	4%	4%
Net evaporation from river channel	0.6	-4%	6%	13%	-4%	6%	13%
Unattributed fluxes							
River unattributed loss	16.1	39%	-8%	-31%	39%	-9%	-31%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190411

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Keepit Dam	-3.0	-5%	3%	10%	-5%	10%	7%
Inflows							
Subcatchments							
Directly gauged	341.0	37%	-6%	-30%	33%	-10%	-33%
Indirectly gauged	47.4	34%	-5%	-27%	32%	-7%	-28%
Sub-total	**388.3**	**37%**	**-6%**	**-29%**	**33%**	**-9%**	**-32%**
Diversions							
Licensed private diversions							
Regulated	1.9	0%	8%	2%	0%	3%	-11%
Outflows							
End-of-catchment flows	327.7	37%	-6%	-30%	33%	-10%	-33%
Net evaporation public storages	31.1	16%	-2%	-14%	14%	-4%	-15%
Net evaporation from river channel	1.8	-1%	5%	9%	-2%	3%	4%
Unattributed fluxes							
River unattributed loss	28.8	57%	-7%	-40%	54%	-10%	-42%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	-0.01%	0.00%	0.00%	-0.01%

Subcatchment 4190221

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Inflows							
Subcatchments							
Directly gauged	354.0	37%	-6%	-30%	33%	-10%	-33%
Indirectly gauged	15.9	35%	-6%	-28%	34%	-7%	-29%
Sub-total	**369.8**	**37%**	**-6%**	**-30%**	**33%**	**-10%**	**-33%**
Diversions							
Licensed private diversions							
Regulated	0.6	-3%	6%	7%	-3%	3%	-3%
Outflows							
End-of-catchment flows	341.0	37%	-6%	-30%	33%	-10%	-33%
Net evaporation from river channel	0.9	-2%	6%	10%	-5%	-2%	1%
Unattributed fluxes							
River unattributed loss	27.2	43%	-7%	-35%	39%	-10%	-37%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Subcatchment 4190201

River system model average annual water balance	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y	percent change from Scenario A					
Storage volume							
Public storages							
Split Rock Dam	-2.8	-29%	1%	-1%	-23%	-4%	5%
Inflows							
Subcatchments							
Directly gauged	72.3	37%	-6%	-30%	30%	-13%	-36%
Indirectly gauged	32.2	35%	-6%	-29%	34%	-7%	-30%
Sub-total	**104.5**	**36%**	**-6%**	**-30%**	**31%**	**-11%**	**-34%**
Diversions							
Licensed private diversions							
Regulated	4.7	1%	7%	-1%	1%	2%	-13%
Outflows							
End-of-catchment flows	84.0	39%	-8%	-33%	33%	-13%	-37%
Net evaporation public storages	14.4	16%	2%	-10%	13%	-3%	-18%
Net evaporation from river channel	1.0	-2%	6%	10%	-2%	6%	10%
Unattributed fluxes							
River unattributed loss	3.2	60%	-15%	-49%	54%	-20%	-50%
Mass balance							
Mass balance error (%)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Appendix C River system model uncertainty assessment by reach

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

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

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

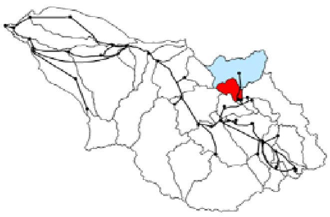
Table	Description
Change-uncertainty ratios	Information on the significance of the projected changes under different scenarios, considering the performance of the river model in explaining observed flow patterns at the end of the reach. In this table, the projected change is compared to the river model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

Downstream gauge	**419020 Manilla @ Brabri**	**Reach 1**
Upstream gauge	**419080 Manilla @ Split Rock Dam storage**	

Reach length (km)	24
Area (km^2)	2038
Outflow/inflow ratio	1.06
Net gaining reach	

Land use	ha	%
Dryland	203,695	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	105	0
Open water*	-	-

* averages for 1990–2006



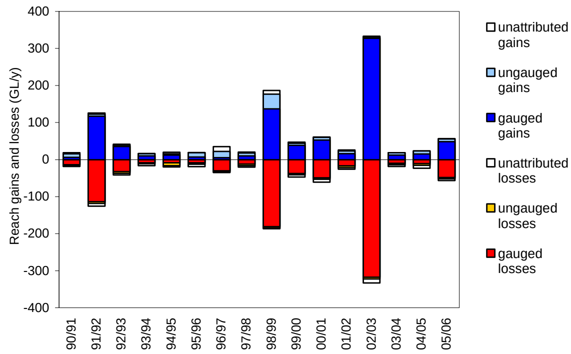
This is a gaining reach. Flows are dominated by inflows from upstream.

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

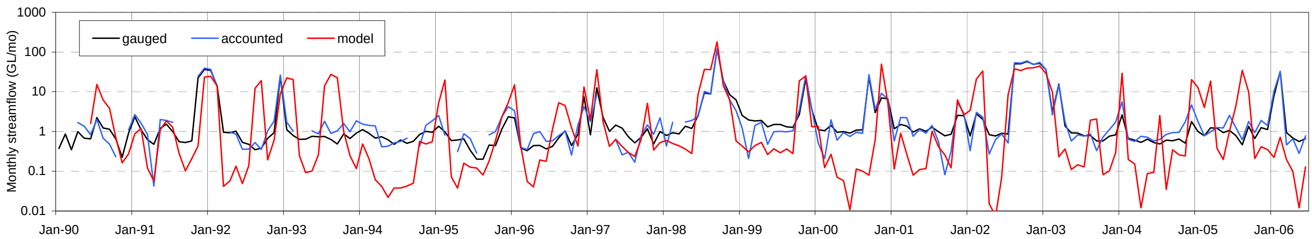
Baseline model performance is rasonable. Accounting explains observed flows extremely well.

The projected changes are greater than model uncertainty for the P, Cwet and Dwet scenarios, and similar to model uncertainty for the Cmid scenario. For the remaining scenarios, changes are similar to model uncertainty for monthly and greater for annual estimates.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.81	0.86	0.83
Attributed	0.95	0.92	0.93
Fraction of variance			
Gauged	0.98	1.00	0.99
Attributed	1.00	1.00	1.00



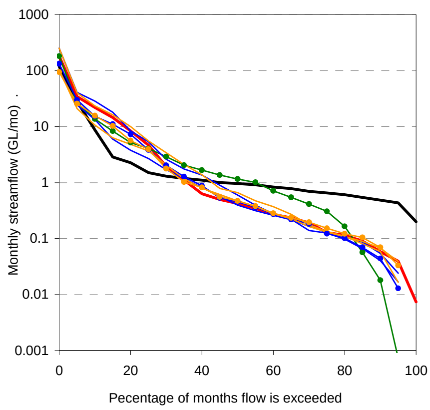
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.33	-0.28	**-0.60**	**-0.54**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.46	**-0.52**	**-0.51**	-0.09	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.91**	**-0.55**	-0.12	-0.39	Adjusted -35.5%



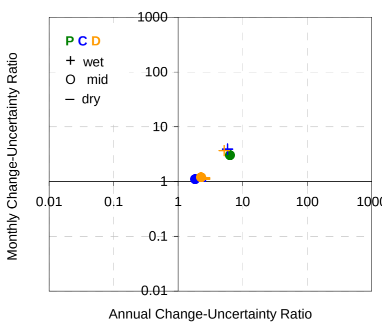
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	61	52	9
Tributary inflows	0	0	0
Local inflows	25	9	16
Unattributed gains and noise	-	3	-3
Losses	GL/y	GL/y	GL/y
Main stem outflows	76	55	22
Distributary outflows	0	0	0
Net diversions	4	3	1
River flux to groundwater	0	-	0
River and floodplain losses	3	1	2
Unspecified losses	2	-	2
Unattributed losses and noise	-	5	-5

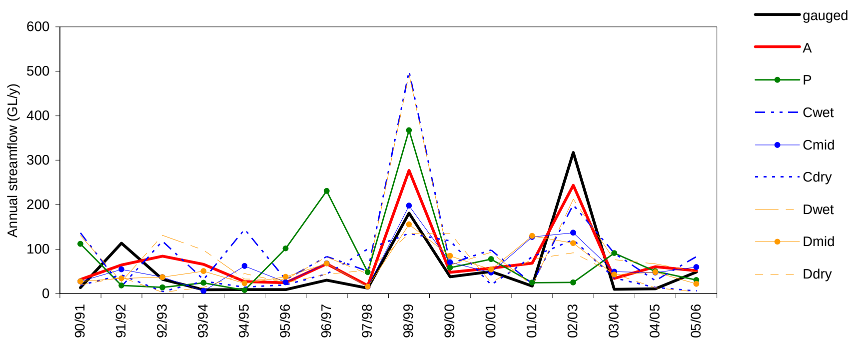
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.38	0.99
Log-normalised	<0	-
Ranked	0.09	0.49
Low flows only	<0	<0
High flows only	0.03	0.99
Annual		
Normal	0.70	1.00
Log-normalised	0.19	0.94
Ranked	0.14	0.78

Definitions:
- low flows (flows<10% percentile) : 0.5 GL/mo
- high flows (flows>90% percentile) : 8.8 GL/mo



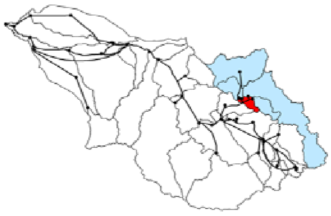
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	6.4		5.8	1.8	2.2	5.2	2.3	2.6
Monthly streamflow	3.0		3.9	1.1	1.0	3.7	1.2	1.1





Downstream gauge	**419022 Namoi @ Manilla**	**Reach 2**
Upstream gauge	**419020 Manilla @ Brabri**	

Reach length (km)	19
Area (km^2)	5105
Outflow/inflow ratio	4.51
Net gaining reach	



Land use	ha	%
Dryland	510,500	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

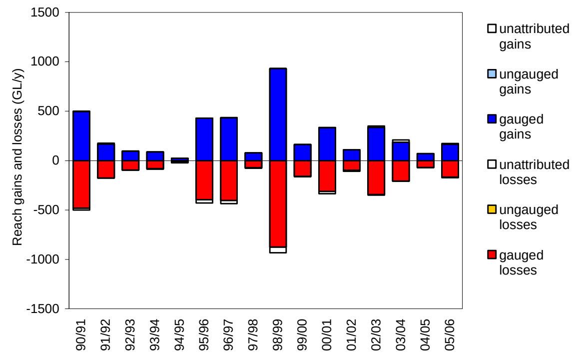
This is a strongly gaining reach. Flows are inflows.

Nearly all of the inflows are gauged. Estimated local runoff does not explain the ungauged gains. There are few recorded diversions and ungauged losses are small.

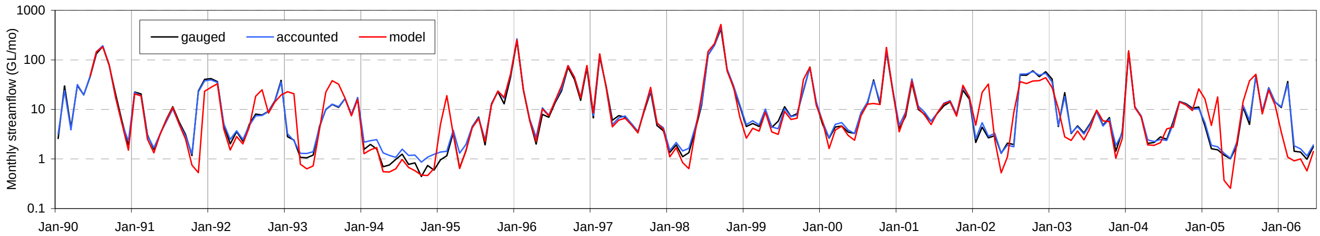
Baseline model performance is very good. Accounting explains observed flows extremely well.

The projected changes are greater than model uncertainty for most scenarios except the Cmid scenario.

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



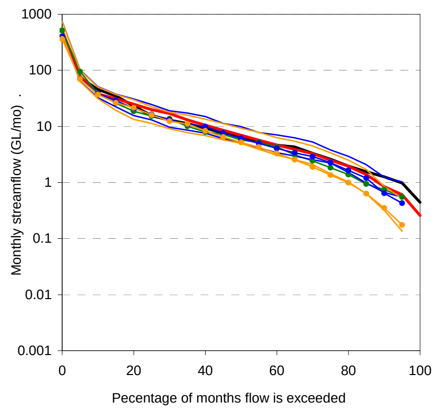
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.18	-0.22	**-0.56**	-0.19	
Tributary inflows	-0.14	-0.12	**-0.81**	-0.31	
Main gauge outflows	-0.23	-0.37	**-0.82**	-0.24	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.17	-0.09	**-0.79**	-0.27	Adjusted -100.0%



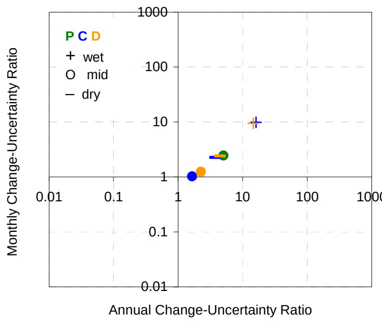
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	276	55	221
Tributary inflows	0	201	-201
Local inflows	9	0	9
Unattributed gains and noise	-	5	-5
Losses	GL/y	GL/y	GL/y
Main stem outflows	263	247	16
Distributary outflows	0	0	0
Net diversions	1	0	1
River flux to groundwater	0	-	0
River and floodplain losses	1	0	0
Unspecified losses	20	-	20
Unattributed losses and noise	-	13	-13
	0.0	0.0	0.0

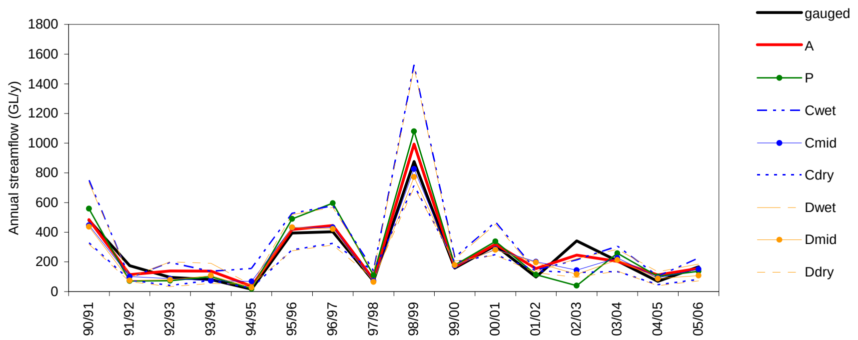
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.94	0.99
Log-normalised	0.73	0.99
Ranked	0.71	0.99
Low flows only	<0	<0
High flows only	0.93	0.98
Annual		
Normal	0.94	0.99
Log-normalised	0.87	0.99
Ranked	0.89	1.00

Definitions:
- low flows (flows<10% percentile) : 1.3 GL/mo
- high flows (flows>90% percentile) : 45.7 GL/mo



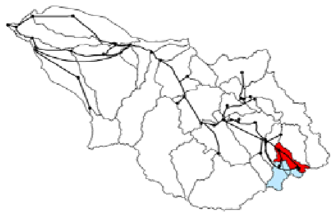
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	5.1		16.2	1.6	3.7	14.7	2.3	4.4
Monthly streamflow	2.5		9.8	1.0	2.3	9.4	1.2	2.4





Downstream gauge	**419015 Peel @ Piallamore**	**Reach 3**
Upstream gauge	**419069 Peel @ Chaffey Dam storage**	

Reach length (km)	35.2
Area (km^2)	1037
Outflow/inflow ratio	1.77
Net gaining reach	



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

Some of the inflows are gauged. Estimated local runoff explains most of the ungauged gains but a moderate adjustment was required. There are some recorded diversions and ungauged losses are small.

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

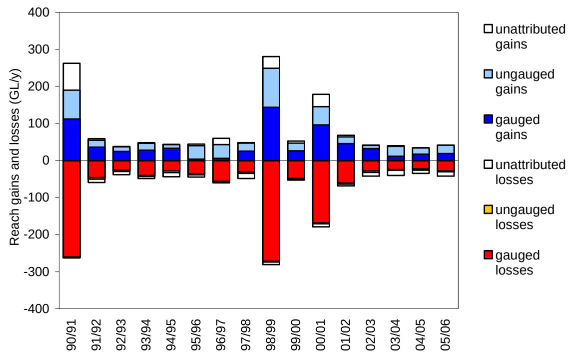
The projected changes are generally greater than the model uncertainty.

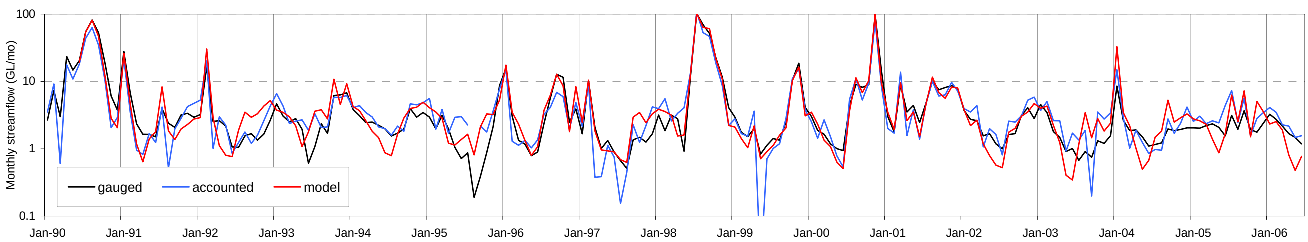
Land use	ha	%
Dryland	103,700	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	- 183	- 0
Open water*	183	0

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.49	0.87	0.68
Attributed	0.86	0.91	0.89
Fraction of variance			
Gauged	0.74	0.99	0.87
Attributed	0.96	0.99	0.98

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.88	-0.03	-0.02	-0.38	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.97	-0.60	-0.14	-0.02	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.91	-0.71	-0.22	-0.49	

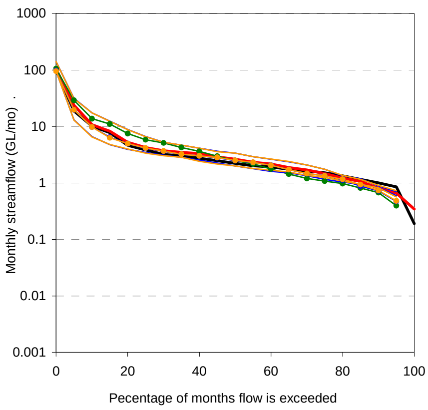




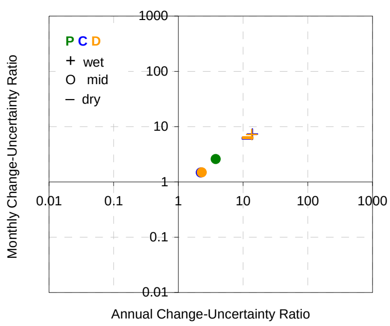
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	67	42	25
Tributary inflows	0	0	0
Local inflows	34	32	2
Unattributed gains and noise	-	12	-12
Losses	GL/y	GL/y	GL/y
Main stem outflows	77	75	2
Distributary outflows	0	0	0
Net diversions	8	2	6
River flux to groundwater	0	-	0
River and floodplain losses	5	1	4
Unspecified losses	12	-	12
Unattributed losses and noise	-	8	-8
	-1	0	-1

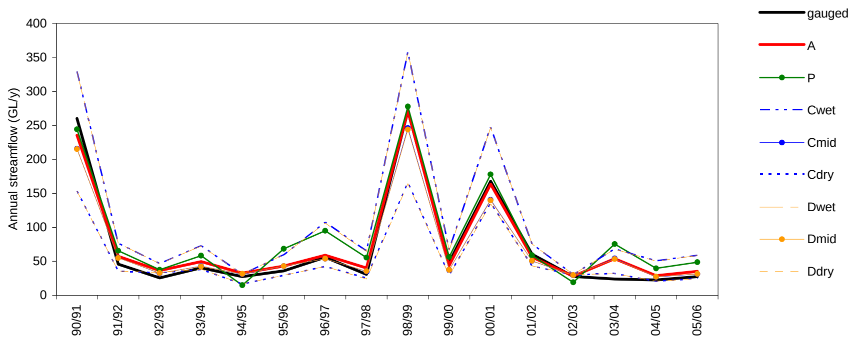
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.97	0.95
Log-normalised	0.75	-
Ranked	0.60	0.62
Low flows only	<0	<0
High flows only	0.98	0.90
Annual		
Normal	0.98	0.93
Log-normalised	0.89	0.90
Ranked	0.65	0.86

Definitions:
- low flows (flows<10% percentile) : 1.0 GL/mo
- high flows (flows>90% percentile) : 10.2 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.8		13.8	2.2	11.6	13.6	2.3	11.8
Monthly streamflow	2.6		7.3	1.5	6.1	7.3	1.5	6.3





Downstream gauge	419024 Peel @ U/S Paradise weir	Reach 4
Upstream gauge	419015 Peel @ Piallamore	

Reach length (km)	17.4
Area (km^2)	2402
Outflow/inflow ratio	1.64
Net gaining reach	

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

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

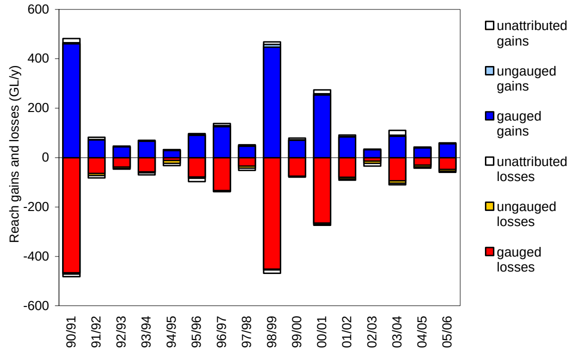
Baseline model performance is excellent. Accounting also explains observed flows extremely well.

The projected changes are greater than model uncertainty for all scenarios and much greater for the wet and dry scenarios.

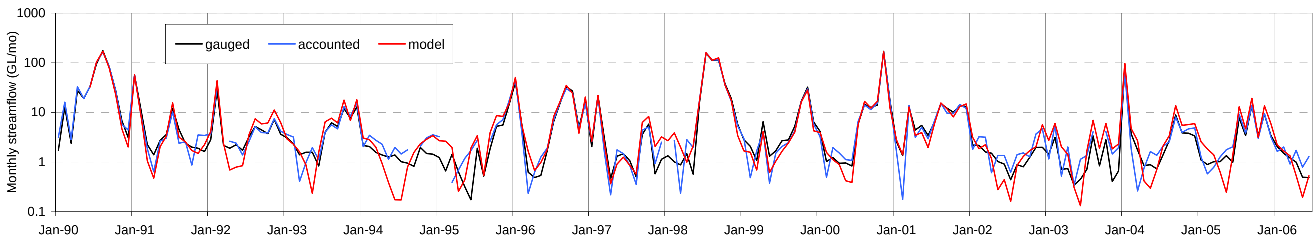
Land use		ha		%
Dryland		240,200		100
Irrigable area		-		-
Open water*		-		-
River and wetlands	-	588	-	0
Open water*		588		0

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.93	0.90	0.91
Attributed	0.95	0.94	0.95
Fraction of variance			
Gauged	1.00	1.00	1.00
Attributed	1.00	1.00	1.00



Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.43	-0.35	-0.14	-0.15	
Tributary inflows	**-0.64**	-0.46	-0.10	-0.36	
Main gauge outflows	**-0.60**	**-0.53**	-0.07	-0.31	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.48	-0.34	-0.05	-0.08	Adjusted -81.2%

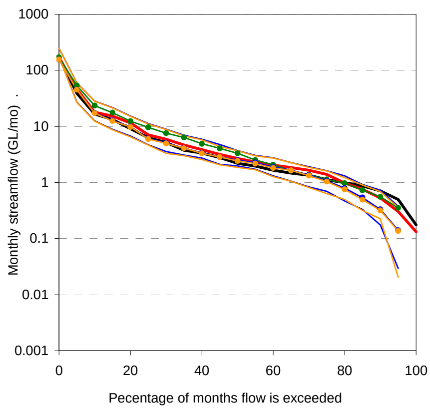


Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	129	75	53
Tributary inflows	0	52	-52
Local inflows	21	3	17
Unattributed gains and noise	-	7	-7
Losses	GL/y	GL/y	GL/y
Main stem outflows	130	124	7
Distributary outflows	0	0	0
Net diversions	4	6	-2
River flux to groundwater	2	-	2
River and floodplain losses	0	0	0
Unspecified losses	13	-	13
Unattributed losses and noise	-	8	-8
	0	0	0

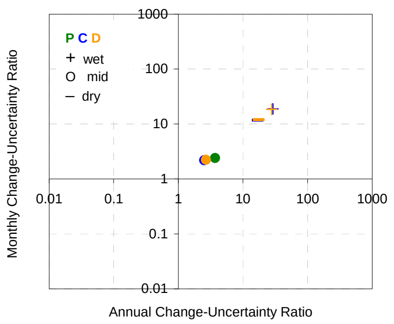
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.99	0.99
Log-normalised	0.79	-
Ranked	0.77	0.80
Low flows only	<0	<0
High flows only	0.98	0.99
Annual		
Normal	0.99	1.00
Log-normalised	0.92	0.97
Ranked	0.93	0.97

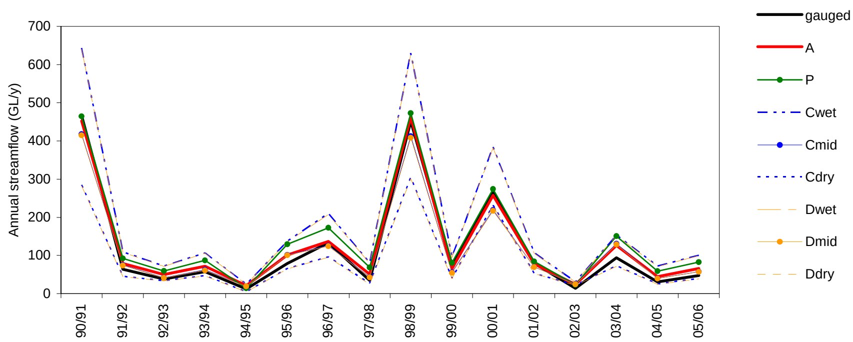
Definitions:

- low flows (flows<10% percentile) : 0.7 GL/mo
- high flows (flows>90% percentile) : 16.7 GL/mo



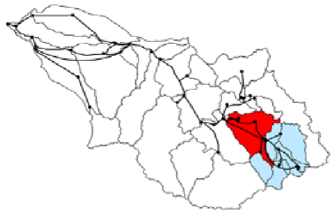
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.7		29.0	2.5	16.9	28.0	2.7	17.6
Monthly streamflow	2.4		18.9	2.2	11.7	18.5	2.2	12.0





Downstream gauge	**419006 Peel @ Carrol Gap**	**Reach 5**
Upstream gauge	**419024 Peel @ U/S Paradise weir**	

Reach length (km)	69.8
Area (km^2)	4619
Outflow/inflow ratio	1.36
Net gaining reach	



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

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

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

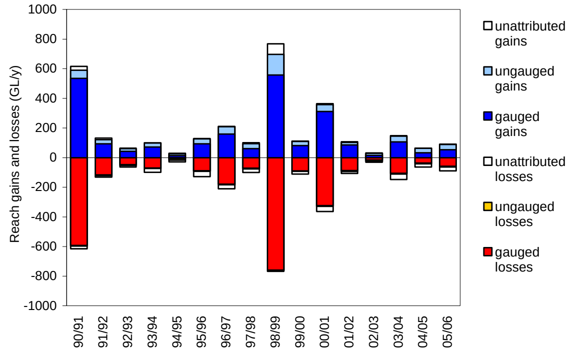
The projected changes are greater than model uncertainty, except for the P, Cmid and Dmid scenarios where projected changes are similar to model uncertainty.

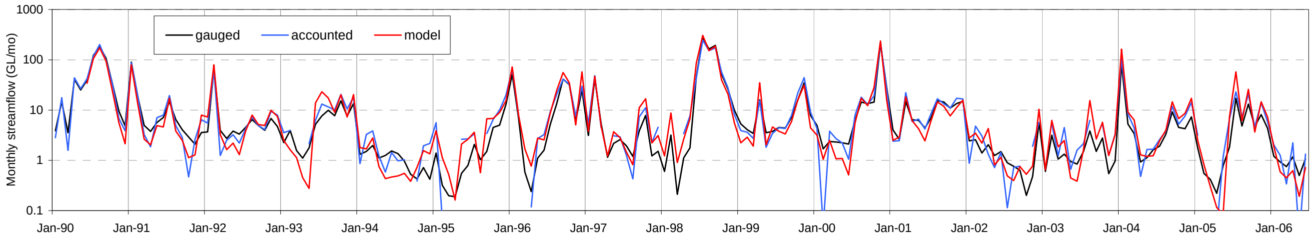
Land use	ha	%
Dryland	461,795	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	- 356	- 0
Open water*	461	0

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.75	0.87	0.81
Attributed	0.95	0.90	0.92
Fraction of variance			
Gauged	0.96	0.99	0.98
Attributed	0.99	0.99	0.99

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.63**	-0.36	-0.36	-0.13	
Tributary inflows	**-0.74**	**-0.54**	-0.14	-0.06	
Main gauge outflows	**-0.78**	**-0.56**	-0.24	-0.09	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.85**	-0.42	-0.06	-0.03	Adjusted -37.7%

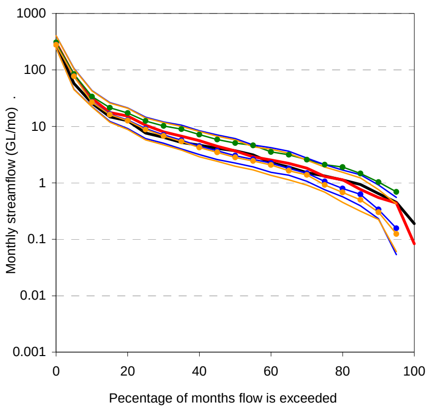




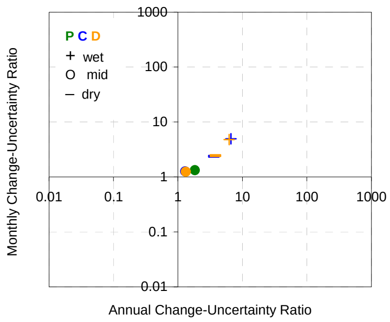
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	154	124	30
Tributary inflows	0	23	-23
Local inflows	84	39	45
Unattributed gains and noise	-	9	-9
Losses	GL/y	GL/y	GL/y
Main stem outflows	189	168	21
Distributary outflows	0	0	0
Net diversions	4	5	0
River flux to groundwater	4	-	4
River and floodplain losses	0	1	-1
Unspecified losses	41	-	41
Unattributed losses and noise	-	20	-20

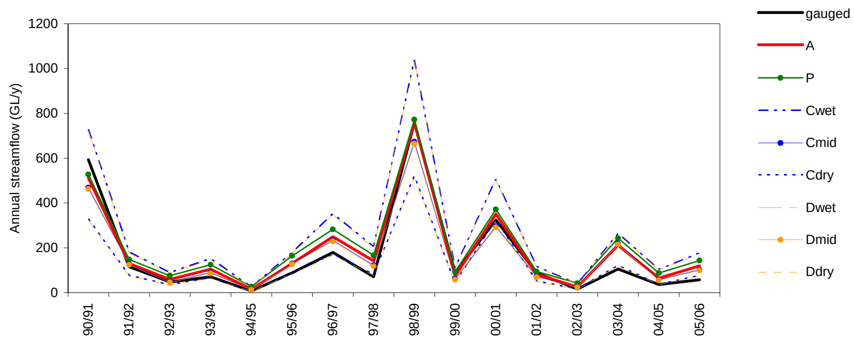
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.93	0.98
Log-normalised	0.80	-
Ranked	0.79	0.84
Low flows only	<0	<0
High flows only	0.88	0.97
Annual		
Normal	0.95	0.99
Log-normalised	0.85	0.94
Ranked	0.80	0.96

Definitions:
- low flows (flows<10% percentile) : 0.6 GL/mo
- high flows (flows>90% percentile) : 25.7 GL/mo



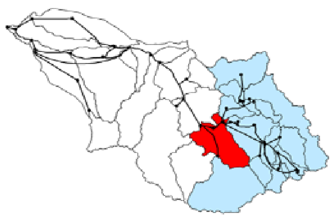
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.8		6.7	1.3	3.6	6.2	1.3	3.8
Monthly streamflow	1.3		4.9	1.3	2.4	4.8	1.2	2.4





Downstream gauge	419001 Namoi @ Gunnedah	Reach 6
Upstream gauge	419041 Namoi @ Keepit dam storage	

Reach length (km)	76
Area (km^2)	17119
Outflow/inflow ratio	2.39
Net gaining reach	



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

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

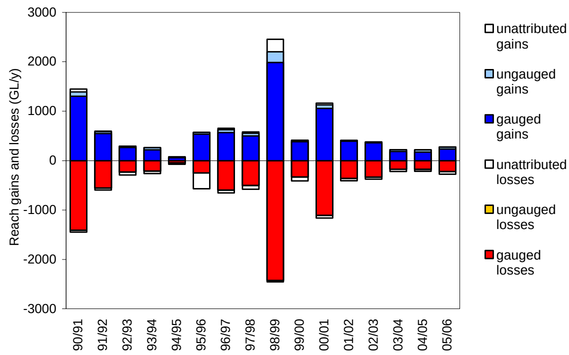
Baseline model performance is good. Accounting explains observed flows extremely well.

The projected changes are generally similar to or less than model uncertainty except for the P, Cwet and Dwet scenarios where they are greater than model uncertainty.

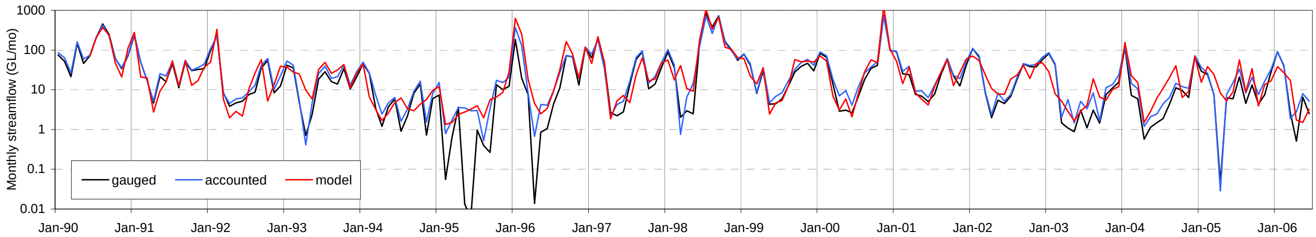
Land use	ha	%
Dryland	1,711,900	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	- 145 -	0
Open water*	145	0

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.88	0.89	0.88
Attributed	0.96	0.90	0.93
Fraction of variance			
Gauged	0.97	0.98	0.97
Attributed	0.99	0.98	0.98



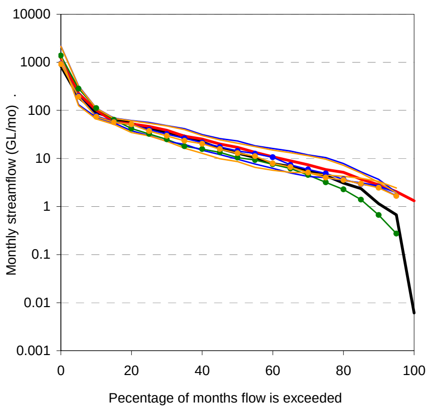
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.13	-0.09	-0.01	-0.42	
Tributary inflows	**-0.77**	**-0.54**	-0.25	-0.08	
Main gauge outflows	**-0.81**	**-0.53**	-0.05	-0.16	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.83**	**-0.54**	-0.05	-0.18	



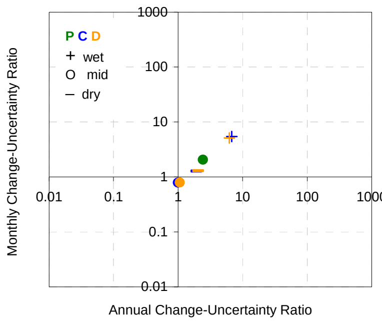
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	574	237	337
Tributary inflows	0	320	-320
Local inflows	350	52	297
Unattributed gains and noise	-	26	-26
Losses	GL/y	GL/y	GL/y
Main stem outflows	657	566	92
Distributary outflows	0	0	0
Net diversions	2	3	-1
River flux to groundwater	3	-	3
River and floodplain losses	0	3	-3
Unspecified losses	258	-	258
Unattributed losses and noise	-	62	-62

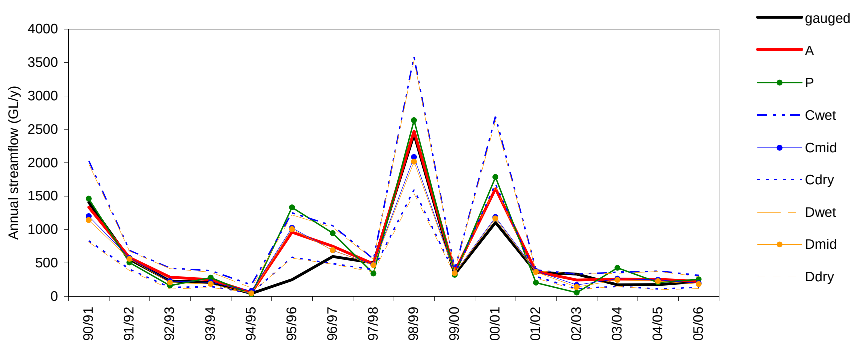
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.73	0.96
Log-normalised	0.60	-
Ranked	0.71	0.96
Low flows only	<0	<0
High flows only	0.56	0.94
Annual		
Normal	0.85	0.97
Log-normalised	0.81	0.92
Ranked	0.68	0.92

Definitions:
- low flows (flows<10% percentile) : 1.1 GL/mo
- high flows (flows>90% percentile) : 91.1 GL/mo



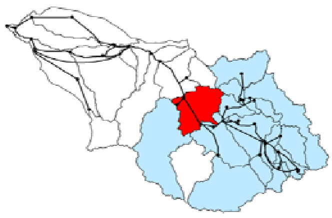
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	2.4		6.8	1.0	1.9	6.2	1.1	2.0
Monthly streamflow	2.1		5.4	0.8	1.3	5.1	0.8	1.3





Downstream gauge	419012 Namoi @ Boggabri	Reach 7
Upstream gauge	419001 Namoi @ Gunnedah	

Reach length (km)	51.5
Area (km^2)	22739
Outflow/inflow ratio	1.15
Net gaining reach	



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

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

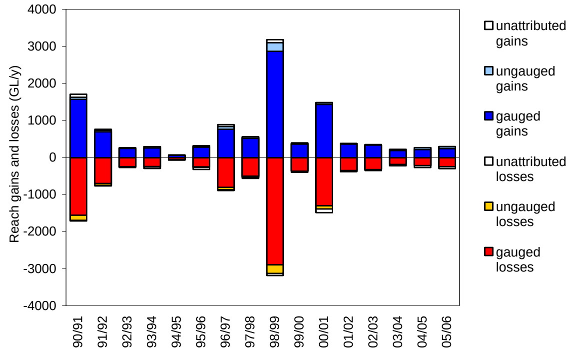
Baseline model performance is good. Accounting explains observed flows extremely well.

The projected changes are generally similar to model uncertainty, except for the Cwet and Dwet scenarios where projected changes are greater than model uncertainty.

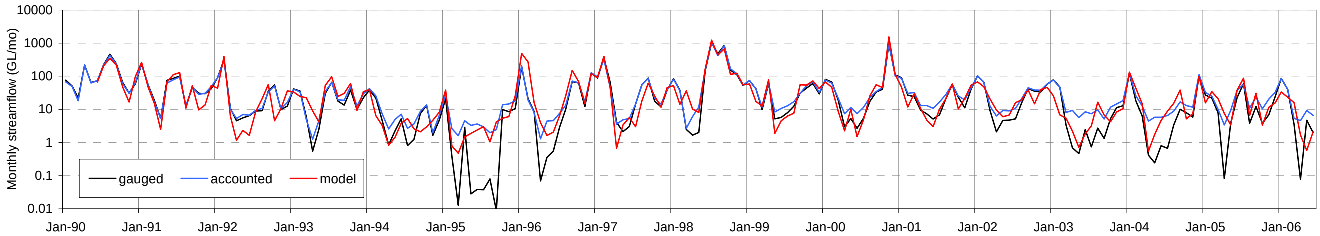
Land use	ha	%
Dryland	2,273,375	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	306	0
Open water*	219	0

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.91	0.89	0.90
Attributed	0.97	0.94	0.96
Fraction of variance			
Gauged	0.99	0.99	0.99
Attributed	1.00	1.00	1.00



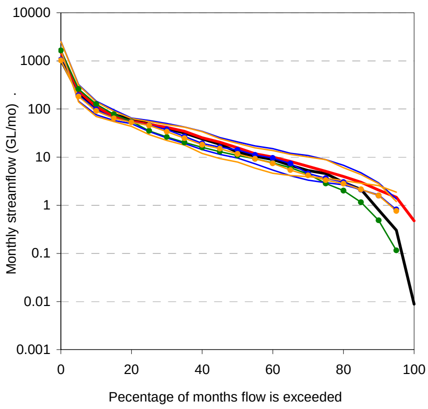
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.43	-0.20	-0.69	-0.42	
Tributary inflows	-0.30	-0.32	-0.83	-0.13	
Main gauge outflows	-0.48	-0.29	-0.69	-0.35	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.71	-0.25	-0.29	-0.10	Adjusted 94.0%



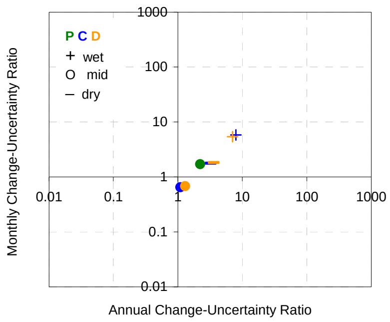
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	748	566	182
Tributary inflows	0	97	-97
Local inflows	93	48	45
Unattributed gains and noise	-	19	-19
Losses	GL/y	GL/y	GL/y
Main stem outflows	716	651	65
Distributary outflows	0	0	0
Net diversions	4	2	2
River flux to groundwater	8	-	8
River and floodplain losses	0	33	-33
Unspecified losses	113	-	113
Unattributed losses and noise	-	44	-44

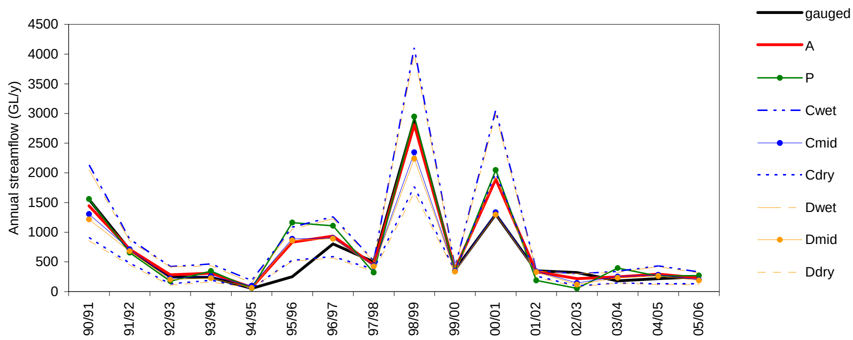
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.80	1.00
Log-normalised	0.64	0.68
Ranked	0.74	0.96
Low flows only	<0	<0
High flows only	0.61	0.99
Annual		
Normal	0.91	1.00
Log-normalised	0.85	0.97
Ranked	0.72	0.95

Definitions:
- low flows (flows<10% percentile) : 0.8 GL/mo
- high flows (flows>90% percentile) : 99.8 GL/mo



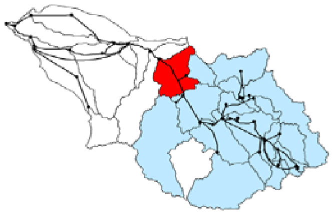
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	2.2		8.0	1.1	3.2	7.0	1.3	3.6
Monthly streamflow	1.7		5.8	0.6	1.8	5.4	0.7	1.8





Downstream gauge	419003 Namoi @ Narrabri	Reach 8
Upstream gauge	419012 Namoi @ Boggabri	

Reach length (km)	60.8
Area (km^2)	25051
Outflow/inflow ratio	0.98
Net losing reach	



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

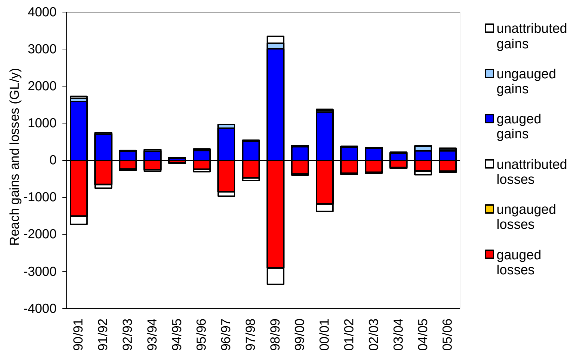
Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains but a moderate adjustment was required. There are recorded diversions and ungauged losses are small.

Modelling was not reported for this reach. Accounting explains observed flows very well.

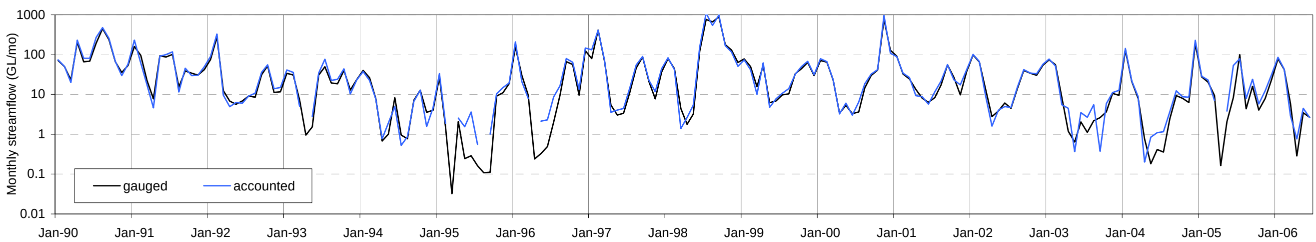
Land use	ha	%
Dryland	2,505,100	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.90	0.86	0.88
Attributed	0.97	0.87	0.92
Fraction of variance			
Gauged	0.99	0.96	0.97
Attributed	1.00	0.96	0.98



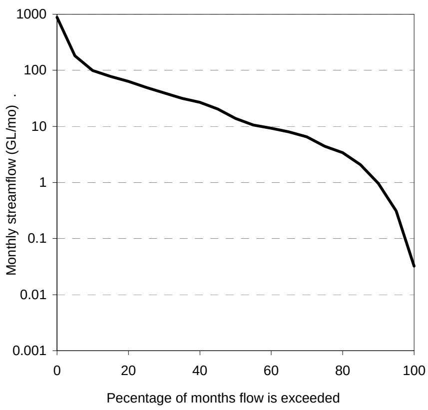
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.24	-0.09	**-0.80**	**-0.52**	
Tributary inflows	-0.39	-0.19	-0.36	-0.20	
Main gauge outflows	-0.39	-0.19	**-0.67**	-0.44	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.41	-0.15	-0.34	-0.16	Adjusted 29.3%



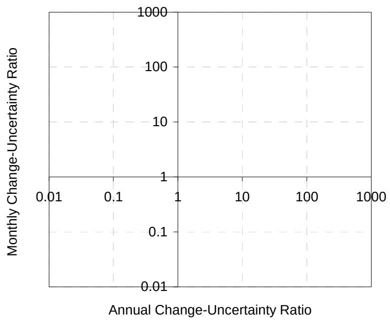
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	651	-651
Tributary inflows	0	20	-20
Local inflows	0	51	-51
Unattributed gains and noise	-	22	-22
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	640	-640
Distributary outflows	0	0	0
Net diversions	0	4	-4
River flux to groundwater	0	-	0
River and floodplain losses	0	5	-5
Unspecified losses	0	-	0
Unattributed losses and noise	-	95	-95

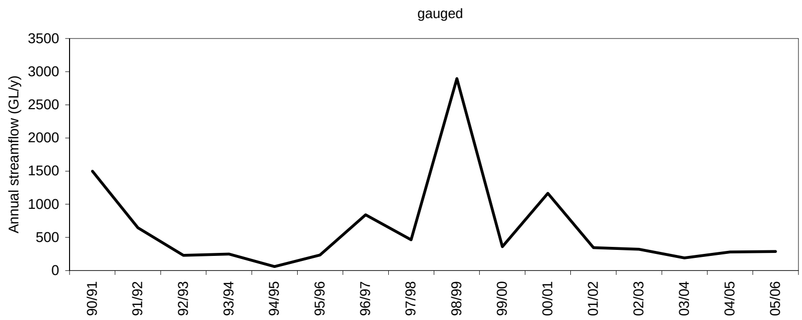
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.93
Log-normalised	-	-
Ranked	<0	0.96
Low flows only	<0	<0
High flows only	<0	0.93
Annual		
Normal	<0	0.98
Log-normalised	-	-
Ranked	<0	0.96

Definitions:
- low flows (flows<10% percentile) : 1.0 GL/mo
- high flows (flows>90% percentile) : 99.3 GL/mo



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



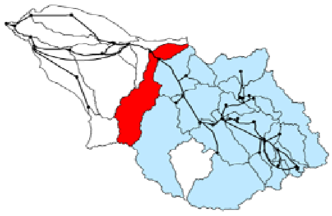


Downstream gauge	**419039 Namoi @ Mollee**	**Reach 9**
Upstream gauge	**419003 Namoi @ Narrabri**	

Reach length (km)	8.3
Area (km^2)	27725
Outflow/inflow ratio	1.07
Net gaining reach	

Land use	ha	%
Dryland	2,772,185	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	315	0
Open water*	-	-

* averages for 1990–2006



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

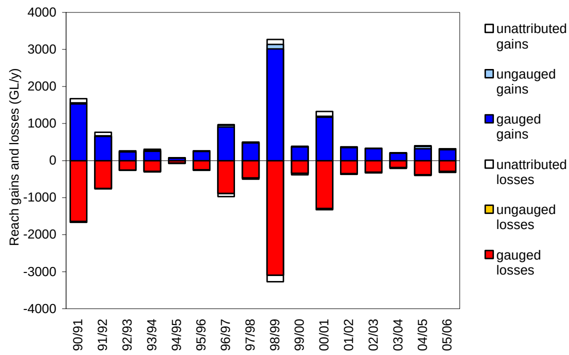
Most of the inflows are gauged. Estimated local runoff explains some of the ungauged gains but a moderate adjustment was required. There are recorded diversions and ungauged losses are small.

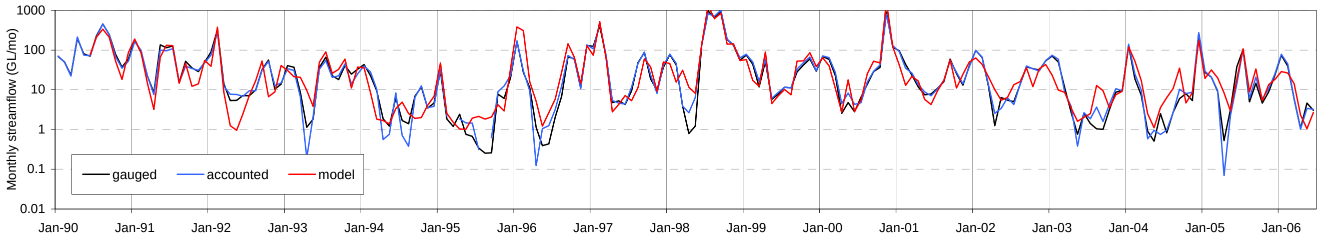
Baseline model performance is good. Accounting explains observed flows extremely well.

The projected changes are generally similar to model uncertainty, except for the Cwet and Dwet scenarios where projected changes are greater than model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.91	0.95	0.93
Attributed	0.95	0.96	0.95
Fraction of variance			
Gauged	0.99	1.00	0.99
Attributed	0.99	1.00	0.99

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.60**	-0.20	**-0.53**	-0.36	
Tributary inflows	-0.31	-0.25	**-0.57**	-0.14	
Main gauge outflows	**-0.68**	-0.29	-0.46	-0.28	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.47	-0.22	-0.33	-0.18	Adjusted -8.1%

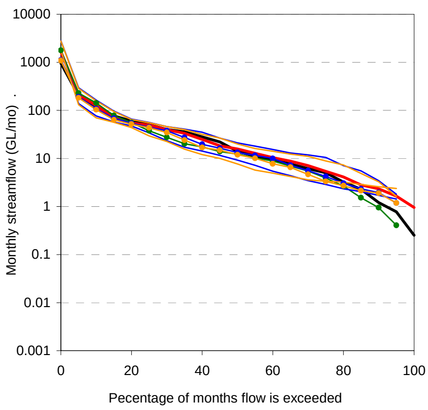




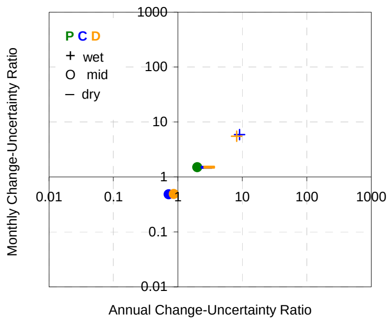
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	735	640	95
Tributary inflows	0	20	-20
Local inflows	113	28	85
Unattributed gains and noise	-	38	-38
Losses	GL/y	GL/y	GL/y
Main stem outflows	753	687	66
Distributary outflows	0	0	0
Net diversions	10	3	7
River flux to groundwater	8	-	8
River and floodplain losses	1	2	-2
Unspecified losses	77	-	77
Unattributed losses and noise	-	32	-32

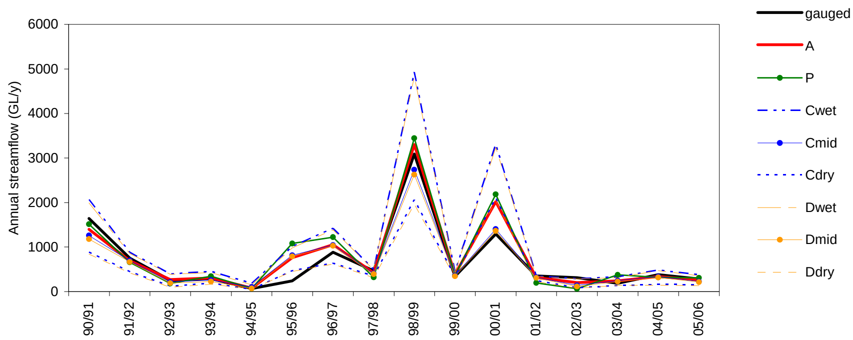
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.73	0.98
Log-normalised	0.74	-
Ranked	0.74	0.97
Low flows only	<0	<0
High flows only	0.51	0.97
Annual		
Normal	0.89	1.00
Log-normalised	0.85	0.99
Ranked	0.64	0.97

Definitions:
- low flows (flows<10% percentile) : 1.2 GL/mo
- high flows (flows>90% percentile) : 122.7 GL/mo



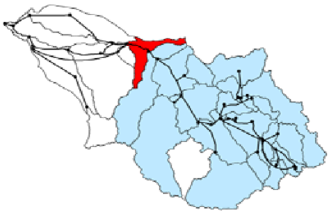
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	2.0		9.1	0.7	2.8	8.2	0.9	3.1
Monthly streamflow	1.5		5.9	0.5	1.5	5.5	0.5	1.5





Downstream gauge	419059 Namoi @ D/S of Gunidgera	Reach 10
Upstream gauge	419039 Namoi @ Mollee	

Reach length (km)	55.8
Area (km^2)	28656
Outflow/inflow ratio	0.58
Net losing reach	



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

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains. There are large recorded diversions and ungauged losses are small, except in one year of very high flows and another of moderate flows (when large flows overflowed down Pian Creek).

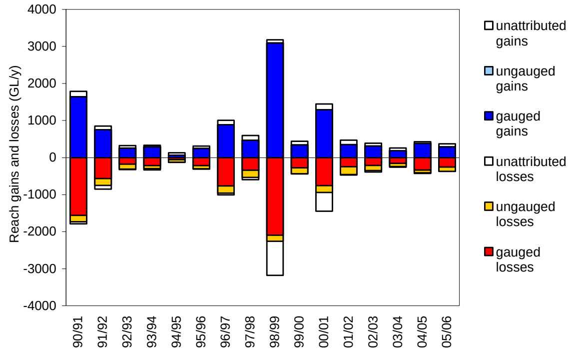
Baseline model performance is very good. Accounting also explains observed flows very well.

The projected changes are much greater than model uncertainty for all scenarios.

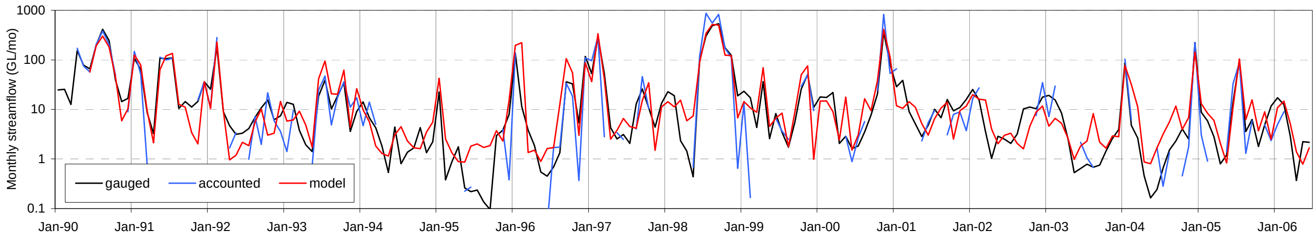
Land use	ha	%
Dryland	2,864,970	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	630	0
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.88	0.67	0.78
Attributed	0.88	0.86	0.87
Fraction of variance			
Gauged	0.99	0.82	0.91
Attributed	0.99	0.82	0.91



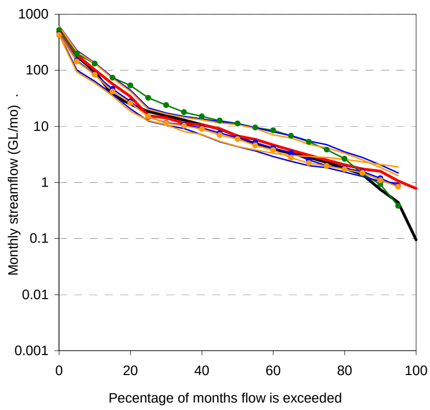
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.21	-0.14	**-0.85**	**-0.63**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.39	-0.23	**-0.58**	**-0.51**	
Distributary outflows	-0.17	-0.06	**-0.72**	**-0.66**	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.06	-0.23	-0.27	-0.03	Adjusted -100.0%



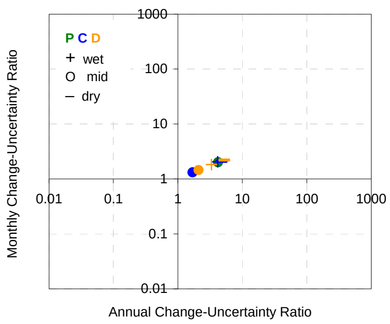
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	753	687	66
Tributary inflows	0	0	0
Local inflows	93	0	93
Unattributed gains and noise	-	94	-94
Losses	GL/y	GL/y	GL/y
Main stem outflows	415	399	16
Distributary outflows	315	126	189
Net diversions	62	131	-69
River flux to groundwater	1	-	1
River and floodplain losses	0	12	-12
Unspecified losses	53	-	53
Unattributed losses and noise	-	112	-112

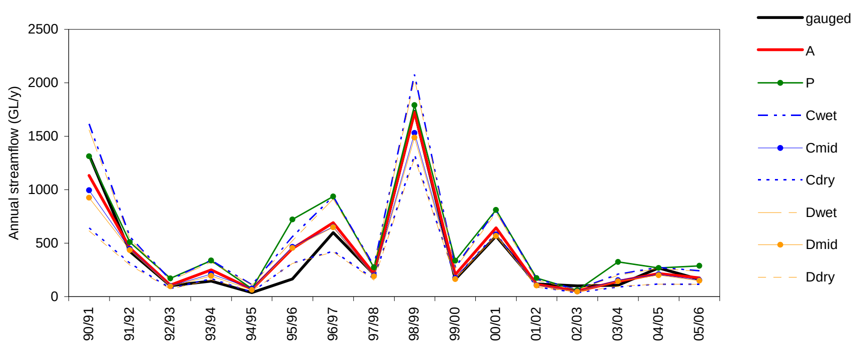
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.91	0.43
Log-normalised	0.70	-
Ranked	0.59	0.41
Low flows only	<0	<0
High flows only	0.88	<0
Annual		
Normal	0.96	0.75
Log-normalised	0.85	-
Ranked	0.89	0.91

Definitions:
- low flows (flows<10% percentile) : 0.8 GL/mo
- high flows (flows>90% percentile) : 95.0 GL/mo



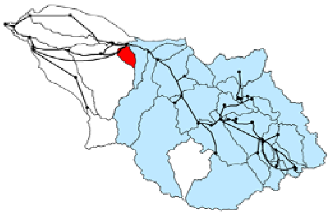
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.2		4.2	1.7	4.8	3.3	2.1	5.2
Monthly streamflow	2.0		2.1	1.3	2.1	1.8	1.4	2.2





Downstream gauge	**419068 Namoi @ D/S of Weeta weir**	**Reach 11**
Upstream gauge	**419059 Namoi @ D/S of Gunidgera**	

Reach length (km)	16.4
Area (km^2)	28951
Outflow/inflow ratio	0.95
Net losing reach	



Land use	ha	%
Dryland	2,894,575	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	525	0
Open water*	-	-

* averages for 1990–2006

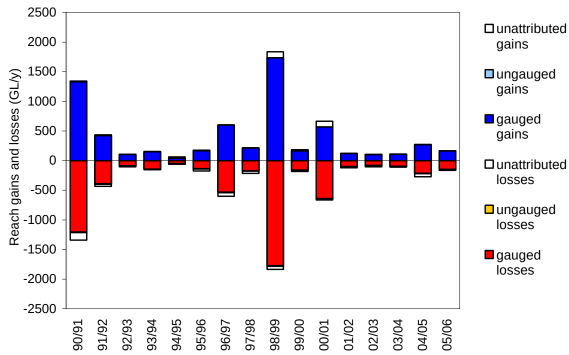
This is a slightly losing reach. Flows are dominated by inflows from upstream.

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

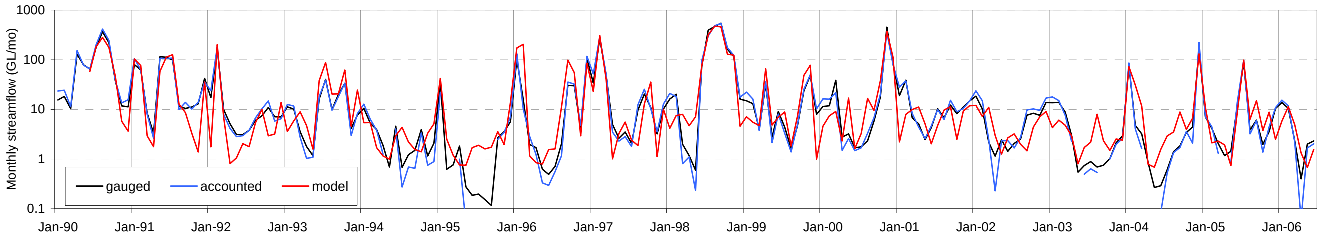
Baseline model performance is very good. Accounting explains observed flows extremely well.

The projected changes are greater than model uncertainty for the P, Cdry and Ddry scenarios, and for annual estimates of all scenarios except the Cmid scenario; otherwise, the projected changes are similar to model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.95	0.90	0.93
Attributed	0.95	0.92	0.94
Fraction of variance			
Gauged	0.99	0.99	0.99
Attributed	0.99	0.99	0.99



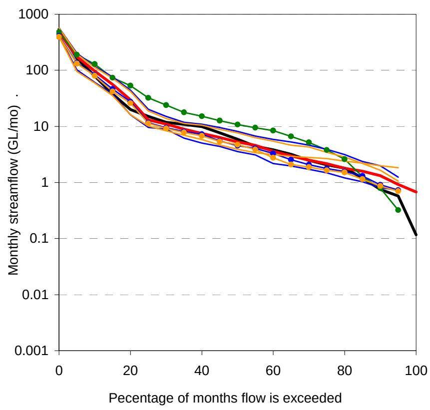
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.41	-0.00	**-0.61**	**-0.67**	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.53**	-0.09	**-0.51**	**-0.61**	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.19	-0.26	-0.48	-0.18	Adjusted -100.0%



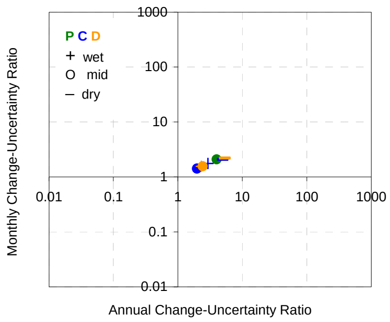
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	415	399	16
Tributary inflows	0	0	0
Local inflows	7	0	7
Unattributed gains and noise	-	19	-19
Losses	GL/y	GL/y	GL/y
Main stem outflows	379	378	2
Distributary outflows	0	0	0
Net diversions	16	3	13
River flux to groundwater	0	-	0
River and floodplain losses	0	5	-5
Unspecified losses	28	-	28
Unattributed losses and noise	-	33	-33
			0

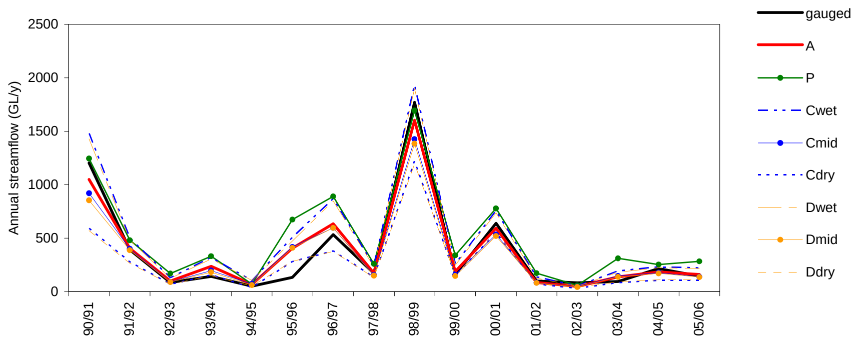
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.92	0.98
Log-normalised	0.67	-
Ranked	0.51	0.98
Low flows only	<0	<0
High flows only	0.91	0.93
Annual		
Normal	0.96	0.99
Log-normalised	0.86	0.97
Ranked	0.77	0.95

Definitions:
- low flows (flows<10% percentile) : 0.8 GL/mo
- high flows (flows>90% percentile) : 79.7 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.0		2.9	2.0	5.0	2.3	2.4	5.3
Monthly streamflow	2.1		1.8	1.4	2.1	1.6	1.6	2.2



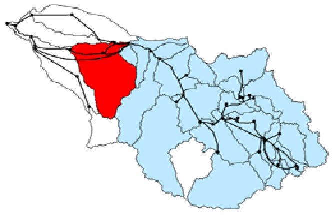


Downstream gauge	419021 Namoi @ Bugilbone	Reach 12
Upstream gauge	419068 Namoi @ D/S of Weeta weir	

Reach length (km)	61.1	
Area (km^2)	32534	
Outflow/inflow ratio	1.30	
Net gaining reach		

Land use	ha	%
Dryland	3,238,385	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	15,015	0
Open water*	-	-

* averages for 1990–2006



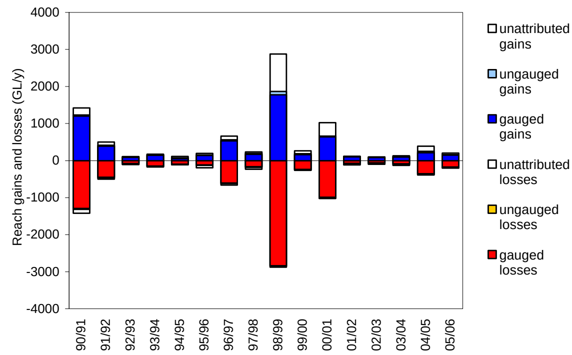
This is a losing reach. Flows are dominated by inflows from upstream.

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

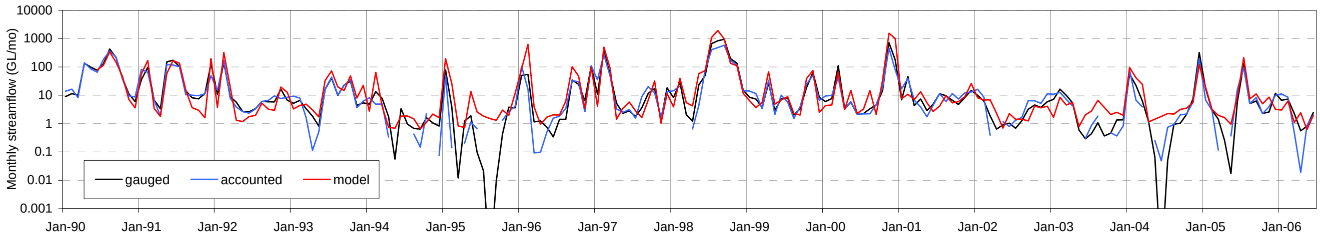
Baseline model performance is poor. Accounting explains observed flows well.

The projected changes are similar to or less than model uncertainty, except for the Cwet and Dwet scenarios where they are greater than model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.70	0.91	0.81
Attributed	0.75	0.95	0.85
Fraction of variance			
Gauged	0.84	1.00	0.92
Attributed	0.86	1.00	0.93



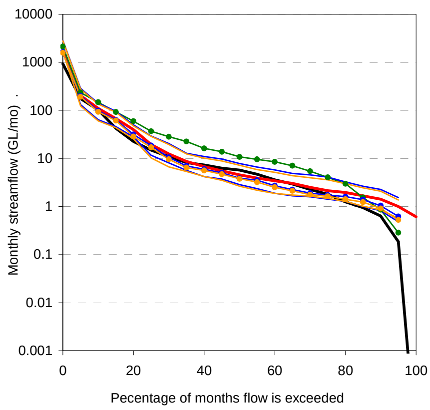
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.87	-0.41	-0.13	-0.26	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.95	-0.61	-0.01	-0.01	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.80	-0.58	-0.05	-0.22	



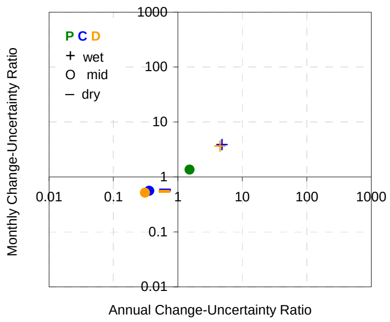
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	379	378	2
Tributary inflows	0	0	0
Local inflows	564	25	539
Unattributed gains and noise	-	135	-135
Losses	GL/y	GL/y	GL/y
Main stem outflows	763	491	271
Distributary outflows	48	0	48
Net diversions	43	0	43
River flux to groundwater	0	-	0
River and floodplain losses	0	19	-19
Unspecified losses	90	-	90
Unattributed losses and noise	-	27	-27

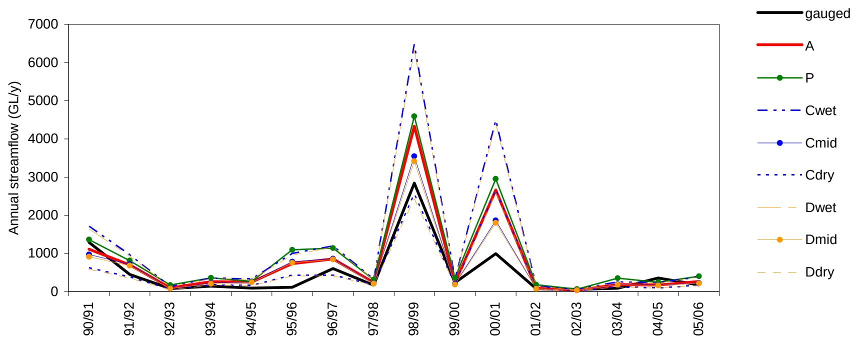
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.85
Log-normalised	0.52	-
Ranked	0.67	0.89
Low flows only	<0	<0
High flows only	<0	0.68
Annual		
Normal	0.28	0.85
Log-normalised	0.60	0.94
Ranked	0.65	0.92

Definitions:
- low flows (flows<10% percentile) : 0.6 GL/mo
- high flows (flows>90% percentile) : 102.4 GL/mo



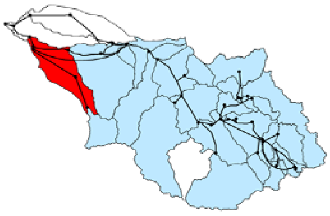
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.5		4.8	0.4	0.6	4.5	0.3	0.6
Monthly streamflow	1.4		3.9	0.6	0.6	3.7	0.5	0.5





Downstream gauge	419026 Namoi @ Goangra	Reach 13
Upstream gauge	419021 Namoi @ Bugilbone	

Reach length (km)	85.1
Area (km^2)	35786
Outflow/inflow ratio	1.04
Net gaining reach	



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

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

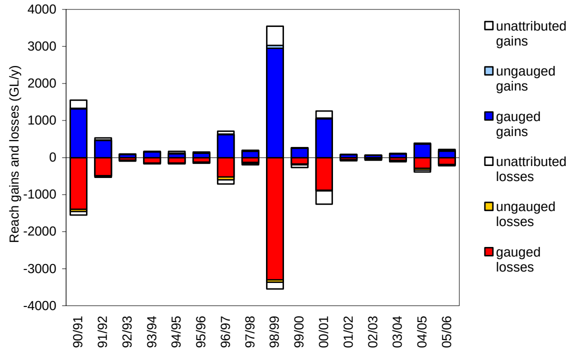
Baseline model performance is poor to moderate. Accounting explains observed flows very well.

The projected changes are similar to or less than model uncertainty, except for the Cwet and Dwet scenarios where they are greater than model uncertainty.

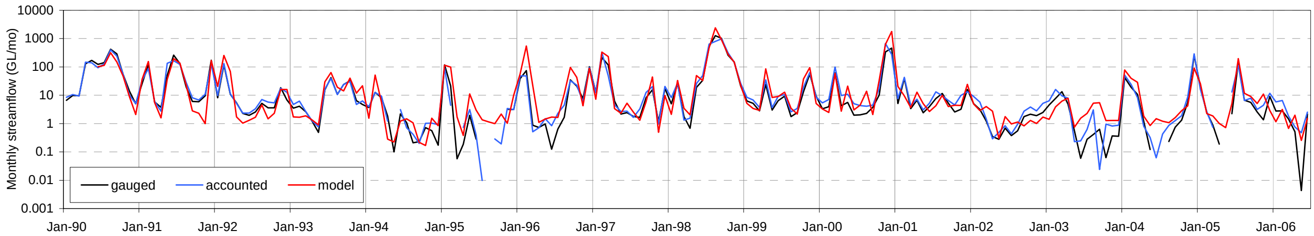
Land use	ha	%
Dryland	3,554,345	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	24,255	1
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.84	0.85	0.84
Attributed	0.87	0.89	0.88
Fraction of variance			
Gauged	0.94	0.94	0.94
Attributed	0.94	0.97	0.95



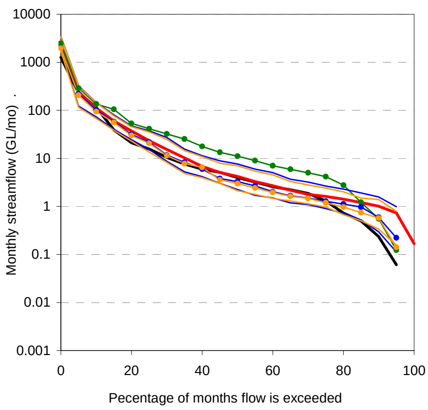
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.53**	-0.45	**-0.56**	-0.33	
Tributary inflows	-0.28	-0.35	**-0.75**	-0.23	
Main gauge outflows	**-0.76**	**-0.53**	-0.27	-0.20	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.30	-0.26	-0.47	-0.22	



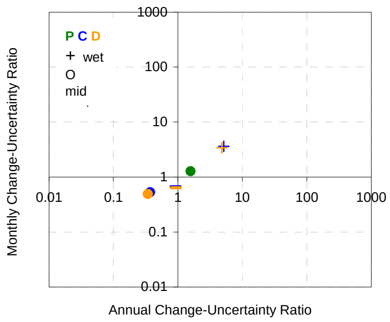
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	777	491	286
Tributary inflows	0	16	-16
Local inflows	55	21	34
Unattributed gains and noise	-	76	-76
Losses	GL/y	GL/y	GL/y
Main stem outflows	729	513	216
Distributary outflows	0	0	0
Net diversions	11	0	11
River flux to groundwater	0	-	0
River and floodplain losses	3	26	-24
Unspecified losses	90	-	90
Unattributed losses and noise	-	65	-65

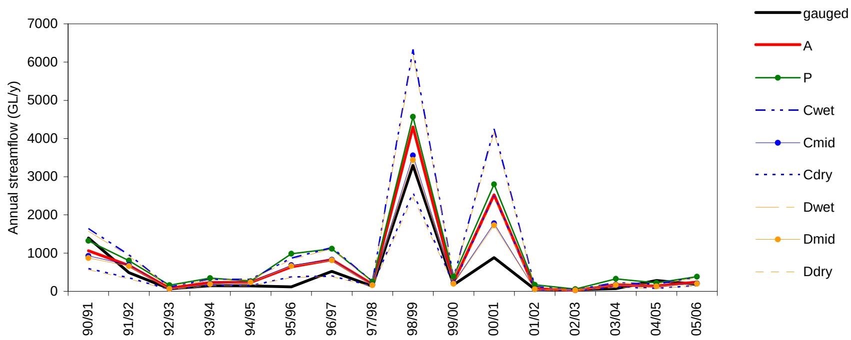
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.05	0.88
Log-normalised	-	-
Ranked	0.71	0.94
Low flows only	<0	<0
High flows only	<0	0.78
Annual		
Normal	0.59	0.98
Log-normalised	0.71	0.97
Ranked	0.73	0.94

Definitions:
- low flows (flows<10% percentile) : 0.2 GL/mo
- high flows (flows>90% percentile) : 116.0 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.6		5.1	0.4	0.9	4.8	0.3	0.9
Monthly streamflow	1.3		3.6	0.5	0.7	3.4	0.5	0.6





Contact Us

Phone: 1300 363 400
+61 3 9545 2176

Email: enquiries@csiro.au

Web: www.csiro.au

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Enquiries

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