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Water Availability in the Gwydir

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

December 2007

Murray-Darling Basin Sustainable Yields Project acknowledgments

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

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Photo on cover: Gwydir River near Bingara, courtesy of the Australian Department of Environment and Water Resources

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 Gwydir 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 Gwydir region is in north-eastern New South Wales and represents 2 percent of the total area of the MDB. The region is based around the Gwydir River. The population is approximately 26,500 or 1.4 percent of the MDB total. The largest town is Moree. The dominant land use is dryland pasture used for beef and sheep grazing. Lucerne and pasture are grown on the narrow alluvial floodplains of the upper Gwydir River and dryland crops are grown on the western plains. Approximately 85,000 ha of irrigated cotton were grown in 2000 on the western plains. The Gwydir Wetlands on the floodplain of the lower Gwydir River are of regional, national and international importance. There are four Ramsar-listed sites in the region: one on the Lower Gwydir Watercourse and three in the Gingham Watercourse. The region uses 3.5 percent of the surface water diverted and 2.8 percent of the groundwater used in the MDB. The Gwydir River is regulated by a large storage and affected by major water extractions. There are also many farm dams and ring tanks in the region. On average nearly 90 percent of the water for irrigation is diverted from the river.

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 mean annual rainfall and modelled runoff averaged over the Gwydir region are 644 mm and 41 mm respectively. Rainfall is generally higher in the summer half of the year and runoff is relatively uniform throughout the year. The region generates about 3.4 percent of the total runoff in the MDB.

Current average surface water availability is 782 GL/year. The current level of surface water use in the Gwydir is very high – 41 percent of the average available water is diverted for use. Around 54 percent of the water allocated as general security water is used.

Current groundwater use represents 12 percent of total water use in the region on average and 55 percent in years of minimum surface water diversions. Groundwater use in the region was 46.2 GL in 2004/05. This level of use is 12 percent of total water use in the region on average and 55 percent in years of minimum surface water diversions. About 77 percent of this came from the Lower Gwydir Alluvium Groundwater Management Unit (GMU). Extraction from the Lower Gwydir Alluvium GMU currently exceeds the long-term average extraction limit (LTAEL) due to usage under supplementary licences for which the entitlements will decrease to zero by 2015.

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 Lower Gwydir groundwater source.

Groundwater extraction in the Lower Gwydir area (33 GL/year) represents 63 percent of total groundwater recharge (including lateral inflow) and 74 percent of recharge excluding lateral inflow. This is a moderate to high level of development. Extraction from the Lower Gwydir Alluvium GMU (assuming the current spatial pattern of pumping bores) can be sustained and would avoid reversals of gradients that might otherwise lead to groundwater salinisation. There is no net impact on streamflow due to current groundwater extraction reaching dynamic equilibrium as a 4.4 GL/year gain in part of the region is offset by a 4.4 GL/year loss in another part of the region

Groundwater is more saline in the west of the Lower Gwydir Alluvium GMU and in the Great Artesian Basin (GAB) Alluvium GMU so irrigation relies on surface water in these areas. Neither extraction nor irrigation recharge will have large impact on future streamflow in the Gwydir River. The time lag between extraction and stabilisation of surface–groundwater fluxes appears to be very short.

There has been a large (more than 75 percent) increase in the average period between flood events that inundate 20,000 ha (or about 20 percent) of the Gwydir Wetlands because of water resource development. There has also been a large (64 percent) increase in the maximum period between events which has risen from 7 to 11.5 years. The average annual flooding volume has also been reduced (by 42 percent). However on average, individual flood events are now 8 percent larger in terms of flooding volume because of the reduction in flood frequency. These changes are consistent with the stressed ecological condition of the wetlands.

Recent climate and current development (Scenario B)

The average annual rainfall and runoff over the past 10 years (1997 to 2006) are 7 percent and 18 percent higher respectively than the long-term (1895 to 2006) average values. However because of the inter-annual variability and the relatively short 10-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 is 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 Gwydir region is more likely to decrease than increase. The best estimate 2030 climate scenario indicates a 9 percent reduction in mean annual runoff. The extreme estimates from the high global warming scenario range from a 28 percent reduction to a 31 percent increase in mean annual runoff. The extreme estimates from the low global warming scenario range from a 9 percent reduction to an 8 percent increase in mean annual runoff.

Under the best estimate 2030 climate there would be a 10 percent reduction in average surface water availability and a 6 percent reduction in end-of-system outflows. Diversions would be reduced by 8 percent overall but effects vary between water products. General security irrigation use would drop by 9 percent and high security irrigation use would increase by 3 percent. Surplus water access would be reduced by 7 percent and high security town water supplies would be unaffected. The possible extreme climates for 2030 indicate that under the wet extreme climate, average surface water availability would increase by 34 percent, total diversions by 20 percent and end-of-system flows by 33 percent. Under the dry extreme climate, average surface water availability would decrease by 29 percent, total diversions by 25 percent and end-of-system flows by 27 percent.

The best estimate 2030 climate would have relatively small effects on surface–groundwater exchanges assuming use at the LTAEL. Loss to groundwater would decrease by 0.2 GL/year but this would be more than offset by a 0.3 GL/year reduction in the inflow to the river from groundwater.

Under the best estimate 2030 climate the average and the maximum period between inundation events would not change greatly. However, the average annual flooding volume would fall by 20 percent relative to current conditions to be less than half the pre-development volume. The average flooding volume per event would be 20 percent less than current, or 13 percent lower than in pre-development. These changes in flood volume would be likely to have additional effects on the vegetation condition and structure in the wetlands and affect their use by waterbirds for breeding.

Under the dry 2030 climate extreme there would be large increases in the average period between flows (52 percent relative to current conditions) such that flooding would only occur every 3.5 years on average, instead of every 15 months under pre-development conditions. Although the average size of individual events would increase, the average annual flooding volume would be half of the current average annual volume and only 29 percent of the pre-development average annual volume. These changes would be likely to have serious consequences for all aspects of the Gwydir Wetlands ecology with possible losses of some important elements.

Under the wet extreme 2030 climate the frequency of flood events would almost return to the pre-development frequency, and the average annual flooding volume would be very close to the pre-development value.

Future climate and future development (Scenario D)

The projected growth in commercial forestry plantations in the Gwydir region is negligible. The total farm dam storage volume over the entire Gwydir region is projected to increase by 15,100 ML by 2030. This is an increase of 14 percent over current farm dam volume. This projected increase in farm dams will reduce mean annual runoff by about 1.5 percent or about one-sixth of the best estimate climate change scenario effect on runoff (9 percent). The best estimate of the combined effects of climate change and new farm dams is a 10 percent reduction in average annual runoff with extreme estimates ranging from a 29 percent reduction to a 30 percent increase.

Projected future development (additional groundwater extraction and farm dams) would reduce inflows (under the best estimate future climate) by 2 percent or 24 GL/year. Of this, 13 GL/year is due to additional farm dams and 11 GL/year is due to increases in groundwater extraction. There would be an additional 2 GL/year reduction in streamflow due to increased average net leakage to groundwater. Diversions would reduce by an additional 3 percent to be 11 percent lower than current. The impact on average end-of-system flows would be a total reduction (development and climate impacts) of 8 percent. The relative level of use would be 43 percent – this is a very high level of development and is 2 percent higher than the current level.

There would be negligible additional effects on the groundwater balance in the Lower Gwydir area. Extraction would remain sustainable under the 2030 climate with new farm dams and with groundwater extraction at the LTAEL.

Groundwater extraction is however expected to increase 12-fold overall by 2030 outside of the Lower Gwydir area and the increase in the New England Fold Belt GMU is assessed to be 24-fold. These increases would lead to a high level of extraction for some GMUs. For example, extraction from the Miscellaneous Alluvium of Barwon Region GMU would almost equal rainfall recharge. The total effect of these future levels of extraction outside of the Lower Gwydir area would be an estimated 37 GL/year reduction in streamflow. This is 14 times the ultimate impact of prolonged groundwater extraction at 2004/05 levels. Average regional groundwater extraction would rise from 12 to 36 percent of total water use as a result of these increases and would rise from 55 percent to 85 percent of total water use in years of minimum surface water diversion.

New farm dams and increased groundwater extraction would have limited additional effect (over and above climate change) on the hydrology of the Gwydir Wetlands.

Uncertainty

The runoff estimates in the Gwydir region are relatively good because there are many gauged catchments 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 appears to be of good quality and generally suitable for the current purpose. The greatest uncertainty is associated with the lower reaches, in particular the distributaries – Meehi River, Carole and Gil Gil creeks. Losses are high and introduce considerable uncertainty in modelling results and the model does not always reproduce flows well in these reaches.

The Lower Gwydir Alluvium GMU has been given a 'high priority' rating in the context of the project and the whole of the MDB and therefore a 'thorough' assessment would be appropriate. However, the groundwater model available for the Lower Gwydir area only allowed a 'moderate' assessment. Thus although the assessment is reasonably reliable, the importance of the resource warrants additional investigation. The model used in the project was previously used to prepare groundwater sharing plans and so has had a high level of scrutiny. However, data on extraction and aquifer properties are limited, the model calibration period is short, and the model has not been calibrated for steady-state pre-development conditions. Additional data for model parameterisation and recalibration over a longer period would enable more reliable assessment.

There is considerable uncertainty in the projections of groundwater extraction outside of the Lower Gwydir area but the estimates do show the importance of development in these areas. The estimates of future groundwater extraction are considered to generally represent the upper limit as this can be constrained by pumping rules, groundwater quality and land suitability. However, the estimates of development impacts are generally conservative due to the use of entitlements in determining stream impacts and the use of connectivity estimates based on conservative 'best guesses'.

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).

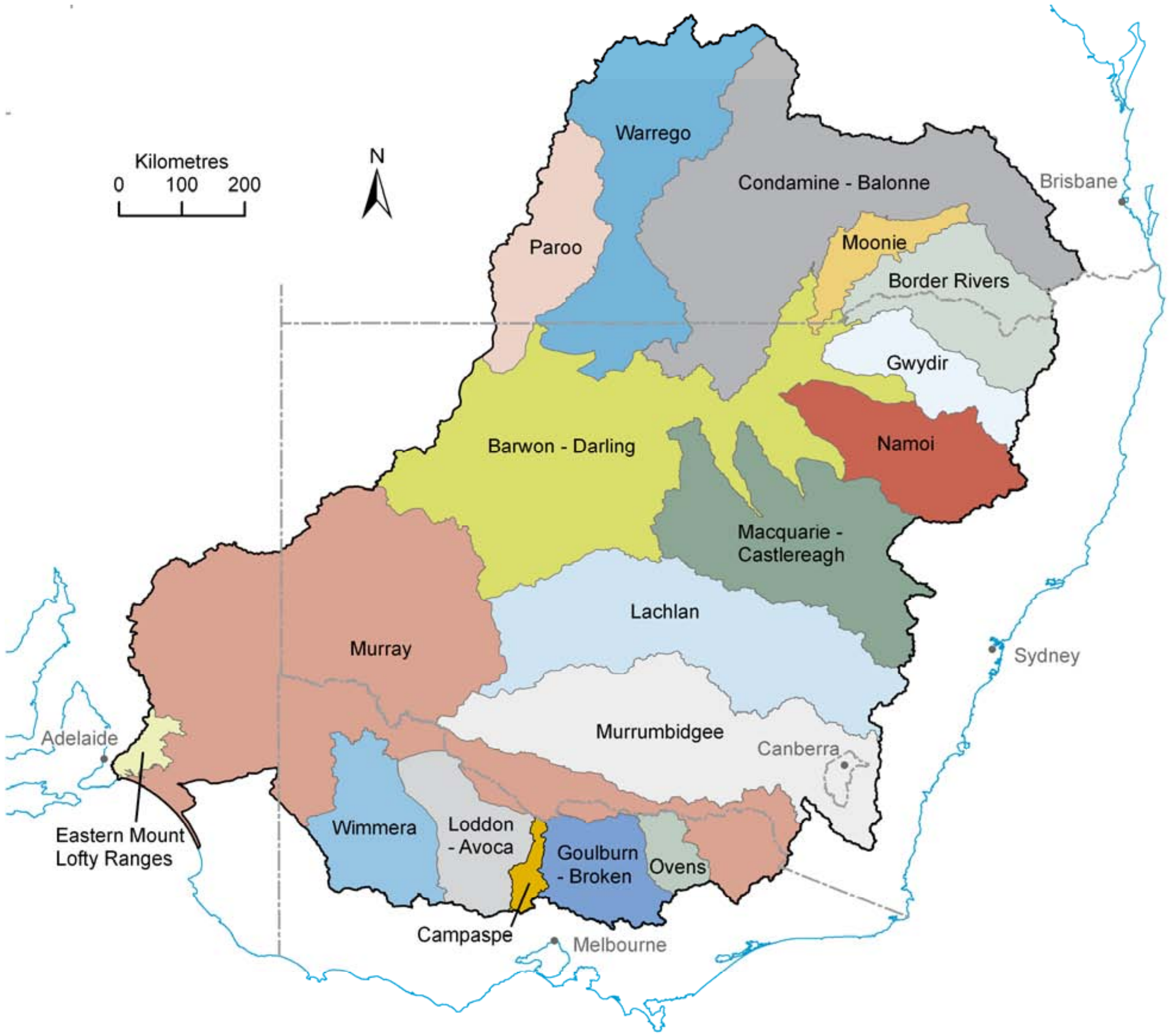

Figure 1-1. Region by region map of the Murray-Darling Basin

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.

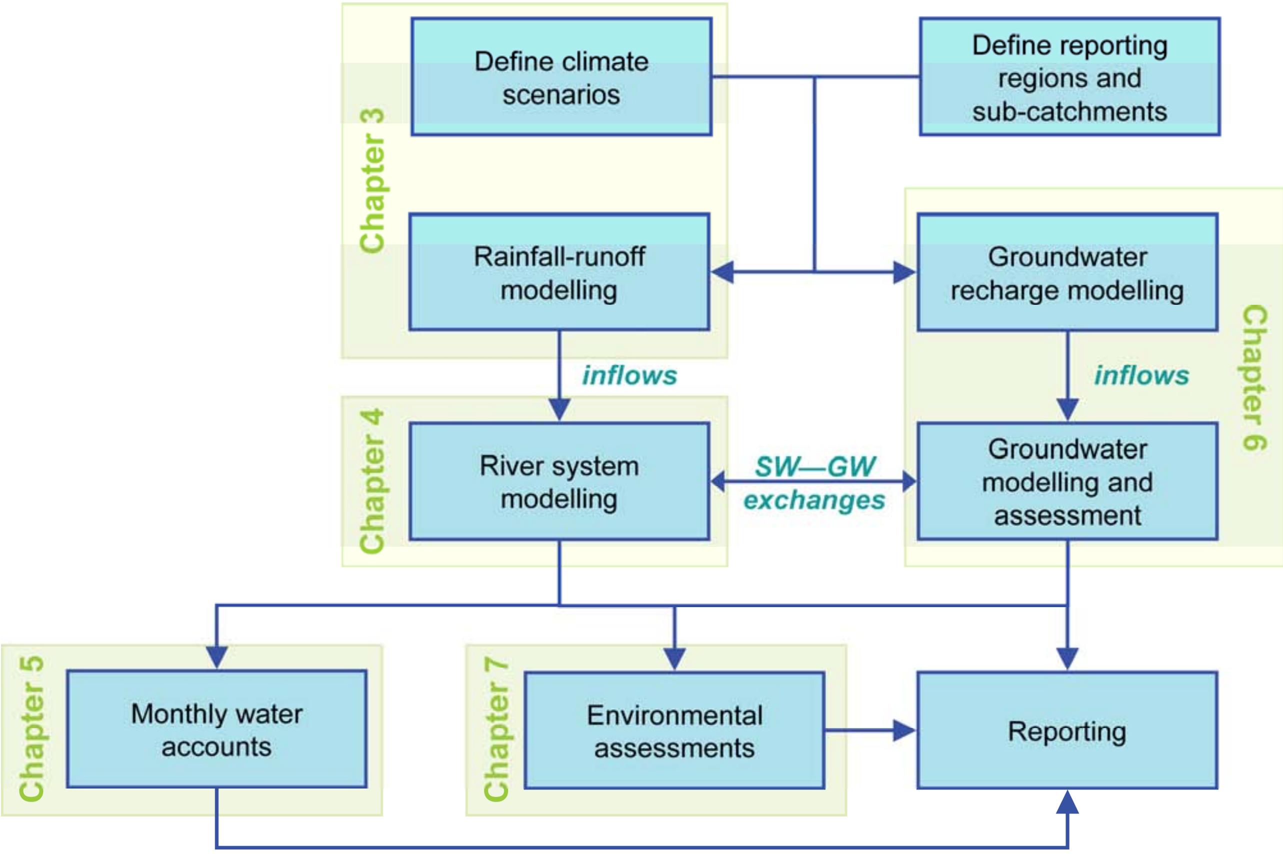

Figure 1-2. Methodological framework for the Murray-Darling Basin Sustainable Yields Project

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

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

1.3.2 Recent climate and current development

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

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

1.3.3 Future climate and current development

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

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

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

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

1.3.4 Future climate and future development

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

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

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

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

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

1.4 Rainfall-runoff modelling

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

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

The model is calibrated against 1975 to 2006 streamflow data from about 200 unregulated catchments of 50 km^2 to 2000 km^2 across the MDB (calibration catchments). Although unregulated, streamflow in these catchments for the calibration period may 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.

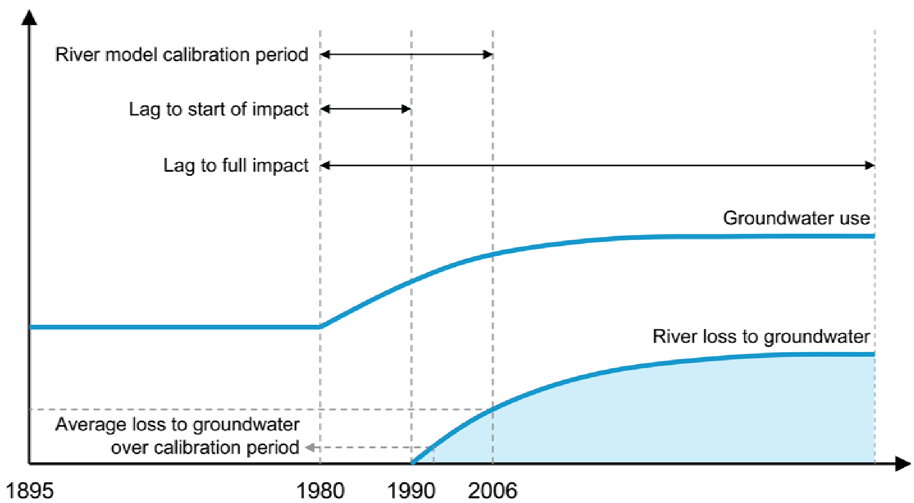

Figure 1-3. Timeline of groundwater use and resultant impact on river

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 Gwydir region is in northeastern New South Wales and represents 2 percent of the total area of the Murray-Darling Basin (MDB). The region is based around the Gwydir River. The population is approximately 26,500 or 1.4 percent of the MDB total, concentrated in the major centre of Moree. The dominant land use is dryland pasture used for beef and sheep grazing. Lucerne and pasture are grown on the narrow alluvial floodplains of the upper Gwydir River and dryland crops are grown on the western plains. Approximately 85,000 ha of irrigated cotton were grown in 2000 on the western plains. The Gwydir Wetlands on the floodplain of the lower Gwydir River are of regional, national and international (Ramsar) importance. The Ramsar-listed sites include three in the Gingham Watercourse and one in the Lower Gwydir Watercourse.

The region uses 3.5 percent of the surface water diverted within the MDB and groundwater use is 2.8 percent of the MDB total. On average, nearly 90 percent of the irrigation water is from surface water diversions. The Gwydir River is regulated by Copeton Dam and flows are affected by major water extractions. There are a considerable number of hillside farm dams and on-farm irrigation storages (ring tanks) in the region.

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

2.1 The region

The Gwydir region is located in northeastern New South Wales and covers 24,947 km^2 or 2 percent of the MDB. The region is bounded to the east by the Great Dividing Range, to the north by the Border Rivers region, to the south by the Namoi region and to the west by the Barwon-Darling region. The region terminates on the Gwydir River at Collymongle 9 km upstream of the junction with the Barwon River, on Gil Gil Creek at Galloway, and on the Mehi River at Collarenebri. These three outflows are inflows into the Darling region. The region's topography spans from tablelands in the east, through the central slopes to the western plains where the Ramsar-listed Gwydir Wetlands are located.

Major water resources in the Gwydir region include the Gwydir River, alluvial aquifers, wetlands and water storages. Water storages include private farm dams and public infrastructure, including Copeton Dam.

The mean annual rainfall for the region is 644 mm ranging from around 850 mm in the east and central south to 500 mm in the west. Rainfall is generally higher in the summer months (Figure 2-1). The region's average annual rainfall has remained relatively consistent over the past 50 years. The mean annual rainfall over the ten-year period 1997 to 2006 (688 mm) is around 7 percent higher, but not statistically significantly different, than the long-term 112-year (1895 to 2006) mean.

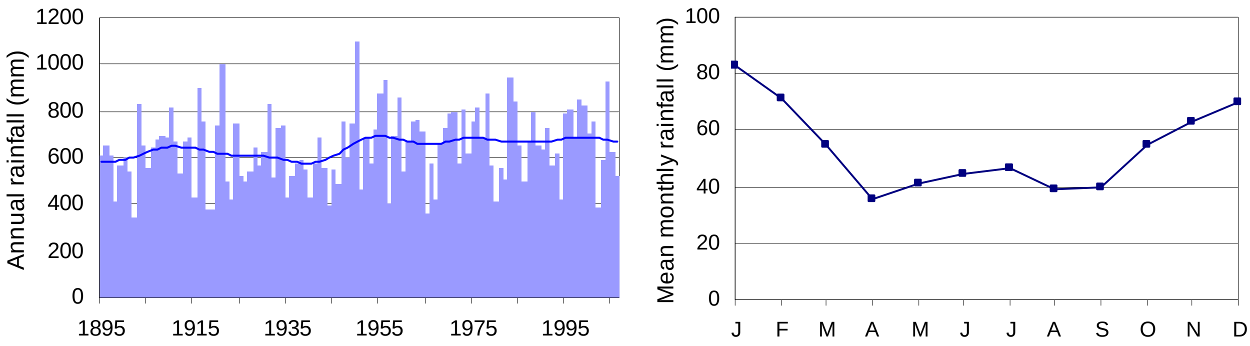

Figure 2-1. 1895–2006 annual and monthly rainfall averaged over the region. The curve on the annual graph shows the low frequency variability

The Gwydir region contributes about 3.4 percent of the total runoff in the MDB. The mean annual modelled runoff over the region for the 112-year period is 41 mm and is relatively uniform throughout the year. The mean annual modelled runoff over the ten-year period 1997 to 2006 has been 18 percent higher but not statistically significantly different to the long-term mean. The runoff estimates in the Gwydir region are relatively good as there are a number of gauged catchments within the region.

The regional population is approximately 26,500 which is 1.4 percent of the MDB population. The largest town is Moree. The dominant land use on the tablelands is grazing. Lucerne and pasture are grown on the narrow alluvial floodplains of the upper Gwydir River and its tributaries and broadacre crops are grown on the western plains. Irrigated crops were grown on slightly over 90,000 ha on the western plains of the region in 2000, of which cotton accounted for 85,000 ha or 95 percent of the irrigated area (Figure 2-2).

The land use area (Table 2-1) is based on the 2000 land use of the MDB grid, derived from 2001 Bureau of Rural Sciences AgCensus data. Irrigation estimates are based on crop areas recorded as irrigated in the census.

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

Land use	Area		
	percent		ha
Dryland crops	22.4%		559,000
Dryland pasture	58.6%		1,462,400
Irrigated crops	3.6%		90,500
Cereals		*3.5%*	*3,200*
Cotton		*94.4%*	*85,300*
Horticulture		*0.3%*	*300*
Orchards		*0.4%*	*400*
Pasture and hay		*1.4%*	*1,300*
Native vegetation	15.0%		372,900
Plantation forests	0.1%		1,500
Urban	0.1%		2,700
Water	0.2%		4,900
Total	**100.0%**		**2,493,900**

Source: BRS, 2000

The Border Rivers – Gwydir Catchment Action Plan (BRGCAP) (BRGCMA, 2006) provides a strategy for managing natural resources in the region. It was prepared under the Catchment Management Authorities Act 2003 and commenced in June 2006 for a term of ten years. The plan is structured around four themes:

- community
- biodiversity and native vegetation
- water
- soils and land use.

Under each theme, the BRGCAP indicates the resource's current condition, the pressures or challenges faced by the resource, and how the targets determined by the Border Rivers – Gwydir Catchment Management Authority (BRGCMA) will achieve improvements in the resource.

The water catchment target within this plan is to: 'By 2015, maintain or improve the condition of all subcatchments across the catchment based on the scores from the 2001 Riverine Condition Assessment (RCA) index.' The main focus of the plan's water targets is to ensure that the quality and quantity of water is maintained or improved. The intent of the water catchment target is to improve the condition of individual subcatchments in the region leading to an overall improvement in the Riverine Condition Assessment Index. In the plan area, 15 of the 50 subcatchments have been rated as either in fair or poor condition (BRGCMA, 2006). Management targets are set within the BRGCAP for water quality, erosion, riparian vegetation, aquatic biodiversity, wetlands and instream salinity.

The plan considers the State Water Management Outcomes Plan and is consistent in its delivery with water sharing plans (WSPs) gazetted under the Water Management Act 2000 including Gwydir Regulated River Water Source WSP (DIPNR, 2004a), and Rocky Creek, Cobbadah, Upper Horton and Lower Horton Water Source WSP (DIPNR, 2004b).

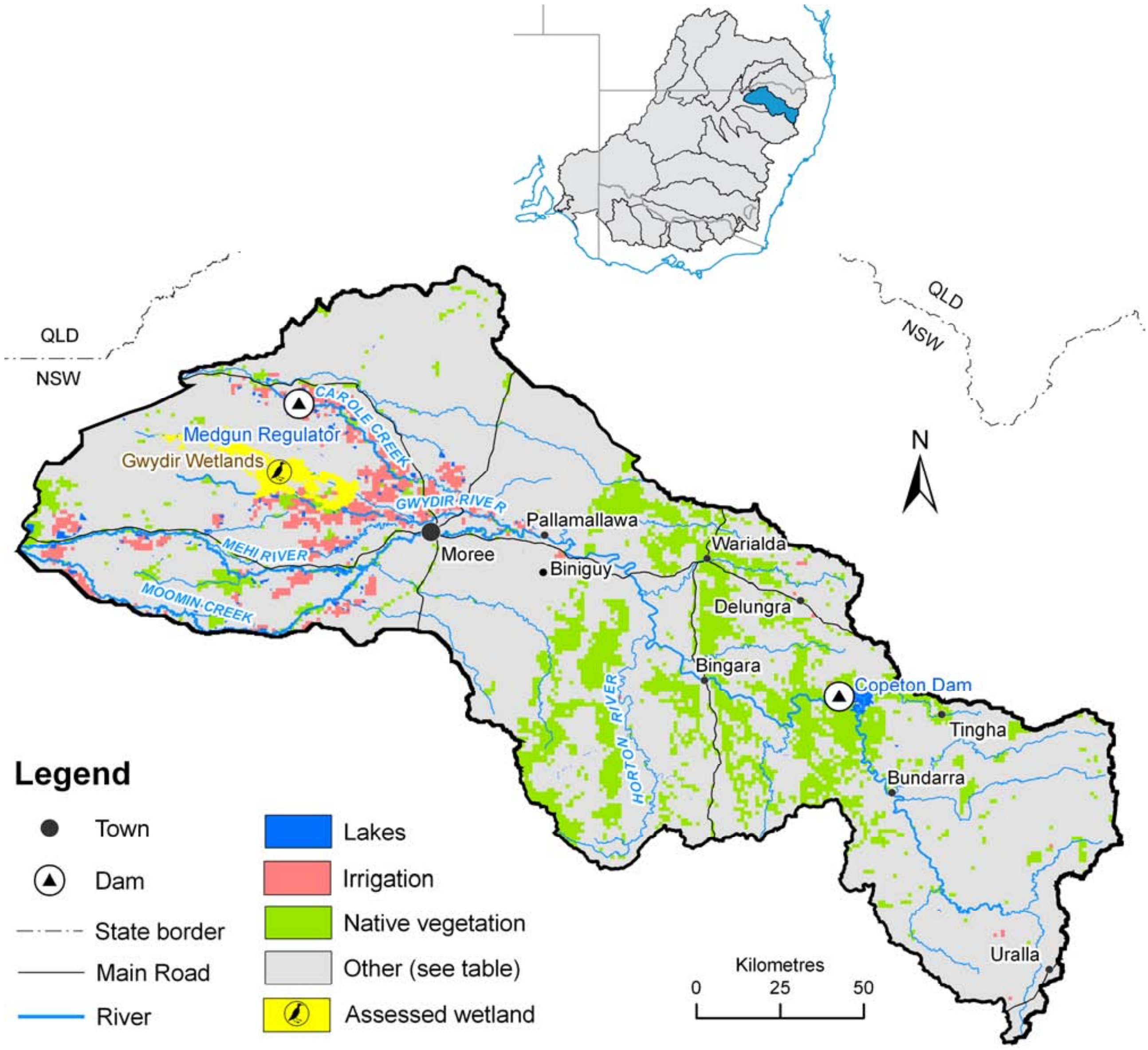

Figure 2-2. Map of dominant land uses of the Gwydir region with inset showing the region's location within the Murray-Darling Basin. The assets shown are only those assessed in the project (Chapter 7) and that fall within the region. A full list of key assets associated with the region is in Table 2-2

2.2 Environmental description

The Gwydir region encompasses tablelands in the upper eastern catchment, as well as central slopes, alluvial valleys, and the western plains in the lower catchment. The tablelands in the east comprise the undulating country upstream of Copeton Dam, with elevations of greater than 600 m. In the lower reaches of the catchment, where the Gwydir joins the Barwon River, elevations are approximately 200 m. Just east of Moree, the landscape becomes flat and black-soil plains extend west to the junction of the Gwydir and Barwon rivers.

The region's vegetation varies from high altitude areas in the east, consisting of patches of forested areas, graduating west to more open forest, shrublands and grassy plains. Soils vary throughout the catchment, reflecting complex topographic and geological characteristics. In the tablelands and slopes area, the steep landscape and poor fertility of soils adjacent to waterways have limited irrigation development. On the slopes below Copeton Dam down to Biniguy, and along the Horton River, irrigation is restricted to alluvial soils on very narrow floodplains. Basalt-derived soils provide reasonable soil structure and fertility for irrigated crops but the availability of good irrigation sites is limited. West of Biniguy, self-mulching grey clays fan out into the plains of the Lower Gwydir catchment. It is in this area that most irrigation occurs (NSW Agriculture, 2003).

The Gwydir River is highly regulated. However, other systems or subcatchments within the region, such as the Georges Creek subcatchment, are considered to have a high conservation value. The BRGCAP states that future catchment management actions will focus on maintaining the condition of the high conservation value systems and improving the condition of those systems where only minimal investment will improve the quality of the water and riparian environment. The mid-catchment tributaries – the Horton River, and the Myall, Warialda and Tycannah creeks – have high salt concentrations.

The wetlands within the region that have national or international importance are listed in Table 2-2. The Gwydir Wetlands, located on the lower Gwydir River floodplain downstream of Moree, are of regional, national and international importance and cover an area of some 100,000 ha (Environment Australia, 2001). They are in two main areas: the Lower Gwydir Watercourse and the Gingham Watercourse just to the north. The Gwydir Wetlands Ramsar site has four components: three in the Gingham Watercourse and one in the Lower Gwydir Watercourse covering some 823 ha in total. These were the first wetlands in Australia on private land to receive Ramsar designation. Portions of the Gwydir Wetlands provide a typical example of an inland terminal wetland delta system.

Widespread inundation of the wetlands occurs primarily from floods arising in the upper catchment. Natural flooding is affected by large-scale water resource development and water extraction upstream of the wetlands. The Gwydir Raft, an accumulation of timber and debris which has built up since the 1940s, has altered the flow distribution between the two watercourses.

The primary ecological features of the wetlands are the large expanse of wetland vegetation, approximately 60,000 ha, including large areas of Coolibah (*Eucalyptus coolabah*) woodland and Water Couch (*Paspalum distichum*), including one of the largest areas of Water Couch in New South Wales. The largest stand of Marsh Club-rush (*Bolboschenus fluviatilis*) in New South Wales – some 1300 ha – is in the Gwydir Watercourse. The Gingham Watercourse has virtually permanent water and is an important waterbird habitat. The Gwydir Wetlands support an appreciable assemblage of rare, endangered and vulnerable species, as well as a number of common species at the edge of their range.

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

Site code	Directory of Important Wetlands in Australia name	Area[1]	Ramsar sites
		ha	
NSW008	Gwydir Wetlands	102,120	Gwydir Wetlands: Gingham and Lower Gwydir (Big Leather) Watercourses *
NSW023	New England Wetlands #	30,000	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.
* Ramsar site, area 823 ha.
# Individual wetlands range from 0.5 to 500 ha.
Source: Environment Australia, 2001.

2.3 Surface water resources

2.3.1 Rivers and storages

The Gwydir River flows in a westerly direction from its headwaters in the Great Dividing Range near Armidale. The upper reaches of the Gwydir river system include the Horton River subcatchment. The Gwydir splits near Moree into the Gwydir and Lower Gwydir River which also receives water from the Waah Waa Creek. The Lower Gwydir includes a number of distributary channels that inundate the floodplain wetlands during periods of high flows from the upper catchment. Copeton Dam is located near Inverell in the upper Gwydir and is the largest water storage in the region with an active capacity of 1345 GL. The estimated total volume of hillside farm dams with their own catchment is about 110 GL (Chapter 3). Additionally, the Gwydir river model includes 521 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.

The water sharing arrangements for this region are contained in the WSP for the Gwydir Regulated River Water Source, which was amended on 1 July 2004 and is valid until 30 June 2014 (DIPNR, 2004a), and the WSP for the Rocky Creek, Cobbadah, Upper Horton and Lower Horton Water Source as amended 1 July 2004 (DIPNR, 2004b).

The Gwydir Regulated River WSP applies to the section of the Gwydir River downstream of Copeton Dam to the junction of the Gwydir River and associated regulated distributary streams to the Barwon River. This plan establishes a bulk access regime for the extraction of water under access licences in this water source with regard to environmental water provisions, basic landholder rights and requirements for water for extraction under access licences.

The Rocky Creek WSP applies to that area of land within the Gwydir Water Management Area, known as the Rocky Creek, Cobbadah, Upper Horton and Lower Horton Water Source. Other rivers in the Gwydir region are not covered by these plans and are currently the subject of separate plans or planning processes. Licensing continues under the Water Act 1912 in those areas where WSPs are not yet gazetted.

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

Table 2-3. Summary of surface water sharing arrangements within the Gwydir region

Water Source Plan		Gwydir Regulated River WSP	Rocky Creek, Cobbadah, Upper and Lower Horton WSP
Water products	Priority of access	Allocated entitlement	Allocated entitlement
		ML/y	ML
Basic rights			
Stock and domestic rights		6,000	5.1 ML/day
Native title		none	0
Extraction shares			
Total licensed (long-term) extraction limit		392,000	not specified
Local water utilities	high	3,836	
High security access	high	19,293 unit shares	
General security access	medium	509,500 unit shares	5509
Supplementary access	low	178,000 unit shares	
Domestic and stock	high	4,245	
Environmental provisions*			
Total environmental share		**749,000	
Environmental allocation	high	45,000 unit shares	

Sources: DIPNR, 2004a; DIPNR, 2004b.

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

** By limiting long-term average annual extractions to an estimated 392,000 ML/y this plan ensures that approximately 66 percent of the long-term average annual flow in this water source (estimated to be 1,141,000 ML/y) will be preserved and will contribute to the maintenance of basic ecosystem health.

2.3.3 Water products and use

Water access is based on a long-term average annual extraction limit. The basic rights (native title and domestic and stock use) and access licences for domestic and stock use and local water utilities are volumetric and are granted highest access priority. Access licences are expressed as a unit share of the total licence volume rather than as an annual extraction volume. Annual allocations for high and general security access licences are based on shares of the water available in the respective year up to the long-term annual extraction limit, with high security licences having priority over general security licences. Water use associated with supplementary access licences is only on the basis of 1 ML per share provided the long-term extraction limit is not exceeded.

The Gwydir Regulated River WSP (DIPNR, 2004a) has environmental water provisions including an environmental contingency allowance held in Copeton Dam and restrictions on extraction on supplementary flow events, with the latter providing the main inflows to the Gwydir Wetlands.

Major irrigation development followed the completion of Copeton Dam in 1976 and has continued to expand with the development of private on-farm storage. The on-farm storage is primarily used to store water diverted from the river system, particularly during periods of high flow.

Water use ranges from less than 100 GL/year to over 500 GL/year over the past 25 years (Figure 2-3) but averages around 300 GL/year, equivalent to about 60 percent of the available irrigation entitlements. Annual water usage of around 500 GL reflects those years when higher irrigation water allocations are available and access to supplementary licence volumes are granted due to high river flows. The region diverted 414 GL in 2000/01 representing 3.5 percent of the total water diversions within the MDB in that year (MDBC, 2007a). Domestic water use (urban and rural) accounts for less than 2 percent of total use in the region.

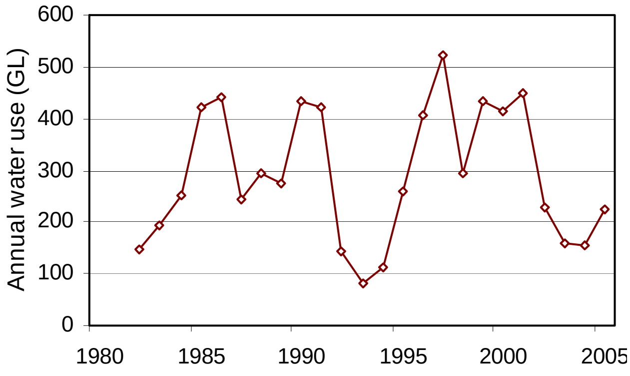

Figure 2-3. Historical surface water diversions within the Gwydir region

2.4 Groundwater

2.4.1 Groundwater management units – the hydrogeology and connectivity

From a hydrogeological perspective, the Gwydir region is divided into two broad areas – the hilly highland country to the east, and the broad flat alluvial plain to the west.

The primary groundwater resource in the region is in the alluvial aquifers associated with the main rivers and prior channels of the western floodplain. Groundwater from these aquifers supply irrigation, stock, domestic and town water. They form a three-layered system composed of the Cubbaroo Formation, overlain by the Gunnedah Formation and then the Narrabri Formation. The Cubbaroo Formation is restricted to the deepest parts of the alluvial sequence, forming coarse-grained, subsurface palaeochannels. The Gunnedah Formation extends across the region and is finer grained than the Cubbaroo Formation.

The dominant proportion of usable low salinity groundwater resources in the Gwydir region is constrained to the Lower Gwydir Alluvium Groundwater Management Unit (GMU). It lies at the eastern end of the broad alluvial floodplain where the Gwydir River emerges from the slightly higher relief country of the eastern valley. Groundwater within the Lower Gwydir Alluvium GMU is largely extracted from the deeper Gunnedah Formation. The Narrabri Formation is composed of shallow alluvial fan sediments deposited by creeks draining the adjacent highlands. Groundwater is contained in small discontinuous sand lenses and varies in quality and yield.

In the highland reaches of the region the hydrogeology is dominated by fractured rock aquifers in a range of different geologies including Palaeozoic and Mesozoic granites, basalts, consolidated sediments and metasediments. Groundwater salinities in the fractured rock aquifers range from 1200 to 3600 mg/L Total Dissolved Salts with yields of 1 to 2 L/s.

The region is underlain by consolidated sandstones, shales and mudstones that form the multi-layered aquifers of the Great Artesian Basin (GAB). The water resources within these aquifers are controlled by the GAB WSP and are not considered in the assessments of this project except where intake beds for the GAB outcrop within the region, because groundwater in these areas has the potential to be connected with surface water systems.

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.

The alluvial plain groundwater system is primarily recharged from stream channel leakage under normal flows, leakage from overbank flooding and infiltration from rainfall. Groundwater moves downward from the Narrabri Formation to the Gunnedah Formation in the eastern parts of the plain, whilst at the western margin the direction is upward.

Groundwater levels in the Gunnedah Formation generally reflect climatic conditions upstream of the irrigated areas on the western floodplain. Within irrigated areas, groundwater levels show large seasonal fluctuations associated with pumping and a consistent downward trend of 3 to 5 m in the Gunnedah Formation from 1977 to 1996. Since then groundwater levels have stabilised. In the western part of the GMU, groundwater fluctuates by less than 1 m over the 30 years of observations. About half of the observations show some rise, about half show some falls and a small number have stable water levels.

There is evidence of periodic recharge from flooding events within the Narrabri Formation, but the longer term groundwater level trend is consistently downward. From 1987 to 1996 groundwater levels fell. These recovered over the period 1996 to 2000, but have since displayed a falling trend. Groundwater salinity in the Narrabri Formation can be high and, with an increased downward hydraulic gradient caused by extraction from the Gunnedah Formation, may result in induced downward leakage of saline water to the underlying Gunnedah Formation.

Recharge to the fractured rocks occurs mainly on hilltops and slopes with discharge areas at the break-of-slope and as baseflow to adjacent streams and valley floors. The rivers of the highland valleys tend to be gaining in nature and rely heavily on baseflow. The basalts receive recharge throughout the landscape and have high recharge and high permeability, resulting in highly flushed systems containing low salinity groundwater.

There has been limited monitoring of groundwater levels in the fractured rock aquifers of the Gwydir region. Hydrographs indicate water levels generally reflect rainfall trends showing a fall of about 3 m in the early 1990s during a period of low rainfall and increasing by about 3 m following increased rainfall.

The Gwydir region is subdivided into seven GMUs for management purposes. These units are three dimensional in nature, allowing for the layered nature of geological formations at different depths. The seven GMUs cover the entire region and were devised based on the hydrogeological setting of the groundwater resource in each case. Current groundwater extraction, entitlement and recharge are itemised for each GMU in the Gwydir region (Table 2-4). The GMU locations are shown in Figure 2-4. The Gwydir region incorporates one GMU – the Lower Gwydir Alluvium GMU – that is completely contained within the reporting area and six GMUs that partially overlap this region and adjacent regions. The Lower Gwydir Alluvium GMU is categorised as high priority in the context of the project and is subject to detailed assessment using a numerical groundwater model (Chapter 6). The six GMUs that are only partially contained by the Gwydir region are categorised as low and very low priority. Prioritisation is based on the degree of development and the stress on the groundwater resource, the hydrogeological complexity, and the degree of connectivity between the groundwater and surface water resources.

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

Code	Name	Priority	Total entitlement	Current extraction (2004/05)***	Long-term average extraction limit ****	Recharge**
			GL/y			
N03	Lower Gwydir Alluvium	high	33.0*	35.52	32.3* (plus basic landholder rights)	32.3 (plus basic landholder rights)
N23	Miscellaneous Alluvium of the Barwon Region	low	1.54	0.87	0.89	1.8
N63	GAB Alluvial	low	3.79	2.6	43.01	99.8
N601	GAB Intake Beds	very low	2.59	1.85	4.02	73.2
N604	Gunnedah Basin	very low	0	0	0.45	0.6
N803	Inverell Basalt	low	2.19	1.4	9.05	18.1
N805	New England Fold Belt	low	5.49	4	158.85	317.7

*Source: DIPNR, 2006.

**This value incorporates all sources of recharge in WSP areas but represents only rainfall recharge in Macro Groundwater Sharing Plan areas. Where indicated the recharge volume does not include the amount of groundwater available for basic rights, which is an additional volume. The volume of recharge does not include recharge to national park areas, which has generally been allocated to environmental purposes and is not available for consumptive use.

***Data for the Lower Gwydir Alluvium GMU is metered data. 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). Data quality is variable depending on the location of bores and the frequency of meter reading.

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

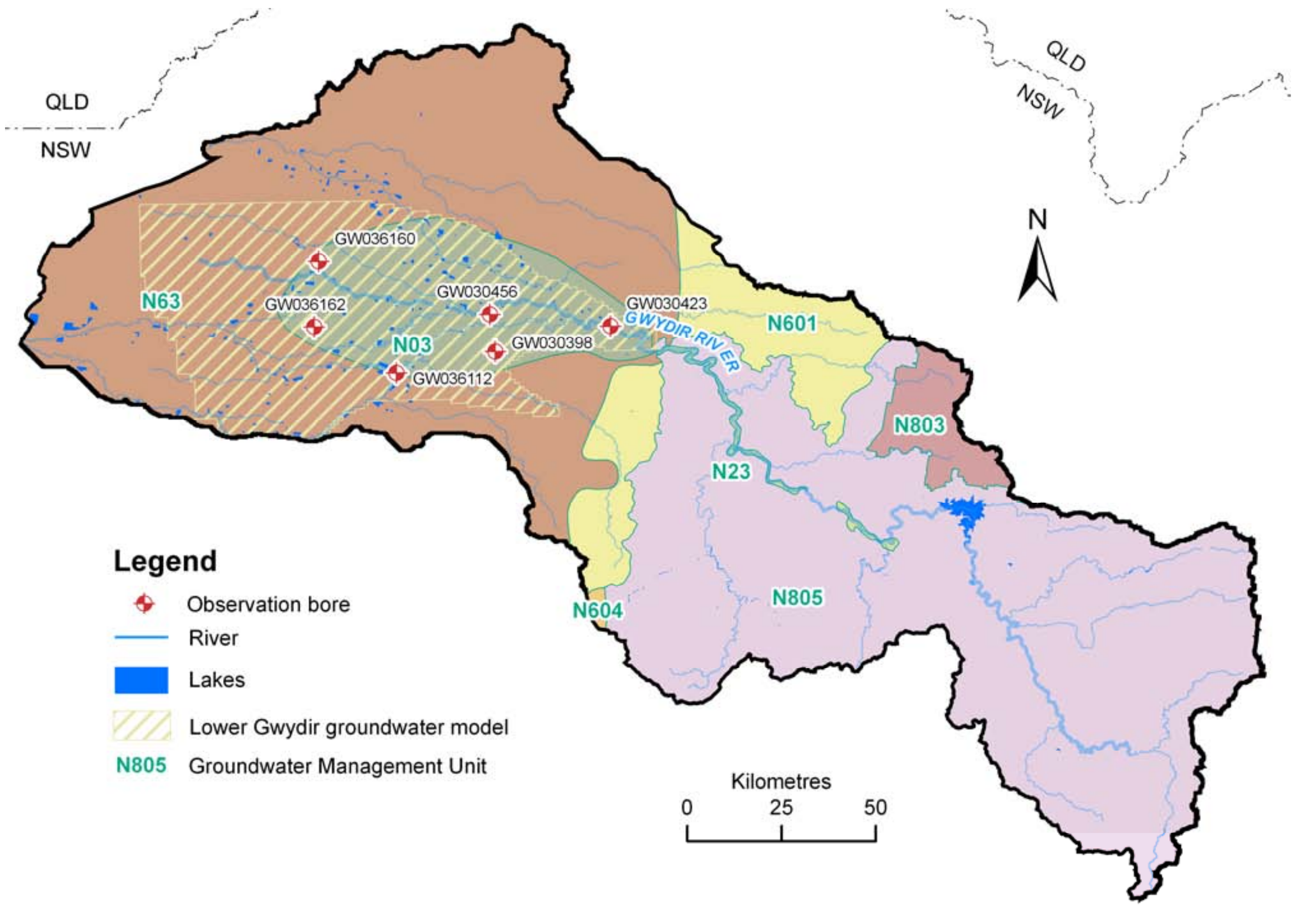

Figure 2-4. Map of groundwater management units within the Gwydir region

2.4.2 Water management institutional arrangements

The Water Management Act 2000 in New South Wales requires the implementation of ten-year plans defining water sharing arrangements between the environment and groundwater users and amongst water user groups in a similar way to that required for surface water diversions. WSPs 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. Where current extraction levels exceed the long-term extraction limit, a supplementary access volume is determined. This access volume will decrease to zero within ten years of commencement of the WSP. Outside of areas covered by WSPs, groundwater extraction will be controlled by Macro Water Sharing Plans (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 groundwater resources of the Lower Gwydir Alluvium are governed by a WSP for the Lower Gwydir Groundwater Source. This plan was developed in accordance with the New South Wales Water Management Act 2000 which requires the implementation of ten-year plans defining water sharing arrangements between the environment and water users and amongst water user groups.

The WSP for the Lower Gwydir groundwater source was enacted in 2006 (DIPNR, 2006). It applies to all water contained in the unconsolidated alluvial aquifers associated with the Gwydir River and all its tributaries downstream of Gravesend. The estimated volume of recharge within this aquifer is 38 GL/year plus a volume equal to the volume available for basic landholder rights.

The WSP (Table 2-5) allows for access licences up to 28.7 GL/year for the planned share and an urban share of 3.6 GL/year. The WSP will reduce groundwater extraction to the long-term average extraction limit (LTAEL) of 32.3 GL/year over the life of the current WSP. Supplementary water licences were introduced in the WSP to ease the transition from the pumping regime pre-2004 to that under the WSP. The volume of the supplementary licences was set at a total of 14.2 GL/year at the commencement of the plan and is being reduced annually to a final share of zero by 2015. An environmental provision of 5.70 GL/year, equal to 15 percent of the long-term average annual recharge to the groundwater source minus basic landholder rights requirements, will be reserved at the commencement of the plan. A domestic and stock entitlement of 0.70 GL/year assumes 2.25 ML/year per bore for domestic use and 0.0088 ML/ha/year per bore for stock use.

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 WSP for the Lower Gwydir groundwater source.

A summary of the groundwater sharing arrangements is presented in Table 2-5.

Table 2-5. Summary of groundwater management plans

Description	Lower Gwydir Alluvium	Great Artesian Basin (Intake Beds)	Remaining GMUs
Name of plan	Water Sharing Plan for the Lower Gwydir Groundwater Source 2003	Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources	Macro Water Sharing Plans
Year of plan	2003	2007	*
Environmental provisions			
Planned share	5.7 GL/y (15% of planned share less basic rights)	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
Basic rights			
	GL/y		
Domestic and stock rights	0.7	0.73	6.52
Native title	0	0	None
Access licences			
Urban	3.58	0.44	0.09
Planned share	28.72	1.41	5.89
Announced allocation	Planned share + supplementary		None
Supplementary provisions	14.2 GL/y decreasing to zero by 2015		

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

2.4.3 Water products and use

Groundwater extraction within the Gwydir region is undertaken by around 3135 licences and accounts for 2.8 percent (46.2 GL) of the total groundwater used in the MDB (excluding confined aquifers of the GAB).

Groundwater extraction from the aquifers is largely confined to alluvial deposits. Large numbers of bores occur in the Lower Gwydir Alluvium. Other areas where there are alluvial deposits include the highland valleys of the miscellaneous units of the Barwon Region. These narrow valleys have comparatively thin deposits of alluvium closely flanking the major rivers. The groundwater in these aquifers has a strong hydraulic connection with the rivers. Outside of the alluvial valleys groundwater extraction bores are distributed relatively widely. These are largely constructed in consolidated and fractured rock aquifers with poorer water quality and yields.

The Lower Gwydir Alluvium GMU is the most developed GMU in the Gwydir region and has been subject to study and management over a long period relative to the other GMUs in the region. Very little information exists for the GMUs other than the Lower Gwydir Alluvium.

Groundwater development in the Lower Gwydir Alluvium began in the late 1970s. Records indicate that groundwater extraction experienced strong growth during the 1980s with extraction at 4.2 GL/year in 1980/81. This was followed by a rapid increase in extraction during the 1990s peaking in 1994/95 at 50.8 GL/year. The level of extraction in 2004/05 was 35.52 GL/year (MDBC, 2007b). This level of use compares to the LTAEL set in the WSP of 32.3 GL/year as the volume of groundwater available for general access use. This does not include rights for stock and domestic groundwater use.

The major use of groundwater in low priority GMUs is for stock and domestic supplies.

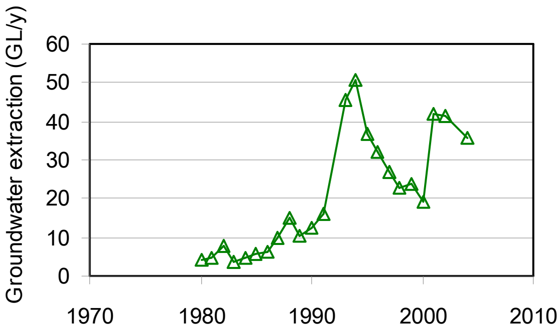

Figure 2-5. Historical groundwater extractions within the Lower Gwydir Alluvium

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3 Rainfall-runoff modelling

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

3.1.2 Key messages

- The mean annual rainfall and modelled runoff averaged over the Gwydir region are 644 mm and 41 mm respectively. Rainfall is generally higher in the summer half of the year and runoff is relatively uniform throughout the year. The Gwydir region covers about 2.3 percent of the MDB and contributes about 3.4 percent of the total runoff in the MDB.
- The mean annual rainfall and runoff over the ten-year period 1997 to 2006 are 7 percent and 18 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 Gwydir 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 9 percent reduction in mean annual runoff by ~2030 relative to ~1990. The extreme estimates, which come from a high global warming scenario, range from a 28 percent reduction to a 31 percent increase in mean annual runoff. By comparison, the range from a low global warming scenario is from a 9 percent reduction to an 8 percent increase in mean annual runoff.
- There is negligible projected growth in commercial forestry plantations in the Gwydir region. The total farm dam storage volume over the entire Gwydir region is projected to increase by 15.1 GL, or an increase of 14 percent of current farm dam storage volume, by ~2030. This projected increase in farm dams would reduce mean annual runoff by about 1.5 percent, a relatively small impact compared to the best estimate climate change impact on runoff (9 percent). The best estimate of the combined impact of climate change and farm dam development is a 10 percent reduction in mean annual runoff with extreme estimates ranging from 29 percent reduction to a 30 percent increase.

3.1.3 Uncertainty

- Scenario A – historical climate and current development
  The runoff estimates in the Gwydir region are relatively good because there are many gauged catchments in the Gwydir from which to estimate 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 a nearby catchment have an error of less than 20 percent in more than half the catchments and less than 50 percent in almost all the catchments.

- 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 explicitly takes into account the current uncertainty in climate change projections 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 median estimate of climate change impact on runoff and as the range of the extreme estimates.
- Scenario D – future climate and future development
  After the Scenario C climate change projections, the biggest uncertainty in Scenario D modelling is in the projections of future increases in commercial forestry plantations and farm dam development and the impact of these developments on runoff. The impact of commercial forestry plantations on runoff is not modelled because the Bureau of Rural Sciences projections indicate negligible growth in commercial forestry plantations in the Gwydir region. The increase in farm dams is estimated by considering trends in historical farm dam growth and current policy controls in New South Wales and there is uncertainty both as to how landholders will respond to these policies and how governments may set 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 Gwydir region

The rainfall-runoff modelling is done to estimate runoff in 0.05^o grid cells in 34 subcatchments as defined for the river system modelling in Chapter 4 for the Gwydir region (Figure 3-1). Optimised parameter values from 12 calibration catchments are used. Eleven of these calibration catchments are in the Gwydir 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 Border Rivers region north of the Gwydir (not shown in Figure 3-1) and its optimised parameter values are used for the subcatchments in the western parts of the Gwydir.

Scenario B modelling was not undertaken for the Gwydir 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 Gwydir region.

The increase in farm dams in each subcatchment is estimated as the lower of the available harvestable right volume based on current policy control and the projected additional storage volume based on extrapolation of historical farm dam growth rate. This resulted in an estimate of a 15.1 GL increase in farm dam storage volume by ~2030 over the entire Gwydir region. The projected increases in farm dam storage volume for each subcatchment are given in Appendix A.

The farm dam projection is dependent on three factors:

- current farm dam storage volume
- growth rate of farm dams
- maximum harvestable right volume 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 Gwydir region is about 140 GL. The estimate of current farm dam storage volume over the entire Gwydir region is about 110 GL, with these farm dams utilising about 40 GL 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. The available harvestable right volume is therefore about 100 GL. The projection of 15 GL increase in farm dam storage volume over the entire Gwydir by ~2030 is therefore an increase of about 14 percent of current farm dam storage volume and about 15 percent of the available harvestable right volume.

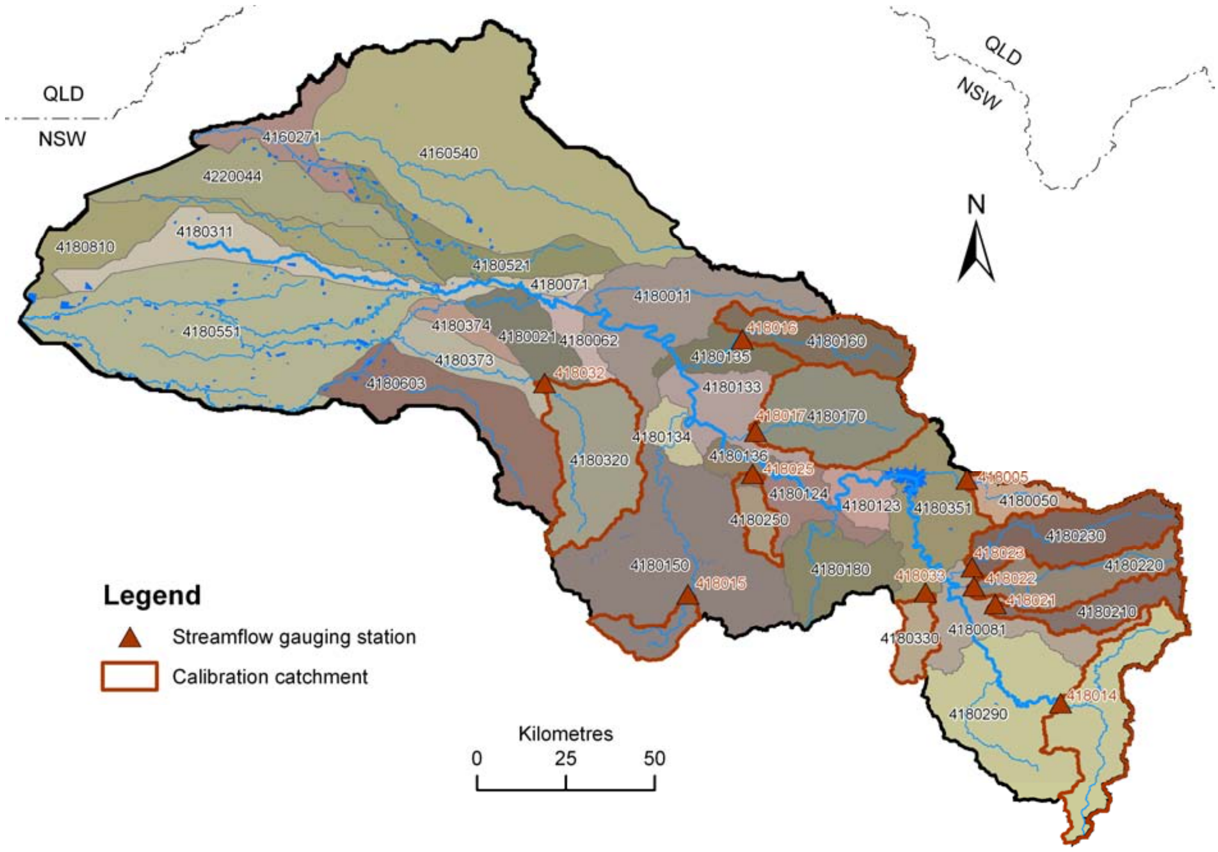

Figure 3-1. Map of the modelling subcatchments and calibration catchments

3.2.3 Model calibration

Figure 3-2 compares the modelled and observed monthly runoff and the modelled and observed daily flow duration curves for the 12 calibration catchments. The results indicate that the SIMHYD calibration can reasonably reproduce 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 0.85). The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration to optimise Nash-Sutcliffe E means that more importance is placed on the simulation of high runoff, and therefore SIMHYD modelling of 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, as shown in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow duration curves. The disagreement between the modelled and observed daily runoff characteristics is discernable for runoff that is exceeded less than 0.1 or 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis.

The runoff estimates for the Gwydir 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.

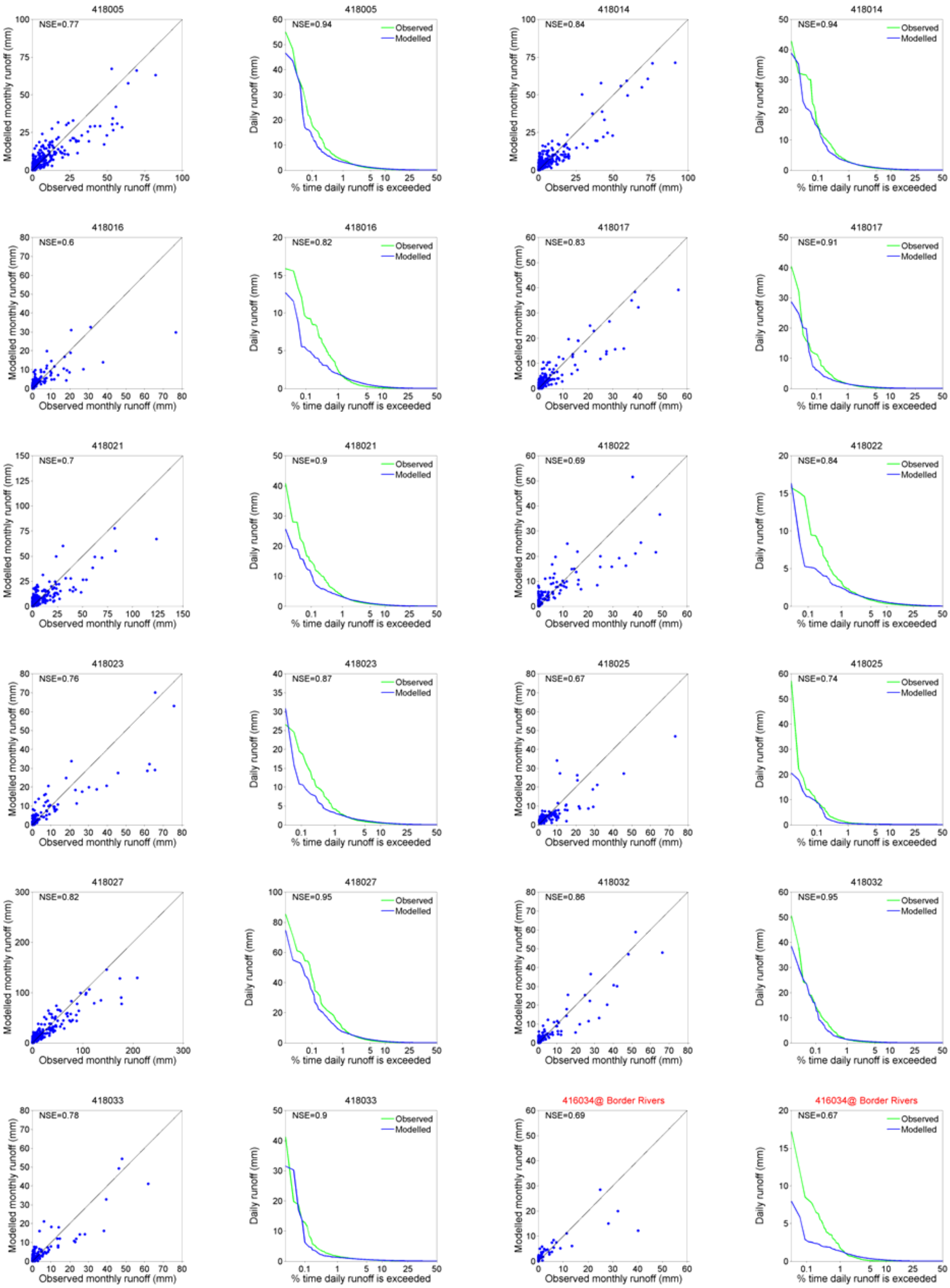

Figure 3-2. Modelled and observed monthly runoff and daily flow duration curve for the calibration catchments

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 Gwydir 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 Gwydir region are 644 mm and 41 mm respectively. The mean annual rainfall varies from about 850 mm in the central-south and east to 500 mm in the west. The modelled mean annual runoff varies from about 100 mm in the central-south and east to 15 mm in the west (Figure 3-3). Rainfall is generally higher in the summer half of the year. Runoff is fairly uniform throughout the year with the highest runoff averaged across the region occurring in January and February (Figure 3-5). The Gwydir region covers about 2.3 percent of the MDB and contributes about 3.4 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 Gwydir are 0.24 and 0.75 respectively, close to the median values for the 18 MDB regions. The tenth percentile, median and ninetieth 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 7 percent and 18 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 $\alpha = 0.2$ (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.

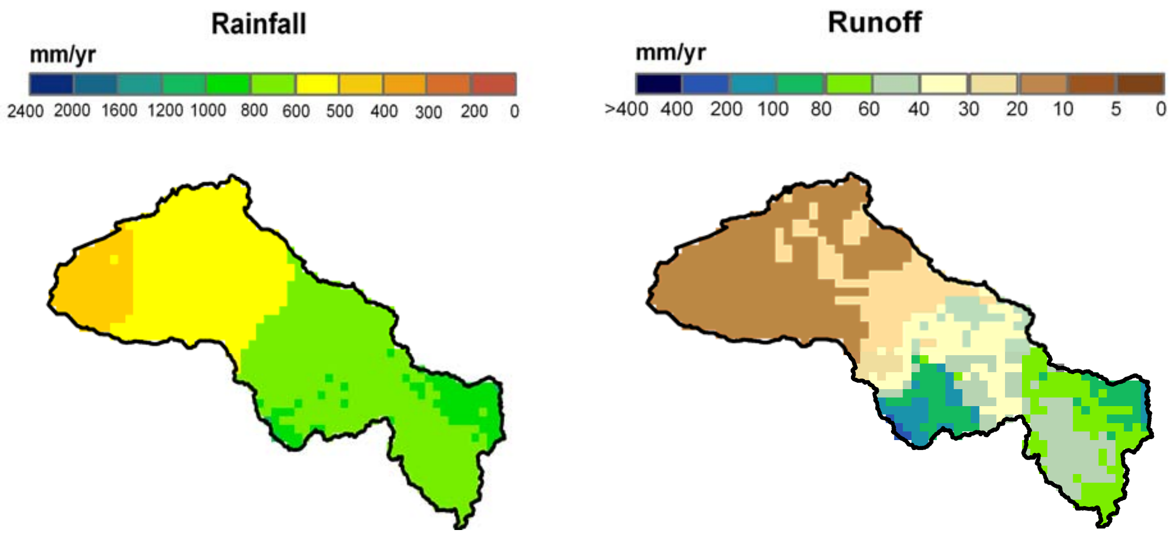

Figure 3-3. Spatial distribution of mean annual rainfall and modelled runoff averaged over 1895–2006

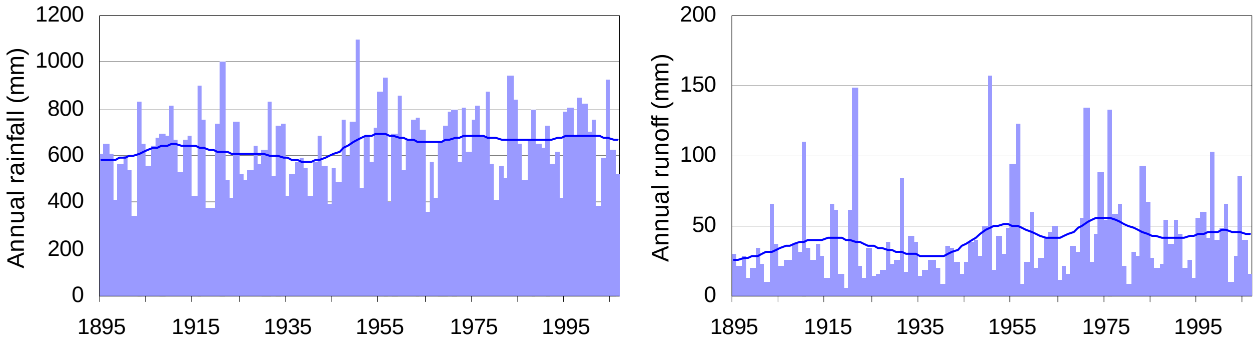

Figure 3-4. 1895–2006 annual rainfall and modelled runoff series averaged over the region (the curve shows the low frequency variability)

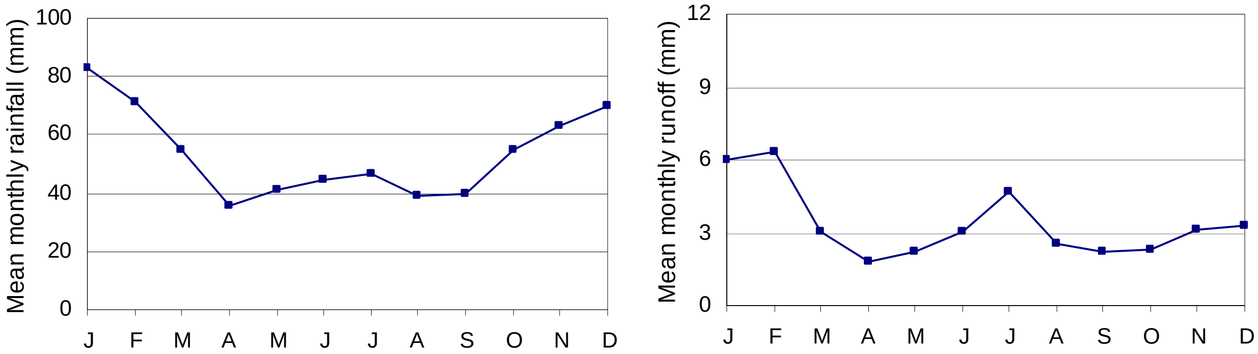

Figure 3-5. Mean monthly rainfall and modelled runoff (averaged over 1895–2006 for the region)

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 Gwydir region for Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and the percentage change in mean annual rainfall from the corresponding GCMs are 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 Gwydir region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from two-thirds of the GCMs shows a reduction in mean annual runoff and rainfall-runoff modelling with climate change projections from one-third of the GCMs shows an increase in mean annual runoff.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff come from the high global warming scenario. For the high global warming scenario, climate change projections from more than half the GCMs lead to decreases in mean annual runoff greater than 10 percent, and climate change projections from about one-quarter of the GCMs lead to increases in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other chapters, only results from an extreme ‘dry’, ‘mid’ and extreme ‘wet’ variant are shown – referred to as Cdry, Cmid and Cwet. 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 a -28, -9 and +31 percent change in mean annual runoff. By comparison, the range based on the low global warming scenario is -9 to +8 percent change in mean annual runoff.

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

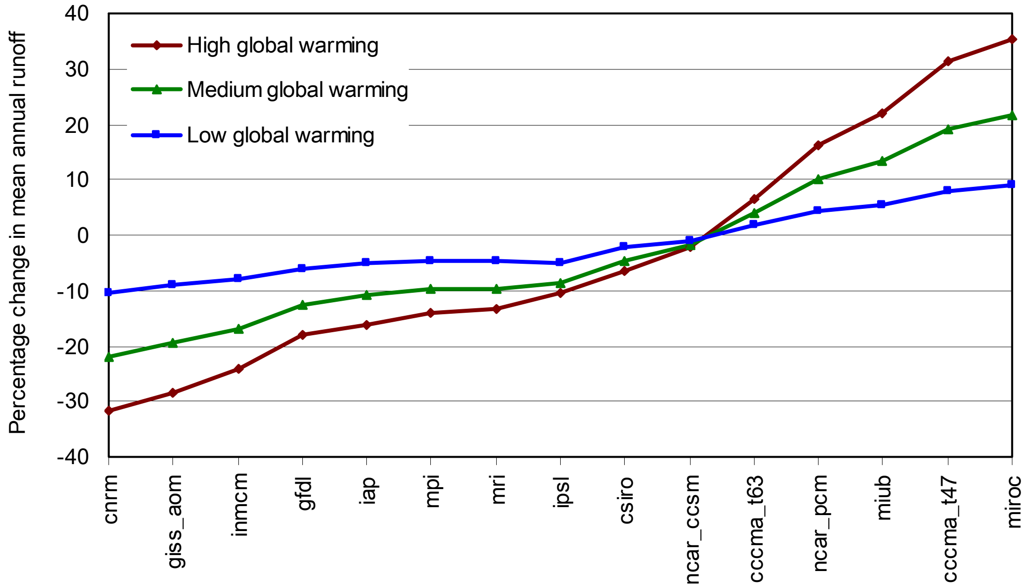

Figure 3-6. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 GCMs and three global warming scenarios) relative to Scenario A runoff

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

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Runoff	GCM	Rainfall	Runoff	GCM	Rainfall	Runoff
cnrm	-10	-32	cnrm	-6	-22	cnrm	-3	-10
giss_aom	**-10**	**-28**	giss_aom	-6	-19	giss_aom	-3	-9
inmcm	-8	-24	inmcm	-5	-17	inmcm	-2	-8
gfdl	-6	-18	gfdl	-4	-13	gfdl	-2	-6
iap	-4	-16	iap	-2	-11	iap	-1	-5
mpi	-6	-14	mpi	-4	-10	ipsl	0	-5
mri	-6	-13	mri	-4	-10	mpi	-2	-5
ipsl	0	-11	**ipsl**	**0**	**-9**	mri	-2	-5
csiro	-4	-6	csiro	-3	-5	csiro	-1	-2
ncar_ccsm	2	-2	ncar_ccsm	1	-2	ncar_ccsm	1	-1
cccma_t63	5	6	cccma_t63	3	4	cccma_t63	1	2
ncar_pcm	6	16	ncar_pcm	4	10	ncar_pcm	2	4
miub	6	22	miub	4	13	miub	2	5
cccma_t47	**12**	**31**	cccma_t47	7	19	cccma_t47	3	8
miroc	12	35	miroc	8	22	miroc	3	9

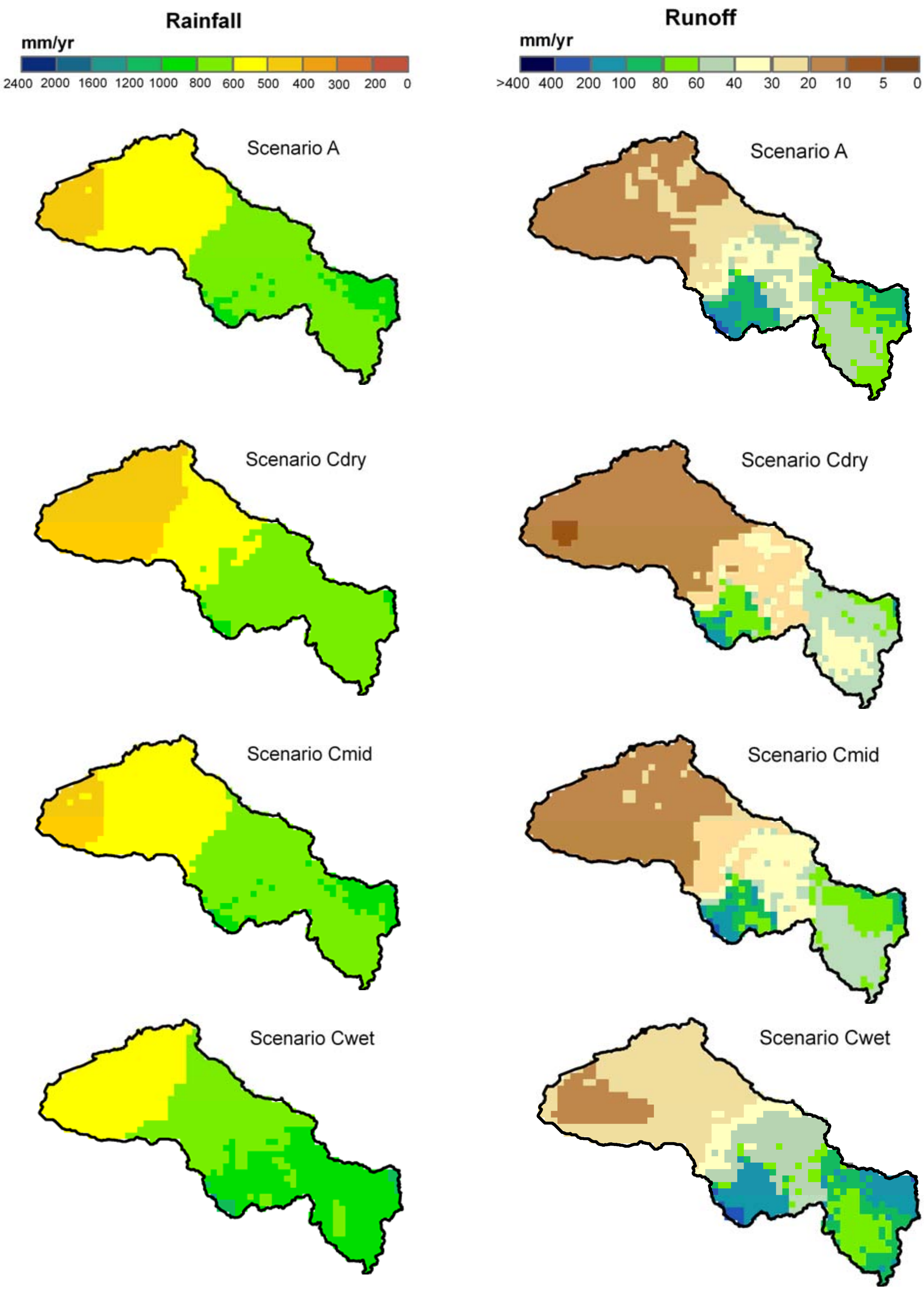

Figure 3-7. Mean annual rainfall and modelled runoff under scenarios A, Cdry, Cmid and Cwet

3.3.3 Summary results for all modelling scenarios

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

Figure 3-8 shows the mean monthly rainfall and modelled runoff for scenarios A, C and D averaged over 1895 to 2006 for the Gwydir region. Figure 3-9 shows the daily rainfall and flow duration curves for scenarios A, C and D averaged over the region. The modelling results for all the subcatchments in the Gwydir 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 3-9 are based on the second lowest and second highest daily rainfall and runoff results at each of the rainfall and runoff percentiles from the high global warming scenario. The lower and upper limits of C range are therefore not the same as the Cdry and Cwet scenarios reported elsewhere and used in the river system and groundwater models. Although two-thirds of the GCMs show a reduction in mean annual rainfall, more than 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).

Scenario B (recent climate and current development) modelling was not carried out for the Gwydir 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 a 9 percent reduction in mean annual runoff by ~2030 (Scenario C). However, there is considerable uncertainty in the results with extreme estimates ranging from -28 to +31 percent.

There is negligible projected growth in commercial forestry plantations in the Gwydir region. The total farm dam storage volume over the entire Gwydir region is projected to increase by 15.1 GL by ~2030. The best estimate of the combined impact of climate change and farm dam development (Scenario D) is a 10 percent reduction in mean annual runoff with extreme estimates ranging from -29 to +30 percent.

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

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	644	41	603
		percent change from Scenario A	
B	–	–	–
Cdry	-10%	-28%	-8%
Cmid	0%	-9%	0%
Cwet	12%	31%	10%
Ddry	-10%	-29%	-8%
Dmid	0%	-10%	0%
Dwet	12%	30%	10%

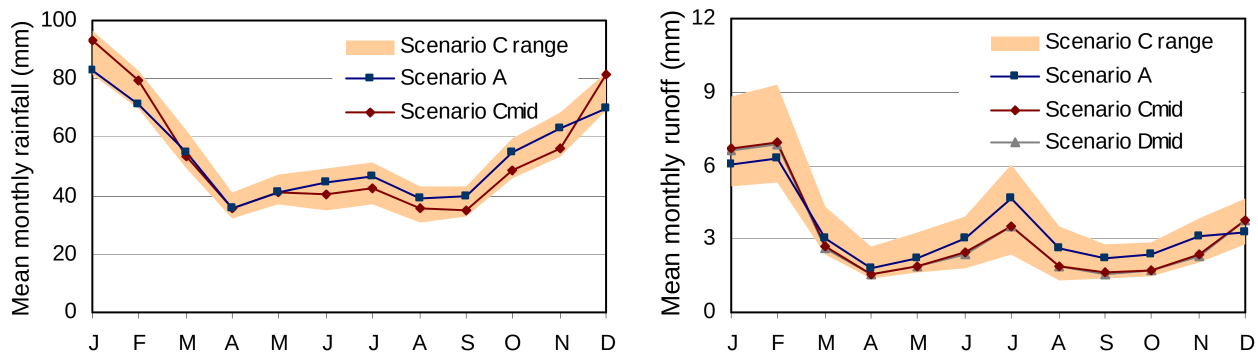

Figure 3-8. Mean monthly rainfall and modelled runoff under scenarios A, C and D averaged over 1895–2006 across the region (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

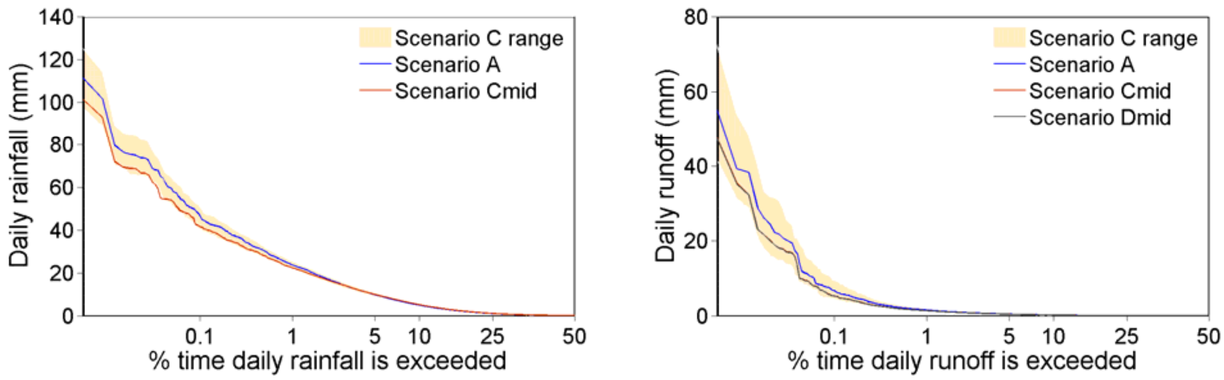

Figure 3-9. Daily flow duration curves under scenarios A, C and D averaged over the region (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

3.4 Discussion of key findings

The mean annual rainfall and modelled runoff averaged over the Gwydir region are 644 mm and 41 mm respectively. The mean annual rainfall varies from about 850 mm in the central-south and east to 500 mm in the west. The modelled mean annual runoff varies from about 100 mm in the central-south and east to 15 mm in the west. Rainfall is generally higher in the summer half of the year and runoff is fairly uniform throughout the year. The Gwydir region covers about 2.3 percent of the MDB and contributes about 3.4 percent of the total runoff in the MDB.

The mean annual rainfall and modelled runoff over the ten-year period 1997 to 2006 are 7 percent and 18 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 Gwydir 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 Gwydir 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 events will be more intense.

The best estimate is a 9 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 -28 to +31 percent. These extreme estimates come from the high global warming scenario, and for comparison the range from the low global warming scenario is -9 to +8 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.

There is negligible projected growth in commercial forestry plantations in the Gwydir region. The total farm dam storage volume over the entire Gwydir region is projected to increase by 15.1 GL by ~2030. The modelled reduction in mean annual runoff from the projected increase in farm dams alone is about 1.5 percent, a relatively small impact compared to the median climate change impact on runoff (9 percent). The best estimate of the combined impact of climate change and farm dam development is a 10 percent reduction in mean annual runoff with extreme estimates ranging from -29 to +30 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 Gwydir 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 Gwydir River system of the New South Wales Department of Water and Energy (DWE) (DNR, 2005).

4.1 Summary

4.1.1 Issues and observations

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

- Scenario O
  This scenario represents the latest version of the water sharing plan river system model supplied by DWE. It covers the original planning period (1 January 1890 to 30 June 2005) used by DWE to develop the Gwydir Regulated River Water Source Water Sharing Plan (WSP) (DIPNR, 2004) and represents 2002/03 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). 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 as Scenario A, that is, the current level of development.
- Scenario D – future climate and future development
  Scenarios Dwet, Dmid and Ddry incorporate Scenario C with flow inputs adjusted for 2030 projected development in farm dams, commercial forestry plantations and groundwater. Future groundwater effects on river reaches are also considered. The farm dam and commercial forestry plantation projections are discussed in Chapter 3 while groundwater development is discussed in Chapter 6.

The change in inflows between scenarios reported in this chapter differs from the changes in runoff reported in Chapter 3. This is due to the difference in areas that are considered to contribute runoff to the surface water model. In Chapter 3 the entire region is considered while a subset of this area is considered in this chapter.

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 Gwydir region is described by the Gwydir River system model. The Gwydir model:

- represents the 2002/03 level of irrigation development. This includes farm infrastructure and irrigated areas. Crop mix is adopted as per observed data in 2001/02. 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 represent current levels of development. The model also includes a risk function that adjusts areas planted according to water availability. Consequently the model represents the change in demand as a function of available resource and climatic conditions
- reflects town water supplies and stock and domestic demands with a fixed demand pattern that does not vary with water availability or climatic conditions. The only time that these demands are not met is when supply storages reach dead storage capacity, as these are high security users.

Analysis of the pre-development flows along the Gwydir system indicates that it changes from a gaining to a losing stream (point of maximum average annual flow) at the Gravesend gauge (418013). The pre-development average annual flow over the modelling period is 782 GL/year.

4.1.2 Key messages

- The average total surface water resources for the existing climate scenario in the Gwydir region is 782 GL/year and on average about 317 GL/year (or 41 percent) of this water is used. This is a very high level of development.
- Flows in the Gwydir River are highly regulated. Copeton Dam regulates 93 percent of all inflows. The maximum modelled years between spills is 32 years and spans the Federation drought.
- General security water in the Gwydir system is highly utilised with 54 percent of the allocated general security water used.
- Current levels of modelled groundwater extraction are not expected to have a net impact on the river system. Widespread streamflow losses totalling 4.4 GL/year are offset by more localised gains of 4.4 GL/year due to irrigation recharge.
- Under the best estimate 2030 climate there would be a 10 percent reduction in water availability, a 6 percent reduction in end-of-system flows and an 8 percent reduction in diversions overall. Diversion impacts would differ between water products. General security water use would decrease by 9 percent. Surplus access would reduce by 7 percent while high security town water supplies are not impacted.
- The climate extremes for 2030 indicate:
    - under the wet extreme there would be increases of 34 percent in water availability, 20 percent in total diversions and 33 percent in end-of-system flows
    - under the dry extreme there would be decreases of 29 percent in water availability, 25 percent in total diversions and 27 percent in end-of-system flows
    - no reduction in high security and town water supply. For high security irrigators the usage increases in the mid and dry future climate scenarios by 3 percent and 7 percent respectively. This is due to under-utilised water being used to meet the increased crop demands.
- The impacts of additional future farm dams and the larger impacts of future increases in groundwater extraction were included in the river modelling. The combined inflow reduction (under the best estimate future climate) would be 24 GL/year (or 2 percent). Of this, 13 GL/year would be due to farm dams and 11 GL/year would be due to increases in groundwater extraction. There would also be an average net streamflow leakage to groundwater of 2 GL/year. Diversions would reduce by an additional 3 percent to be 11 percent lower than current. The impact on average end-of-system flows would be a total reduction (development and climate impacts) of 8 percent. The relative level of use would be 43 percent – this is a very high level of development and is 2 percent higher than the current level.

4.1.3 Robustness

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

Allocations were at zero percent for 53 years and Copeton Dam was drawn down close to dead storage (1364 ML) at 1983 ML during the test and the model 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 0.01 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 Gwydir River model and how the model was developed. Chapter 1 contains more details on the overall project methodology.

4.2.1 General

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

4.2.2 Model description

The Gwydir region is described by the Gwydir River system model (Figure 4-1) based on IQQM V7.60.7. The model commences with headwater inflows from the Gwydir River and Copes Creek into Copeton Dam. The model ends at three locations: Gil Gil Creek after the return of Gingham Watercourse flows, Gwydir River at Collymongle (418031), and Mehi River at Collarenebri (418055). These three outflows are inflows into the Barwon-Darling system.

The model represents the Gwydir system with 301 links and 302 nodes arranged into 29 river sections. There are no natural weir pools and floodplains included in the Gwydir model. The Gwydir wetlands are not explicitly modelled and are implicitly modelled as part of the distributary network at the end of the Gwydir model. Copeton Dam is the only regulated storage in the model (Table 4-1).

The water use is modelled by 55 nodes: 27 general security irrigators, three town water supplies and one high security irrigator (Table 4-2).

Colly Farms irrigation node is able to divert water from both the Gwydir region and the Barwon-Darling region. The extraction from the Barwon region is assumed to be a fixed time series that does not vary between scenarios in the Gwydir model. Preliminary investigations of this simplification indicate that this will not have a significant impact on the Gwydir results. The extraction from the Barwon-Darling region is not accounted for in the Gwydir model mass balance.

The Colly Farms irrigation node is also included in the Barwon-Darling river system model and uses a time series input of total diversions from the Gwydir model that varies between scenarios. In the Barwon-Darling model the extractions from the Barwon-Darling for each scenario are accounted for in the mass balance but the extractions from the Gwydir are not. This approach avoids double accounting of Colly Farms diversions.

The model includes minimum and maximum flow requirements. There is a minimum flow requirement of 10 ML/day at each of the end-of-system gauges. There are maximum flow constraints of 1800 ML/day for Moomin Creek and 5000 ML/day for the Mehi River downstream of the Moomin offtake. The maximum flow constraints limit the regulated supply to the respective limits (Table 4-3).

Surplus flow events upstream of the Mehi offtake are declared when they exceed 500 ML/day and are shared such that 50 percent is not diverted for consumptive use. Surplus flows are shared to consumptive users according to general security licence shares and usage is capped to 178 GL/year. Non-diverted surplus is regulated to the Gwydir River past the Yarraman gauge to replenish key wetlands. Additionally, any flows below 500 ML/day are also regulated to the Yarraman gauge. There is also an Environmental Contingency Allowance (ECA) of 45 GL/year general security water used to supplement events into key wetlands.

Gwydir general security users operate under a continuous accounting scheme. General security users can hold up to 150 percent of their entitlement in storage but are restricted to use 125 percent of their entitlement within a water year. They may not take more than 300 percent in any three-year period. A maximum of 200 percent of ECA annual entitlement can be carried from one year to another, but there is no limit on annual usage (i.e. 200 percent entitlement plus any inflows within a year).

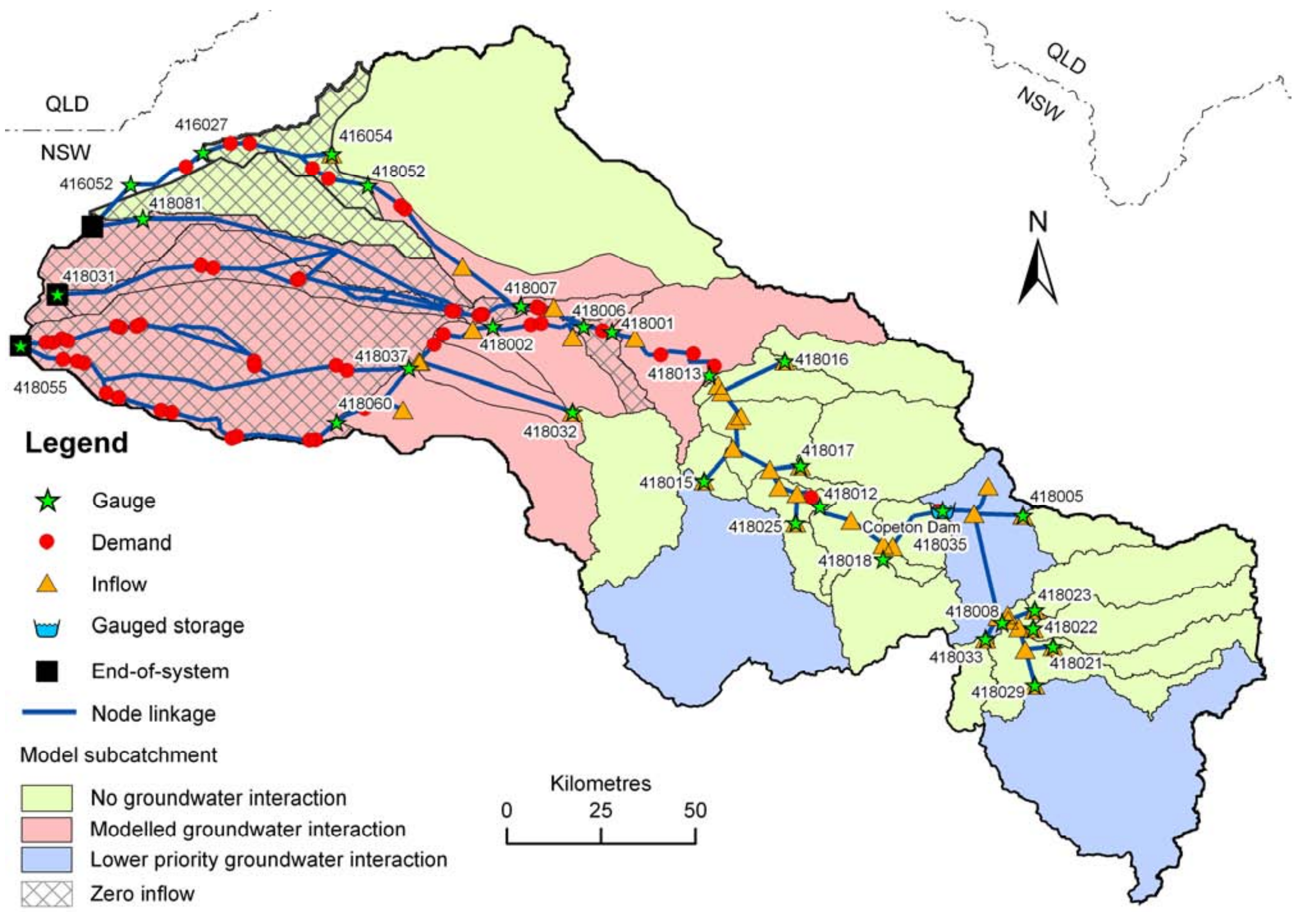

Figure 4-1. River system map showing model subcatchments, reaches, inflow nodes, links and gauge locations

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					
Copeton Dam	1345.51	396.8	347.4	23.3	0.93
Private storage					
On-farm storage	520.8				
Region totals	1866.31	396.8	347.4	23.3	0.93

Table 4-2. Modelled water use configuration

Water users	Number of nodes	Licence	Pump constraints	Planted area	Model notes
		GL	ML/d	ha	
Irrigation					Soil moisture accounting separate store for each crop
General security	27	514.0	21,712	102,624	On-farm storage at nodes
High security	1	13.4	139	700	Crops are changed based on available resources
Surplus flow access	27	178	600		
Town water supply	3	3.8			Fixed demand
Environmental contingency allowance		45			To supplement events to wetlands
Sub-total	**55**	**709.2**	**22,451**	**653,186**	
Crops					
Cottons				82,089	
Lucerne				614	
Pecans				700	
Summer cereal				9,949	
Winter cereal				404	
Wheat				9,568	
Others				404	
Sub-total				**103,324**	

Note the areas used in the Gwydir model are based on irrigation returns that are verified by New South Wales government meter inspectors. This is a different source of information to the numbers reported in Chapter 2.

Table 4-3. Model water management

Flow requirements	
Gil Gil Creek	End-of-system flow 10 ML/d
Gwydir River at Collymongle	End-of-system flow 10 ML/d
Mehi River at Collarenabri	End-of-system flow 10 ML/d
Moomin Creek	Maximum flow 1800 ML/d
Mehi River below Moomin offtake	Maximum flow 5000 ML/d
Surplus flow sharing	
Above Mehi River offtake	Surplus flows shared in excess of 500 ML/d
Sharing	50% water users, 50% environment (targeted to Gwydir Wetlands)
Tributary inflow usage	Up to 500 ML/d are protected from irrigation extraction and are targeted to Gwydir Wetlands
Environmental Contingency Allowance	
ECA	45 GL, maximum of 200% of annual entitlement that can be carried from one year to another, with no limit on annual usage
Gwydir system	Continuous accounting 150% max, 125% use/y, 300% over 3 consecutive years

4.2.3 Model setup

The original Gwydir River model and associated IQQM V7.60.7 executable code were obtained from DWE. This model was run for the original period of 1 January 1890 to 30 June 2005 and was validated against previous results.

The time series rainfall, evaporation and flow inputs to this model did not require extension as this had already been done by DWE. However transfers from the Barwon-Darling model were adjusted to include recent model results for the Barwon-Darling IQQM starting from 1 January 1891 to 30 June 2006.

A pre-development version of the Gwydir model was created by removing Copeton Dam, all irrigators and fixed demands. Several of the regulated distributaries in the model were modified to match pre-development distributary characteristics. A consequence of this is a different distribution of flows in Gil Gil Creek, Gwydir River, Moomin Creek and Mehi River.

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

The model was configured for an extreme dry climate scenario by applying seasonal factors to rainfall, evaporation and inflows (Table 4-5). The model was run and behaved robustly, allocations reached zero percent for 53 years, while Copeton Dam was close to dead storage volume.

Table 4-4. Model setup information

Model setup information		Version	Start date	End date
Gwydir	IQQM	7.60.7	01/01/1890	30/06/2005
Connection				
Gwydir River at Collymongle Gauge	Outflows to the Barwon River			
Mehi River at Collarenabri Gauge	Outflows to the Barwon River			
Gil Gil Creek after confluence with Gingham Watercourse	Outflows to the Barwon River			
Baseline models				
Warm-up period			01/06/1895	30/06/1895
Gwydir	IQQM	7.60.7	01/06/1895	30/06/2006
Connection				
Gwydir River at Collymongle Gauge	Outflows to the Barwon River			
Mehi River at Collarenabri Gauge	Outflows to the Barwon River			
Gil Gil Creek after confluence with Gingham Watercourse	Outflows to the Barwon River			
Modifications				
Data	No data extension required			
Inflows	Residual catchments input time series downstream of loss nodes			
Groundwater loss and gain nodes	Added 20 loss nodes and 8 gain nodes			
Initial storage volume Copeton Dam	1011.15 GL			
Initial storage volume for on-farm storages	Set to level at 31/05/1895			

Warm-up test results				
Setting initial storage volumes	Storages commence empty	Storages commence full	Difference	Percent of full volume
	GL			percent
Copeton Dam storage volume 31/05/1895	1003.2	1019.1	15.9	1.17%
On-farm storages volume at 31/05/1895	86.4	86.2	-0.2	-0.04%
Storage volume 30 May (1895–-2006)	Mean	Median		
	GL			
Copeton Dam	455.3	313.7		
On-farm storages	98.7	61.9		
Robustness test results				
Copeton Dam volume (DSV 1364 ML)	1983 ML			
Years allocation less than 0.5%	53 years			

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

Season	Rainfall	Evaporation	Flow
DJF	0.995	1.064	0.954
MAM	0.943	1.063	0.798
JJA	0.825	1.061	0.445
SON	0.893	1.078	0.640

4.3 Modelling results

4.3.1 River system water balance

The mass balance table (Table 4-6) shows the net fluxes for the Gwydir 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 Gwydir River at Collymongle, Mehi River at Collarenabri and Gil Gil Creek after the confluence with the Gingham Watercourse. The change in storage between 30 June 1895 and 30 June 2006 averaged over the 111-year period is also included. The net evaporation and rainfall harvesting 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 14 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 there was no difference.

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

	O	AO	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	01/01/1890	01/07/1895	01/07/1895	01/07/1895	01/07/1895	01/07/1895	01/07/1895	01/07/1895	01/07/1895
Model end date	30/06/2005	30/06/2006	30/06/2006	30/06/2006	30/06/2006	30/06/2006	30/06/2006	30/06/2006	30/06/2006
	GL/y			percent change from Scenario A					
Storage volume – Copeton Dam									
Change over period	-5.3	-4.5	-4.7	-34%	2%	17%	-30%	6%	21%
Private storages	1.0	-0.4	-0.4	-50%	11%	36%	-48%	12%	34%
Inflows									
Subcatchments									
Directly gauged	791.8	710.9	710.9	32%	-9%	-28%	29%	-12%	-31%
Indirectly gauged	383.0	394.2	394.2	33%	-9%	-29%	31%	-10%	-31%
Sub-total	**1174.8**	**1105.1**	**1105.1**	**32%**	**-9%**	**-29%**	**30%**	**-11%**	**-31%**
Groundwater Gain	0.0	0.0	4.4	27%	12%	-6%	28%	13%	-4%
Sub-total	**1174.8**	**1105.1**	**1109.6**	**32%**	**-9%**	**-29%**	**30%**	**-11%**	**-31%**
Diversions									
Licenced private diversions									
General security (entitlement 513.99 GL)	200.2	195.0	195.3	22%	-9%	-30%	19%	-13%	-34%
High security (entitlement 13.41 GL)	9.4	9.5	9.5	0%	3%	7%	0%	3%	7%
Supplementary flow access (cap 178 GL)	104.0	100.5	100.4	19%	-7%	-20%	18%	-8%	-21%
Floodplain harvesting	7.7	7.7	7.7	15%	-9%	-26%	13%	-12%	-28%
Urban									
Town water supply (entitlement 3.83 GL)	3.8	3.8	3.8	0%	0%	0%	0%	0%	0%
Sub-total	**325.1**	**316.6**	**316.7**	**20%**	**-8%**	**-25%**	**18%**	**-11%**	**-28%**
Outflows									
End-of-system outflow									
Gwydir River at Collymongle Gauge	6.0	5.2	5.1	56%	-15%	-39%	53%	-16%	-40%
Mehi River at Collarenebri Gauge	109.8	102.3	102.3	37%	-5%	-26%	34%	-7%	-28%
Gil Gil Creek after confleunce with Gingham Watercourse	87.2	81.6	81.5	26%	-7%	-26%	24%	-9%	-28%
Sub-total	**203.0**	**189.1**	**188.9**	**33%**	**-6%**	**-27%**	**30%**	**-8%**	**-29%**
Groundwater loss	0.0	0.0	4.4	-3%	-10%	-8%	41%	34%	36%
Net evaporation									
Copeton Dam	24.4	23.3	23.4	24%	-2%	-16%	22%	-4%	-18%
Sub-total	**227.4**	**212.4**	**216.7**	**31%**	**-6%**	**-25%**	**30%**	**-7%**	**-26%**
Unattributed fluxes									
Unattributed flux	627.6	580.7	580.9	39%	-11%	-31%	36%	-13%	-33%
Additional information (not in mass balance)									
Net evaporation from private storages*	130.3	127.8	127.9	10%	0%	-10%	9%	0%	-11%
Irrigator rainfall harvesting*	116.2	116.8	116.8	20%	2%	-15%	20%	2%	-15%

* Already included in irrigation diversions

4.3.2 Inflows and water availability

Inflows

There are several ways that the total inflows into the river system can be calculated. The obvious way would be to sum all of the inflows in the model. This is 1105 GL/year (Table 4-6) for the Gwydir IQQM. However, 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 land use (farm dams and forest cover) and groundwater use impacts. Additionally the calibrated reaches in the river model implicitly include losses to groundwater. Thus the pre-development scenario is not a representation of pre-European settlement conditions.

The pre-development model was run for current climate and each of the C climate scenarios. In some regions a degree of streamflow leakage induced by current groundwater use in other parts of the region is implicitly included in the river model calibration. Another adjustment to the modelled pre-development water availability is required to assess the total pre-development surface water availability, as this is water that is removed from the river due to groundwater extraction. In the Gwydir region, however, no such adjustment was necessary as there is no streamflow leakage implicit in the river model calibration. No adjustments were made in determining surface water availability in scenarios A and C 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.

This can be repeated for each of the climate scenarios by running the pre-development model with each of the climate scenario inputs. The three end-of-system subcatchments with distributary rivers (Gil Gil Creek, Gwydir River at Collymongle and Mehi River at Collarenabri) were summed together to get a total flow for the distributaries.

A comparison between scenarios for reaches (Figure 4-1) along the Gwydir is shown in Figure 4-2. Displaying this transect for the Gwydir system is difficult as there is a braided network at the end of the system. The headwater catchment is above Copeton Dam in this analysis. The transect then follows the Gwydir River down to Tareelaroi Weir (418006) where the Mehi River distributary begins. The combined flows of the various distributaries are considered after this point. Based on this description of the system the location of maximum average annual mainstream flow occurs in subcatchment 4180135 at the Gravesend gauge (418013) with a value of 782 GL/year for the pre-development Scenario A.

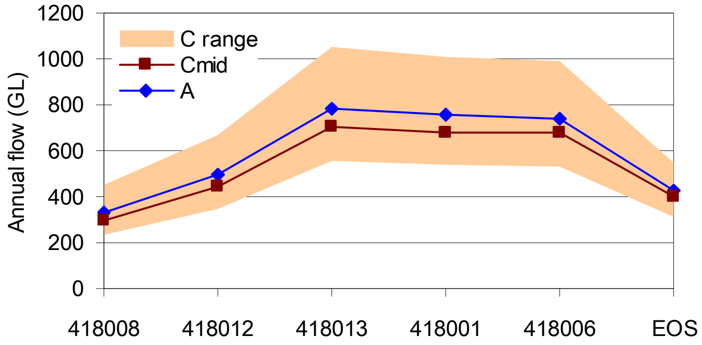

Figure 4-2. Transect of total river flow under pre-development scenarios A and C

Water availability

Table 4-7 shows the maximum mean annual mainstream flow under pre-development scenarios A and C. The point of maximum water availability was taken as the sum of selected inflows under Scenario O and associated modelling period, for the Gwydir Regulated River Water Source WSP (DIPNR, 2004). The value in the WSP is 1141 GL/year. The assessed maximum mainstream mean annual flow of 782 GL/year (Figure 4-2) differs from the WSP value because it is for a different location, is for pre-development conditions and is for a different modelling period.

Table 4-7. Average annual surface water availability for pre-development Scenario A and relative change under pre-development Scenario C

	A	Cwet	Cmid	Cdry
	GL/y			
Total surface water availability (pre-development maximum mean annual mainstream flow)	781.6	1050.7	704.0	554.1
	percent change from Scenario A			
Change in average surface water availability	–	34%	-10%	-29%

A time series of total annual surface water availability under pre-development Scenario A is shown in Figure 4-3. The lowest annual total surface water availability was 75 GL in 1957 while the greatest annual water availability was 3801 GL in 1955. Figure 4-4 shows the difference in annual total surface water availability from pre-development Scenario A to pre-development Scenario C.

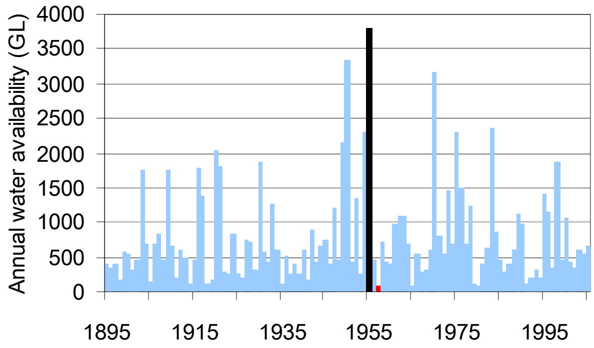

Figure 4-3. Pre-development Scenario A water availability

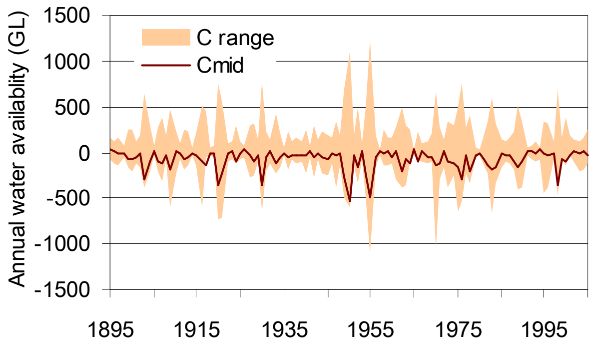

Figure 4-4. Time series of change in total surface water availability relative to pre-development Scenario A under pre-development Scenario C

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 4-8 provides indicators that show the lowest recorded storage volume and the corresponding date for Copeton Dam for each of the scenarios. The average and maximum years between spills is also provided. The period between spills was defined for this study as commencing 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 4-8. Details of Copeton Dam behaviour

Copeton Dam	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Minimum storage volume (GL)	62.63	85.91	69.46	40.83	79.01	59.65	23.47
Minimum storage date	12/06/1920	12/06/1920	12/06/1920	28/04/1983	12/06/1920	28/04/1983	28/04/1983
Average years between spills	8.4	4.8	24.5	30.1	4.8	24.5	30.2
Maximum years between spills	31.8	17.7	55.1	55.1	17.7	55.1	55.1

The time series of storage behaviour for Copeton Dam for the maximum period between spills for each of the scenarios is shown in Figure 4-5.

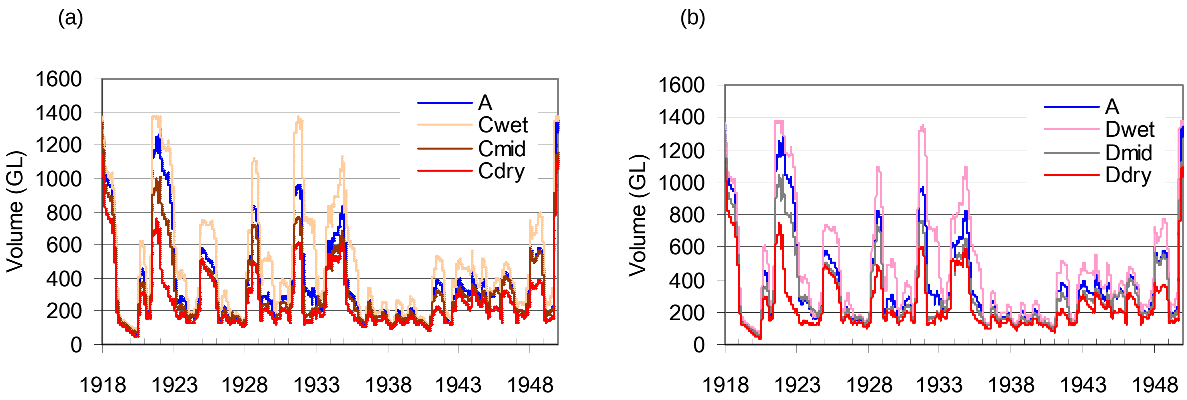

Figure 4-5. Copeton Dam behaviour over the maximum days between spills under Scenario A, with change in storage behaviour under (a) Scenario C and (b) Scenario D

4.3.4 Consumptive water use

Diversions

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

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

Reach	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change relative to Scenario A					
4180081	0.0	0%	0%	0%	0%	0%	0%
4180124	3.0	0%	0%	0%	0%	0%	0%
4180351	0.0	0%	0%	0%	0%	0%	0%
4180135	0.7	0%	0%	0%	0%	0%	0%
4180011	10.7	1%	3%	6%	1%	3%	6%
4180062	2.7	20%	-7%	-28%	18%	-10%	-32%
4160271	30.2	19%	-7%	-25%	18%	-10%	-27%
4180021	1.9	25%	-10%	-31%	23%	-13%	-35%
4180071	22.3	27%	-11%	-30%	25%	-14%	-32%
4180311	41.5	21%	-8%	-26%	19%	-10%	-28%
4180373	4.2	32%	-14%	-35%	29%	-17%	-38%
4180521	46.4	24%	-11%	-29%	22%	-14%	-31%
4180551	152.9	19%	-8%	-26%	17%	-11%	-29%
4180810	0.0	0%	0%	0%	0%	0%	0%
Total	**316.7**	**20%**	**-8%**	**-25%**	**18%**	**-11%**	**-28%**

Figure 4-6 shows total average annual diversions under scenarios A, C and D from upstream to downstream. The usage for reach 4180011 increases during dry climate conditions. This is due to a high security irrigator using more of their entitlement to meet increased crop demands.

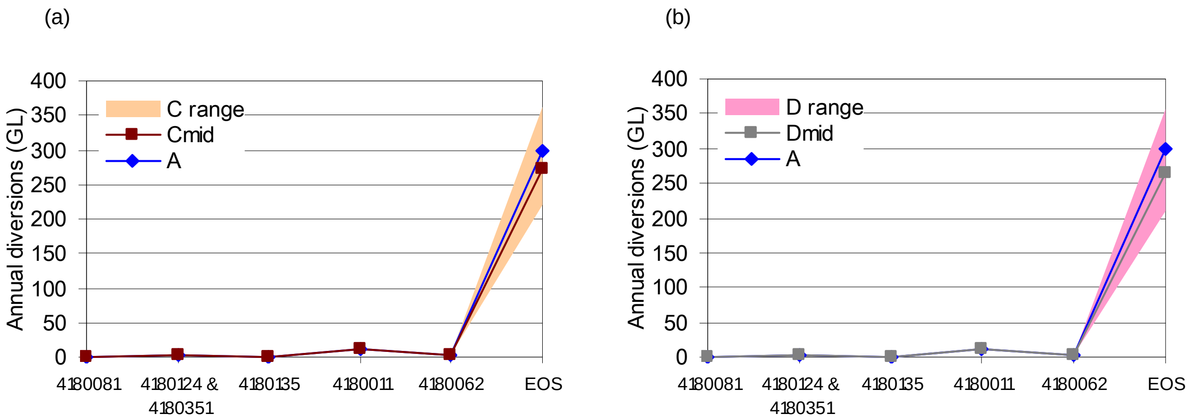

Figure 4-6. Total average annual diversions for subcatchments under (a) scenarios A and C and (b) scenarios A and D

Figure 4-7 shows the annual time series of total diversions under Scenario A and the difference from Scenario A for scenarios C and D. The maximum and minimum diversions under Scenario A are 723 GL in 1951 and 36 GL in 1980 respectively.

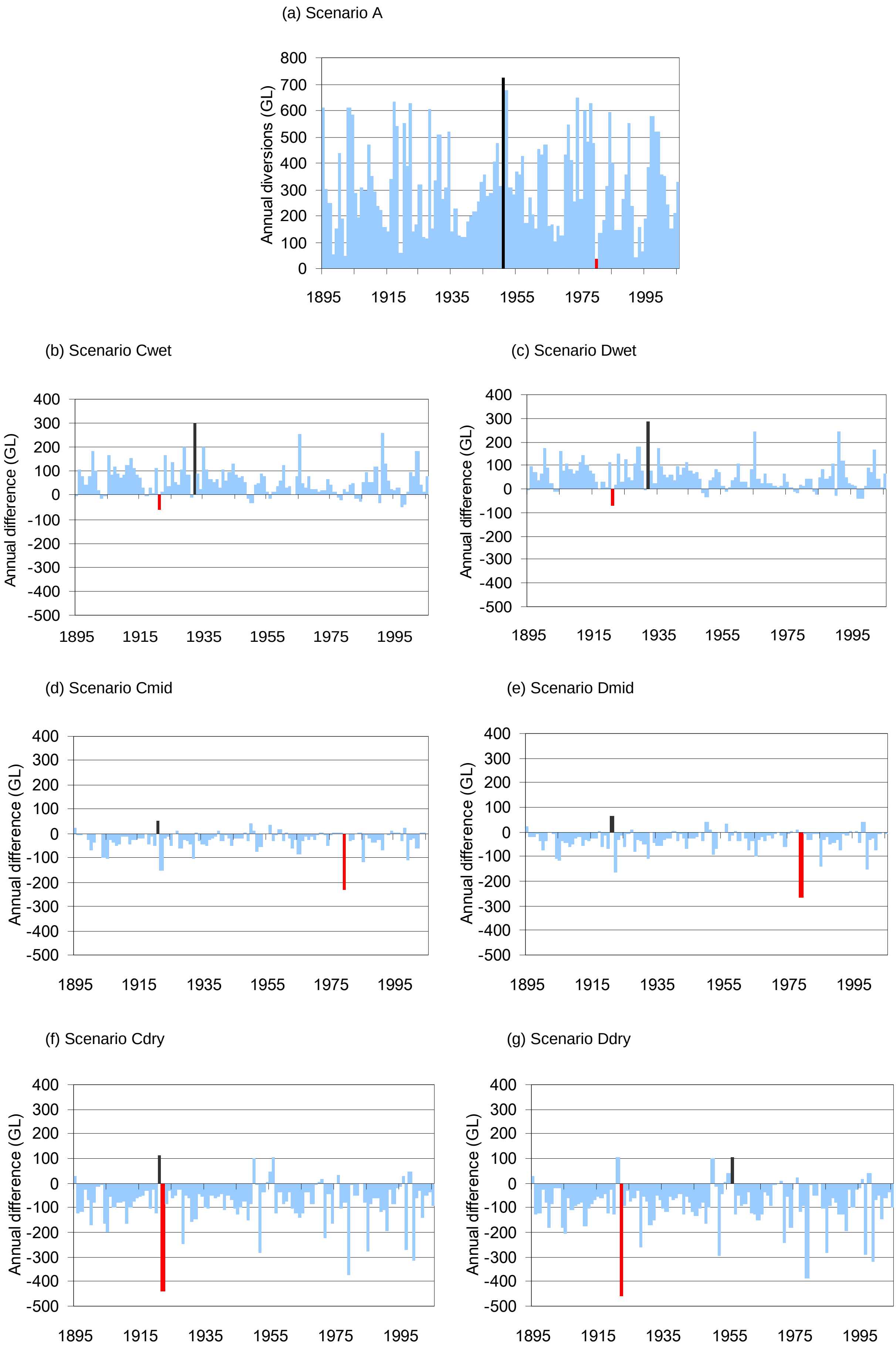

Figure 4-7. Total diversions for (a) Scenario A and difference between total water under (b) Scenario Cwet, (c) Scenario Dwet, (d) Scenario Cmid, (e) Scenario Dmid, (f) Scenario Cdry and (g) Scenario Ddry

Level of use

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

Subcatchment use includes:

- the inflow impacts due to groundwater use. There is no groundwater use implicit in the inflows during model calibration
- inflow impacts due to future farm dams
- an adjustment of these impacts to transfer them to the point of maximum flow. This is done by multiplying all scenarios by the current conditions ratio of flow at the point of maximum flow (782 GL/year) and total inflow (1105 GL/year).

Streamflow use includes:

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

Table 4-10 shows the level of use indicators for each of the scenarios. The level of use is relatively high with 41 percent of the total available surface water resource being diverted for use. Average water use for the Gwydir is reported as 392 GL/year in the WSP (DIPNR, 2004) based on an earlier version of the Gwydir model. This value for use, together with the assessed water availability in the WSP (based on summed inflows), implies a relative level of development of 34 percent. The difference between these two values is primarily due to a different approach to assessing water availability. Also, however, the value of 41 percent is based on a different model and a different water year, and is assessed over a different period. The higher value is considered to be a more realistic assessment of the level of use as it is based on a more robust assessment of water availability.

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

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Total surface water availability	781.6	1049.4	703.1	554.0	1049.4	703.1	554.0
Subcatchment use							
Groundwater use impacts	0.0	0.0	0.0	0.0	7.9	7.9	7.9
Future farm dam impacts	0.0	0.0	0.0	0.0	9.9	9.0	7.9
Future commercial plantation forestry impacts	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Streamflow use							
Total net diversions	316.7	379.2	291.2	236.1	373.3	283.3	227.9
Leakage induced by groundwater use	0.0	-1.3	-1.0	-0.1	0.6	0.9	1.8
Total use	316.7	377.9	290.2	236.0	391.6	301.1	245.5
	percent						
Relative level of use	41%	36%	41%	43%	37%	43%	44%

Use during dry periods

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

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

Annual Diversion	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y	percent change from Scenario A					
Lowest 1-year period	35.5	42%	-12%	-54%	32%	-15%	-55%
Lowest 3-year period	88.3	77%	-1%	-50%	70%	-7%	-57%
Lowest 5-year period	137.9	56%	-20%	-49%	51%	-25%	-53%
Average	316.7	20%	-8%	-25%	18%	-11%	-28%

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 Gwydir region is compared against a licence volume of 513.99 GL, high security irrigation use is compared against a licence volume of 13.41 GL, high security town water supply use is compared against a licence volume of 3.83 GL and the surplus flow access is compared against the 178 GL annual cap. The average reliabilities have been calculated are shown in Table 4-12. The supplementary access is more reliable than the regulated supply.

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

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	percent						
Licensed private usage							
General security (entitlement 513.99 GL)	38%	46%	35%	26%	45%	33%	25%
High security (entitlement 13.41 GL)	71%	71%	73%	76%	71%	73%	76%
Surplus flow access + floodplain harvesting	61%	72%	56%	48%	71%	56%	48%
Urban supply							
Town water supply (entitlement 3.83 GL)	100%	100%	100%	100%	100%	100%	100%

Note: The usage of town water supplies are fixed in the model to represent full utilisation of licences. Consequently the level of under-utilisation is zero for Gwydir town water supplies as usage is equal to the available licence.

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

Figure 4-8 shows the difference between the maximum yearly allocated general security water and the general security use for each of the scenarios in volume reliability plots.

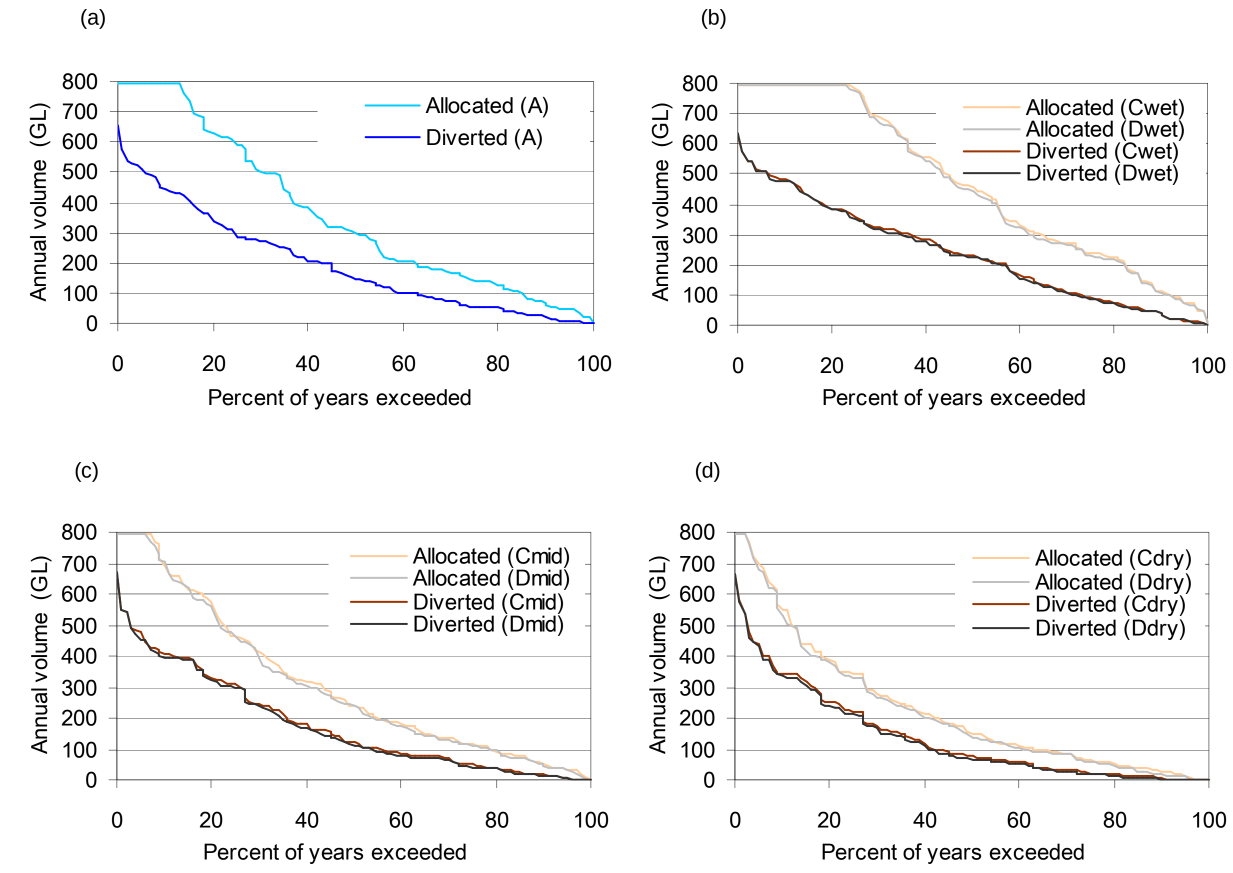

Figure 4-8. General security reliability under scenarios (a) A, (b) Cwet and Dwet, (c) Cmid and Dmid, and (d) Cdry and Ddry

Figure 4-9 shows the reliability of supplementary water access for Gwydir for each of the scenarios.

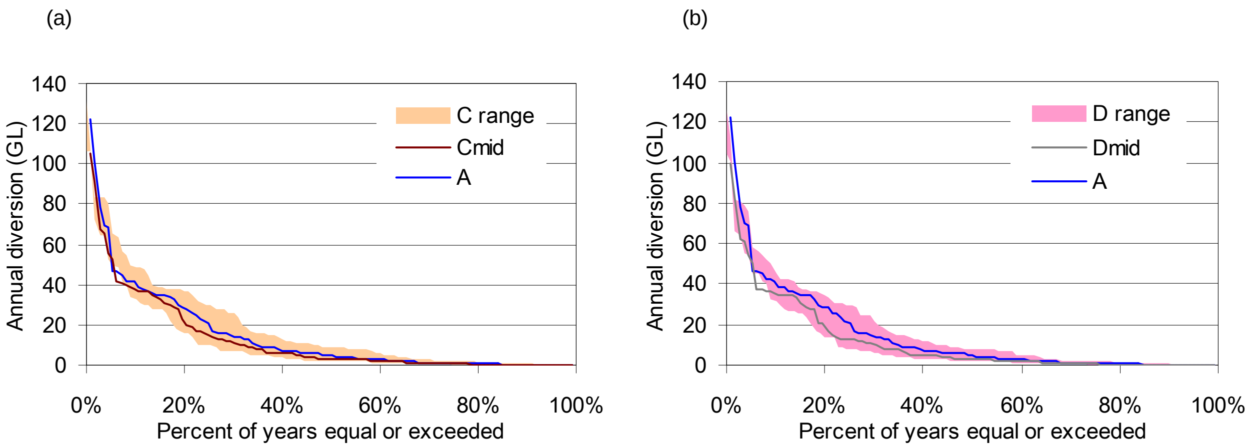

Figure 4-9. Reliability of supplementary water under (a) Scenario C and (b) Scenario D

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

Table 4-13. Average level of utilisation of general security water

	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
	GL/y						
Allocated water	358.4	464.5	310.0	226.1	457.8	301.5	217.9
Diversion	195.3	237.3	177.4	135.9	232.9	170.8	128.8
Difference	163.1	227.2	132.6	90.2	224.8	130.7	89.1

4.3.5 River flow behaviour

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

Mid-river flow characteristics

The flow regime will vary depending on the location in the river that is selected. The location of the middle of the system is defined as the position where the river changes from gaining to losing for this analysis. The selection of this site is discussed in Section 4.3.2. This is the Gravesend gauge (418013) for the Gwydir River system.

Figure 4-10 shows the daily flow duration curves under Scenario A and Scenario P and the range of change under scenarios C and D. The flow duration curves show the change in frequency between scenarios for a given flow. The vertical difference between flow duration curves shows the change in mass between scenarios, although care needs to be taken as the plots use a logarithmic scale that distorts the difference of lower flows and hides the differences at higher flows. Flows below 10 ML/day are not relevant as this is within the accuracy of streamflow measurement.

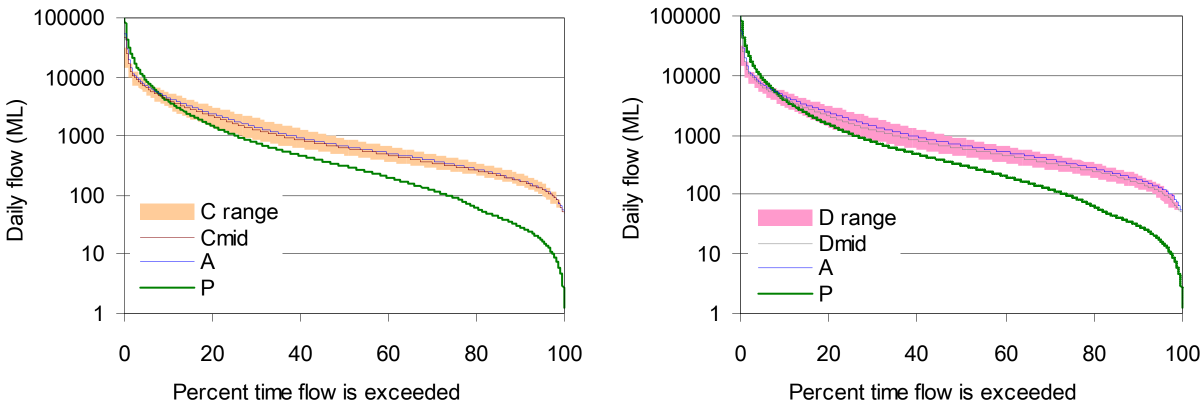

Figure 4-10. Daily flow duration curves at Gravesend gauge (418013) under scenarios A, P, C and D

Figure 4-11 shows the mean monthly flow under the pre-development Scenario P and Scenario A. This shows that the seasonality in the middle of the river is similar between pre-development and Scenario A with the major differences occurring in December when flows are higher to meet downstream demands, and in winter when storages are catching inflows.

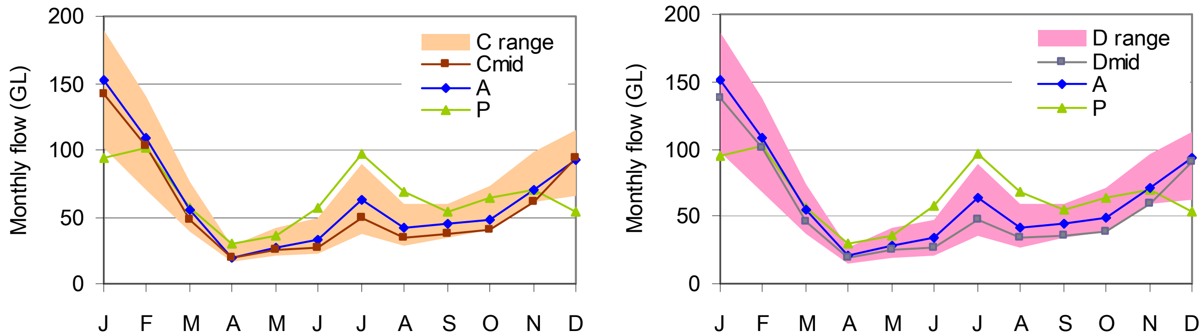

Figure 4-11. Average monthly flow at the end of the gaining reach under scenarios P, A, C and D

Table 4-14 shows the size of daily events with two-, five- and ten-year recurrence intervals under scenarios P, A, C and D. This analysis estimates the average peak daily flow and not the peak flow for a day, which is considerably higher in most river systems. The table shows that from pre-development to Scenario A there has been a 15 percent reduction in the size of two-year events, a 26 percent reduction in five-year events and a 17 percent reduction in ten-year return interval events.

Table 4-14. Daily flow event frequency 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	53,889	45,897	28%	-20%	-35%	27%	-20%	-35%
5	101,343	74,954	47%	-20%	-25%	46%	-21%	-26%
10	142,240	117,927	27%	-14%	-24%	27%	-15%	-24%

End-of-system flow characteristics

Figure 4-12 show the flow duration curves for the three end-of-systems locations: from Gil Gil Creek, Gwydir River at Collymongle and Mehi River at Collarenabri under scenarios P, A, C and D.

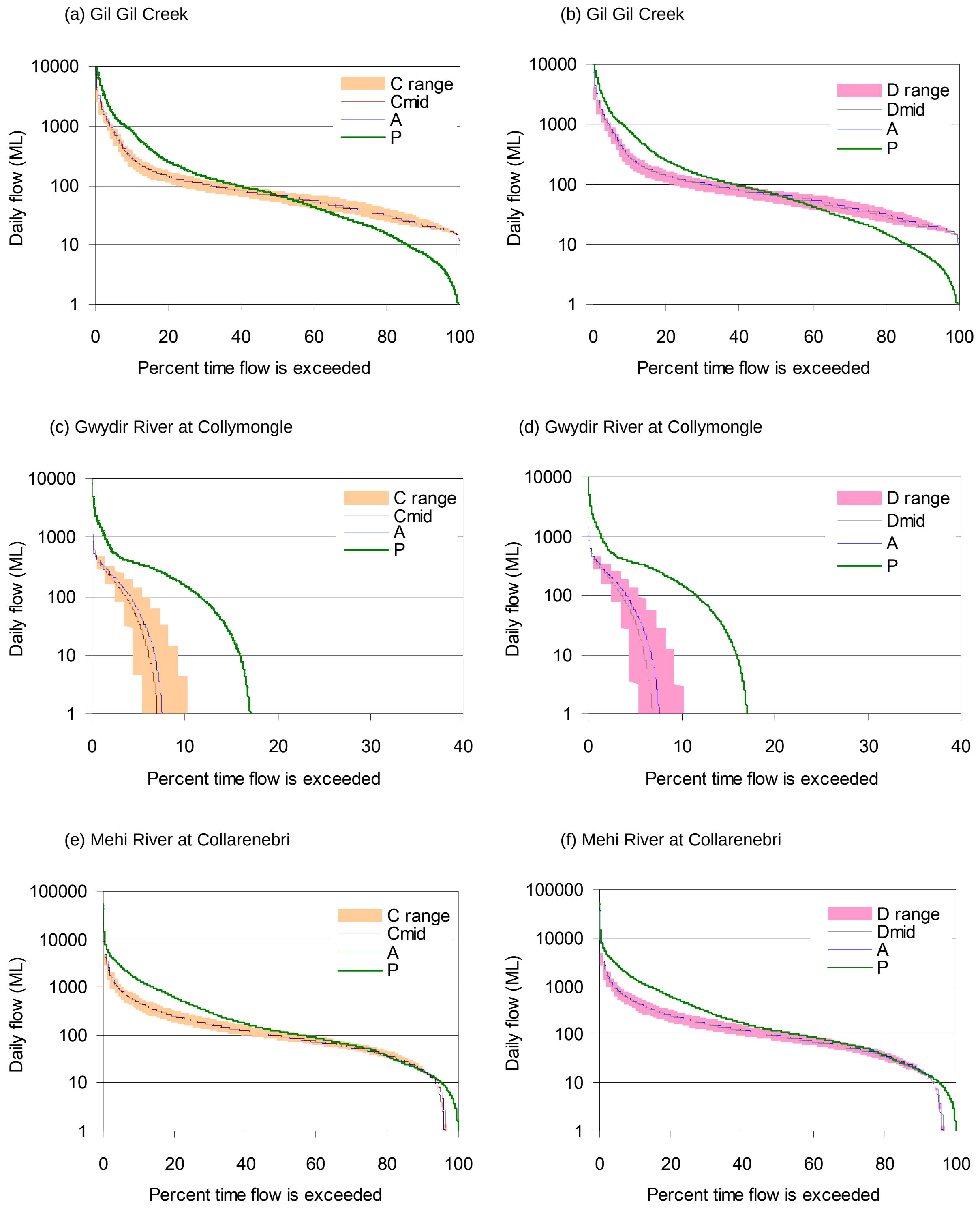

Figure 4-12. Daily flow duration curves for lower end of flows for each end-of-system flow gauge at: Gil Gil Creek, under scenarios (a) P, A and C and (b) P, A and D, Gwydir River at Collymongle under scenarios (c) P, A and C and (d) P, A and D, and Mehi River at Collarenabri under scenarios (e) P, A and C and (f) P, A and D

Figure 4-13 show the mean monthly flow under the pre-development Scenario P, Scenario A, Scenario C and Scenario D for each of the end-of-system flow gauges. This shows that there has been an overall reduction in flows across all seasons from pre-development.

The Cmid flows for the spring months are outside of the indicated C range flows. This is because the C range is described by the Cdry and Cwet scenarios each of which is based on the results from a single global climate model selected according to mean annual runoff values. The seasonal patterns from these different global climate models do not necessarily follow the seasonal patterns of the global climate model used to generate Cmid.

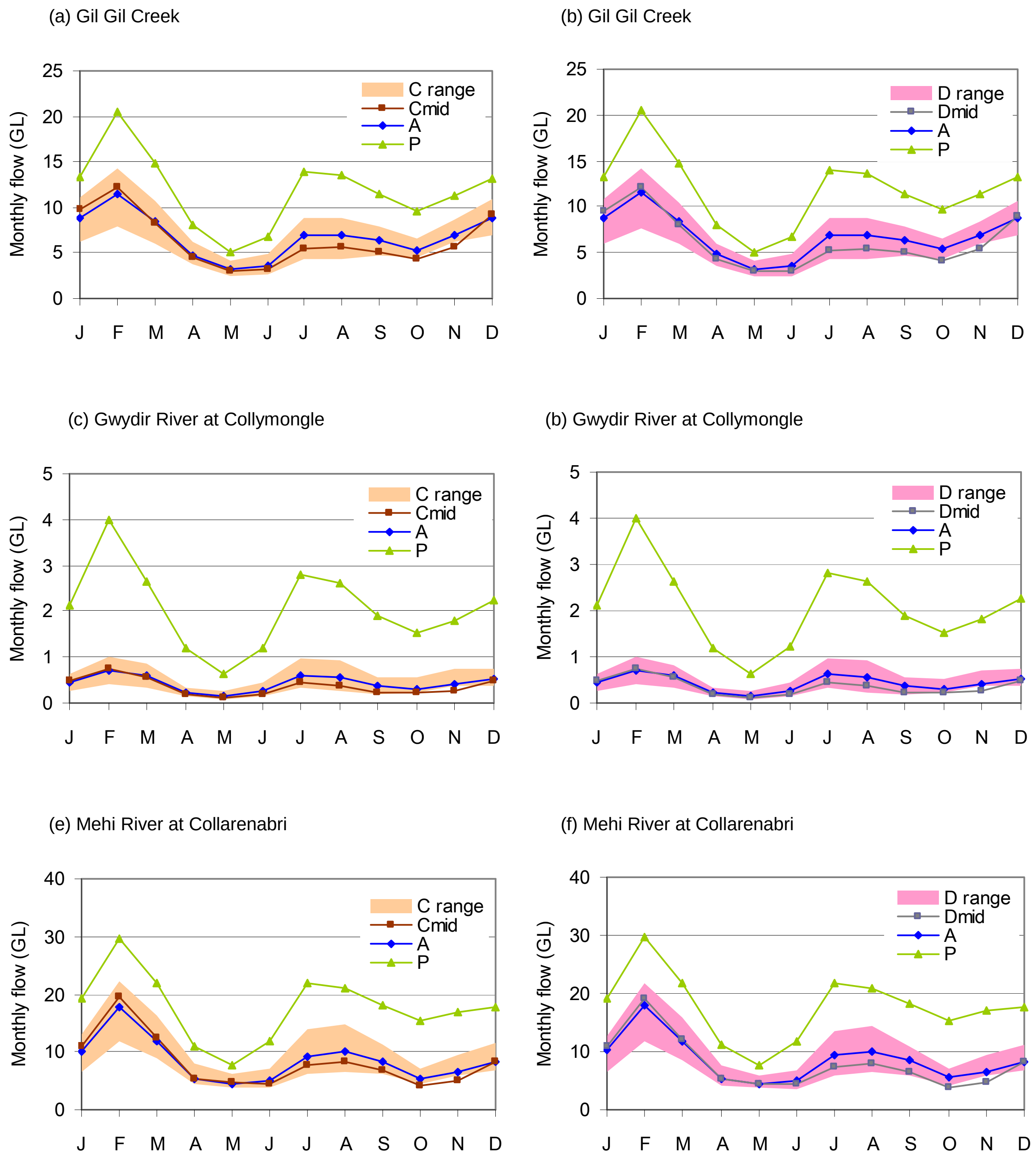

Figure 4-13. Seasonal flow curves at: Gil Gil Creek under scenarios (a) C and (b) D, Gwydir River at Collymongle under scenarios (c) C and (d) D, and Mehi River at Collarenabri under scenarios (e) C and (f) D

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

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

Outflow name	P	A	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Gil Gil Creek	99%	100%	100%	100%	100%	100%	100%	100%
Gwydir River at Collymongle	17%	8%	11%	7%	5%	10%	7%	5%
Mehi River at Collarenabri	100%	96%	96%	97%	97%	96%	97%	97%

4.3.6 Share of available resource

Non-diverted water shares

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

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

Table 4-16. 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 available water	59%	64%	59%	57%	63%	57%	56%
Non-diverted share relative to Scenario A non-diverted share	100%	144%	89%	68%	141%	86%	66%

Combined water shares

Figure 4-14 combines the results from water availability, use and non-diverted water into a bar chart. The size of the bars indicates total surface water availability and the sub-division of the bars indicates the total use and non-diverted fractions.

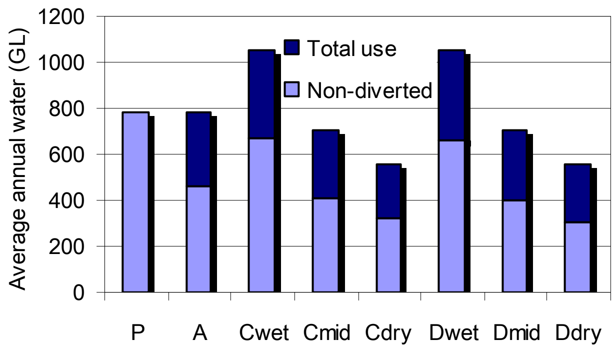

Figure 4-14. Comparison of diverted and non-diverted shares of water under scenarios P, A, C and D

4.4 Discussion of key findings

4.4.1 Scenarios

The Gwydir model was setup up by DWE to operate over the period 1 January 1890 to 30 June 2005. The results from this study are presented for the common modelling period 1 July 1895 to 30 June 2006. The Gwydir Regulated River WSP (DIPNR, 2004) is based on the different modelling period (1 January 1890 to 30 September 2000). Results presented in this report may differ from numbers published in the WSP report due to the different modelling period. Table 4-6 shows that there is a 5 percent decrease in inflows for the common modelling period compared to the longer 1890 to 2000 period. This difference can be attributed to the wetter conditions from 1890 to 1895. Further changes in flows would also be expected when the drier 2000 to 2005 period is excluded.

Scenarios A0 and A are presented so that the impacts of current levels of groundwater development reaching dynamic equilibrium can be considered. The time for this to reach dynamic equilibrium is discussed in Chapter 6. Table 4-6 shows a 4.4 GL/year increase in loss to groundwater that is offset by a 4.4 GL/year gain elsewhere in the river making the net change zero. This means that the results for scenarios A0 and A are similar.

Additional farm dam development is estimated to cause a 1 percent decrease in inflows into the system (Chapter 3). This equates to 13 GL/year less water entering the system under the best estimate 2030 climate scenario. In addition to this, future groundwater development in the headwater catchments causes a further 11 GL/year reduction in inflows (Chapter 6) under the best estimate 2030 climate. There would also be an average net streamflow leakage to groundwater of 2 GL/year. The combined impact is 2 percent reduction in total net diversions and end-of-system outflows. The impacts of the best estimate 2030 climate scenario are a 9 percent reduction in inflows. The combined impacts of development and future climate are 11 percent on total net diversions and 8 percent on end-of-system flows.

4.4.2 Storage behaviour

For current levels of development and historical climate, the maximum years between spills for Copeton Dam is 32 years and spans the Federation drought. The average years between spills is eight years, which is reduced by the wetter conditions after 1950. Additionally Copeton Dam regulates 93 percent of the inflows. This shows that Copeton Dam has a high degree of regulation.

4.4.3 Consumptive use

The Gwydir irrigators are modelled to include general security access, supplementary flow access, floodplain harvesting and rainfall harvesting. 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 under Scenario A are general security (195.3 GL/year), supplementary flows (100.4 GL/year), floodplain harvesting (7.7 GL/year) and rainfall harvesting (116.8 GL/year). The impact of climate on these different sources of water varies considerably.

The Gwydir River region is managed under a continuous water accounting scheme. Traditionally, many regions operated under annual accounting systems where allocation announcements were made throughout a year that set the proportion of licences that was 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 150 percent. Users are limited to a maximum usage of 125 percent of their entitlement in any year. The model keeps account of each irrigation node's account balance in storage and maintains these balances as water inflows and is diverted. Consequently each individual will have a different allocation depending on their level of usage 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 4-8. Due to the nature of individual balances actual usage may exceed allocated water as individual irrigators with higher allocations than the average divert their water. Hence in the reliability figures it is possible for diversions to exceed averaged allocations.

There is no significant impact on high security users as general security allocations are predominantly above zero (Figure 4-8). When there is a general security allocation the high security users will receive their full entitlement. Due to carry-over reserve in the resource assessment sufficient water is reserved such that high security town water supply requirements are met in all scenarios (Table 4-9 and Figure 4-5). The existing reserves in Copeton Dam are sufficient to meet high security requirements.

The model contains one high security irrigator. The usage of this irrigator is driven by crop requirements that are a function of climate inputs. As the high security licence is not fully utilised during drier climate conditions usage will increase as under-utilised water is used to meet higher crop demands. Table 4-6 shows that under scenarios Cmid, Cdry, Dmid and Ddry, usage increases.

4.4.4 Flow behaviour

The impacts of current development on end-of-system flows for the Gwydir at Collymongle and the Mehi at Collarenabri are greater than the impacts of the reduction in inflows due to climate change and future development. This is despite 45 GL of general security ECA that is used to supplement flow events in the Gwydir River.

The impacts of climate change on consumptive users and the end-of-system are similar across all scenarios. This is due to surplus flow access rules and the ECA. These rules help to maintain the balance between consumptive and non-consumptive use.

4.4.5 Water availability and level of use

There are differences between the water availability and level of use numbers quoted in the WSP (DIPNR, 2004) and this report (Table 4-7 and Table 4-10). The point of maximum water availability is estimated to be at Gravesend gauge (418013) with a value of 782 GL/year under Scenario A (pre-development). However, the point of maximum water availability in the WSP is a combination of inflows with a value of 1141 GL/year. In addition to this, the WSP 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. This reduces water availability by 5 percent due to the exclusion of larger inflows in the 1890 to 1895 period in modelling for this project.

The allowable level of use is not directly stated in the WSP but is implied to be 34 percent based on the long-term average annual diversion limit for Gwydir water use (392 GL/year) and an assessment of average water availability based on summed inflows (1141 GL/year). In this project current average surface water availability is assessed to be 782 GL/year based on mean annual pre-development streamflow. Also in this project an updated Gwydir model has been used and run over a different period leading to an assessment of current average water use of 317 GL/year. This gives an estimate of the current average level of use in the Gwydir system of 41 percent.

4.5 References

DIPNR (2004) Water Sharing Plan for the Gwydir Regulated River Water Source 2003. Effective 1 July 2004 and cease ten years after that date. Department of Infrastructure, Planning and Natural Resouces, Sydney. New South Wales Government Gazette.

DNR (2005) Draft Gwydir River Valley: IQQM Cap Implementation Summary Report. Department of Natural Resources, Sydney, New South Wales.

5 Uncertainty in surface water modelling results

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

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

5.1 Summary

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

5.1.1 Issues and observations

- Data availability in the Gwydir region is considered adequate. The density of the gauging network is similar to the Murray-Darling Basin (MDB) average and is appropriate to the level of development.
- The region is characterised by gaining reaches upstream of Pallamallawa and large losses downstream due to several distributary systems.
- Water accounts were only established for those reaches where model results were available for comparison.

5.1.2 Key messages

- Overall the river model appears to be of good quality and suitable for the purposes of this project.
- Groundwater systems in the Lower Gwydir are generally not well connected to the river and the overall impact of groundwater extractions on current flow patterns appears negligible. Groundwater may play a role in the losses from the distributaries.
- The greatest uncertainty is associated with the lower reaches, in particular the distributaries Mehi River, Carole Creek and Gil Gil Creek. Ungauged losses are high and introduce considerable uncertainty in modelling. The model does not always reproduce flows well in these reaches. However, this uncertainty is less than the uncertainty associated with the climate change scenario results.
- The model generally performs less well at reproducing the 10 percent lowest flow patterns. Projected changes in low flows should therefore be interpreted with some caution.
- The projected changes under the pre-development scenario are greater than the model's internal uncertainty.
- The results of climate change scenarios appear only moderately distinguishable from current flows due to model bias at different points along the river. The model may be still adequate to provide estimates of relative flow change under future scenarios, though this could not be verified.

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 which 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 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 climate change studies like this.

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

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 that is not attempted herein. A possible framework for users of the project results to consider the implications of the assessed uncertainties is shown in Table 5-1.

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

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

5.2.2 Information sources

Information on the gauging network was obtained from the Water Resources Station Catalogue (www.bom.gov.au/hydro/wrsc) and the Pinneena 8 Database (provided on CDROM by New South Wales Department of Water and Energy (DWE)). The model calibration report for the Gwydir IQQM model (O'Neill et al., 2005) was provided by DWE. 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 2005/06. Water accounts were established for ten successive reaches. The associated subcatchments are shown in Figure 5-1, and are related to water accounting reaches in Table 5-2.

Reaches 5, 11 and 21 all cover the same part of the river system: sections of the Gwydir River, Carole Creek and Mehi River where they branch off from each other. They only differ in which of the three downstream gauges is considered to be the main gauge (the two others are considered to be distributaries). This was done so model performance in simulating streamflow patterns at the downstream gauge could be evaluated for all three gauges. Reach 5 (terminating at 418004 Gwydir River at Yaraman Bridge) is for the main channel, Reach 11 terminates on the Carole Creek distributary (418052 Carole Creek at Garah) and Reach 21 terminates on the Mehi River distributary (418037 Mehi River at Combadello).

Model results for reaches 5 to 8 were not available within the project time frame. Water accounts were established for these reaches, but these could not be compared to modelled flows and water balance terms.

Table 5-2. Comparison of water accounting reaches with river model reaches

Water accounting reach	Subcatchment code(s)	Description (gauge number)
1	4180330, 4180351, 4180050	Gwydir @ D/S Copeton Dam (418026)
2	4180180, 4180123, 4180124	Gwydir @ Pinegrove (418012)
3	4180133, 4180134, 4180135, 4180136, 4180160	Gwydir @ Gravesend (418013)
4	4180011	Gwydir @ Pallamallawa (418001)
5*	4180062, 4180071	Gwydir @ Yaraman Bridge (418004)
11*	4180062, 4180071	Carole Ck @ Garah (418052)
21*	4180062, 4180071	Mehi @ Combadello (418037)
12	4180271	Gil Gil @ Weemelah (418027)
6	4180311	Gwydir @ D/S Tyreel Offtake (418063)
7	4180311	Gwydir @ Brageen Crossing (418053)
8	4180311	Gwydir @ Millewa (418066)
22	4180551, 4180603	Mehi River @ D/S of Collarenabri (418055)
Not assessed		Reason
	4180291, 4180081, 4180210, 4180220, 4180250	Contributing headwater catchment (to Reach 1)
	4180150, 4180170, 4180250	Contributing flow directly to Reach 3
	4180521	Contributing headwater catchment (to Reach 8)
	4180373, 4180374, 4180021, 4180320	Contributing headwater catchment (to Reach 9)
	4220044, 4180810	Contribute to Barwon-Darling region

* These gauges cover the same part of the river system, but were accounted for differently (see text).

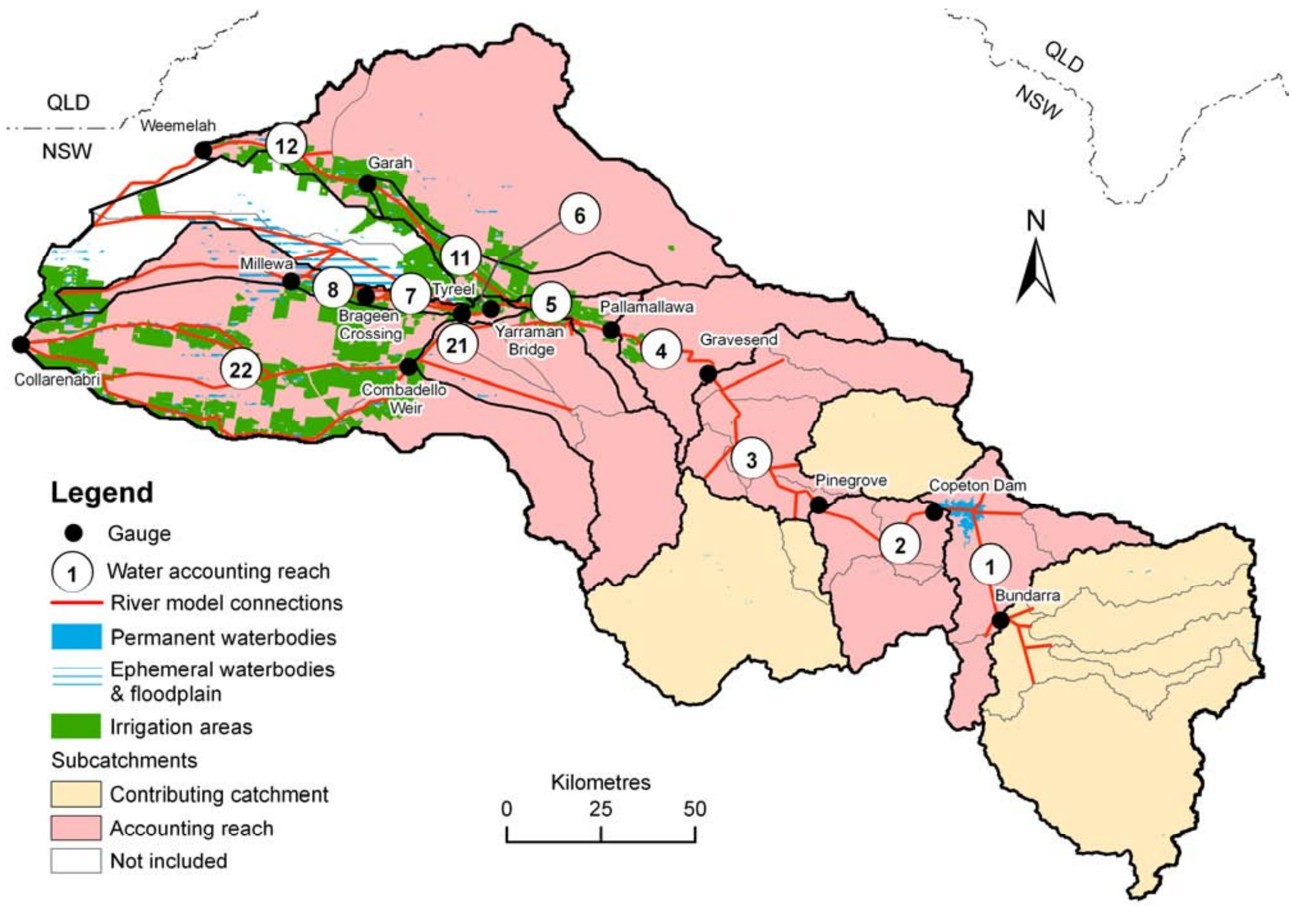

Figure 5-1. Map showing the subcatchments used in modelling, with the reaches for which river water accounts were developed ('accounting reach') and tributary catchments with gauged inflows ('contributing catchment'). 'Ephemeral water bodies and floodplain' are areas classified as subject to periodic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

5.2.4 Diversion Data

Diversion records covering the accounted reaches for the water accounting period were provided by New South Wales DWE.

Wetland and irrigation water use

The results of the remote sensing analyses (Chapter 1) are shown in Figure 5-1.

Calculation and attribution of apparent ungauged gains and losses

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

5.2.5 Model uncertainty analysis

The river model results, gauging network, and water accounts were used to derive measures of model uncertainty. The different analyses are described below. Details on the formulas 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 the hydrological observation network

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

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

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

Comparison of modelled and accounted reach water balance

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

Climate range

If the period of model calibration is characterised by climate conditions that are a small subset or atypical of the range of climate conditions that is 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 in the 111-year climate sequence 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 Gwydir region has a gauging network that is slightly denser than the average for the MDB (ranked 10^{th} out of 18 in terms of network density). Several gauges in runoff producing areas upstream of Copeton Dam have been closed since 1990 but flows are gauged before they are diverted so the resource is effectively gauged. Lowland river reaches and distributaries have a large number of gauges relative to some of the other regions.

Table 5-3. Some characteristics of the gauging network of the Gwydir region (24,947 km^2) compared with the entire Murray-Darling Basin (1,062,443 km^2)

Gauging network characteristics	Gwydir		Murray-Darling Basin	
	Number	per 1000 km^2	Number	per 1000 km^2
Rainfall				
Total stations	187	7.50	6,232	5.87
Stations active since 1990	83	3.33	3,222	3.03
Average years of record	37		45	
Streamflow				
Total stations	44	1.76	1,090	1.03
Stations active since 1990	38	1.52	881	0.83
Average years of record	17		20	
Evaporation				
Total stations	3	0.12	152	0.14
Stations active since 1990	3	0.12	104	0.10
Average years of record	16		27	

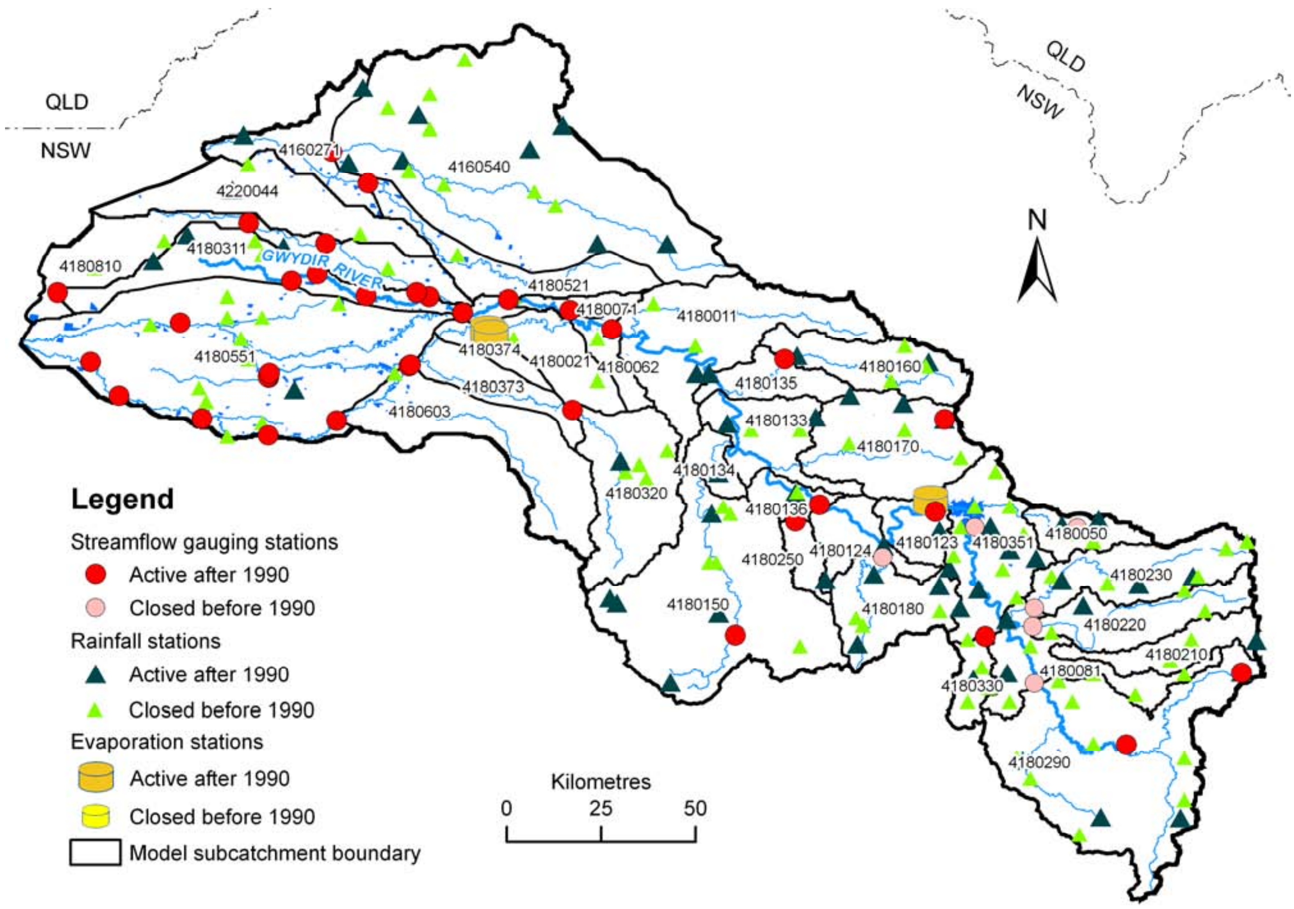

Figure 5-2. Map showing the rainfall, streamflow and evaporation observation network, along with the subcatchments used in modelling

5.3.2 Review of model calibration and evaluation information

Model description

An IQQM application was developed and calibrated for the Gwydir catchment in 2005 covering the regulated part of the catchment from Copeton Dam to the confluence with the Barwon River. The aim was to develop a tool capable of simulating daily river hydrology over periods in excess of 100 years and being used for Cap Implementation. Details on model concepts, assumptions, calibration and performance assessment, as reported in O'Neill et al. (2005), are reviewed in the remainder of this section. Very little data were available on the area irrigated using groundwater. It was assumed by O'Neill et al. (2005) that these diversions do not contribute to the crop areas reported for regulated surface water users.

Data availability

Main-stream gauging stations were used to derive losses and flow routing parameters for each river reach. The 11 gauged inflows to the model comprised five gauging stations selected by O'Neill et al. (2005) to represent inflows upstream of Copeton Dam and six gauging stations downstream of Copeton Dam. Thirteen rainfall stations with long, continuous records were used to represent the spatial rainfall distribution and three weather stations represented the spatial evaporation distribution to drive the crop water requirements in the different geographic zones of the Gwydir region. An additional evaporation site was used to represent the evaporation from Copeton Dam. The Moree site (053048) had evaporation data for a relatively long period (over 26 years) but analysis of its data revealed a number of problems regarding quality. Wallangra (054036) and Walgett (052026) were used instead, even though these evaporation stations are located just outside the Gwydir region.

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. Calibration periods varied between reaches, starting earliest in 1965 and ending latest in 2000 (inclusive).
- On-allocation diversion calibration reproduced observed on-allocation irrigation extractions given observed crop areas, the crop mix pump capacities and on-farm storage (OFS) development. Irrigation efficiency, rainfall losses, soil moisture stores, on-farm storage operation (including OFS reserves and rainfall and floodplain harvesting) were calibrated during this step. The calibration period was 1992 to 2004, limited by poor quality diversion data prior to 1992/93.
- Supplementary water diversion calibration reproduced observed off-allocation (OFA) extractions and announcement periods. Monthly supplementary water thresholds were calibrated during this step.
- Storage behaviour calibration reproduced the observed volumes in Copeton Dam. The calibration period was 1988 to 2004.
- 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 was over two periods: 1989 to 1995 and 1999 to 2004.
- The resource assessment configuration reflected regional practices in making allocation announcements decisions in the model's resource assessment module. Loss functions, storage, minimum inflow and announcement constraints were configured.

Model performance

As each aspect of calibration is of similar importance they were given equal weighting in the overall assessment of the model.

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).

The lack of good quality diversion information for most reaches limited the period of calibration. This information was required on a daily time step and therefore the historical data needed to be disaggregated. The small diversions In the Pallamallawa reach were disaggregated using a fixed extraction pattern and a target annual volume. A flow calibration on periods prior to significant irrigation development was also performed for most sites to check the derived losses. The flow calibration indicated that at most locations a high to very high quality calibration for both the flow frequency and the time series comparisons were obtained (Table 5-4). Some problems occurred with the high flow rating at Pallamallawa. Difficulties occurred in simulating low flows at Yarraman and Garah because of the significant number of zero flow days at these two locations. These problems were attributed to the disaggregation of the diversion data to daily time steps, but were not significant considering the actual quantity of water involved.

Table 5-4. Gauges used for model calibration and flow calibration quality assessment

Station	Location	Flow frequency			Relative accuracy in reproducing	
		Low range	Mid range	High range	Daily values	Annual totals
418001	Gwydir River @ Pallamallawa	high	high	high	very high	very high
418002	Mehi River @ Moree	very high	high	high	very high	very high
418004	Gwydir River @ Yarraman	low	moderate	very high	high	high
418052	Carole Creek @ Garah	moderate	very high	very high	moderate	high
Overall		moderate	high	very high	high	high

Diversion calibration was rated as high to very high quality. The overall volume match for the on-allocation diversions showed a small (3.8 percent) overestimate, while the off-allocation diversions showed a slight (-6.3 percent) underestimate in diversions.

The farmers' risk function was calibrated by comparing the modelled and historical planted areas for the planted area calibration. The model assumed a single date at which the cropping area is decided (1 October). Any water unavailable on this date is not considered in the planted area decision. This results in the model under estimating the planted areas in some seasons in the 1988 to 1995 period. Overall, the model calibration was assessed as high to very high performance for summer planting areas and low to moderate for winter planting areas.

Overall quality ratings were applied to the components of the model calibration as follows:

- streamflow: high
- diversions: high for both on- and off-allocation
- storage behaviour calibration: very high
- planted area calibration: high.

Overall model performance was very high.

A simulation was performed for 1988 to 1995 to validate the 1993/94 scenario regarding a cap on surface water diversions. The observed and simulated results were compared for a number of processes including allocations, planted areas, on- and off-allocation diversions and Copeton storage behaviour. Validation of the 1993/94 scenario was assessed as very good. Even though the model assumes a static level of development, simplified management, stock and domestic releases, and environmental flow rules.

Identified areas of weakness

A number of processes were not modelled due to their assumed insignificance, lack of data or because they were beyond the scope of the model. Some processes were modelled in a simplified form. Licensed water extractions from unregulated streams are considered to be of a small volume and have largely been excluded.

Past operation of these licences has not been closely monitored and there has generally been very little data collected on water extractions and cropping by these licences. No adjustment of historical inflows to represent any changes in unregulated licence activity was made.

The transfer market was not modelled explicitly. The model assumes full activation of water shares within an irrigation node and therefore there is some transfer component internally. However no transfer of water shares from node to node was modelled.

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 gauged gains and losses for each reach is shown in Figure 5-3(a). Reaches 1 to 8 are located on the Gwydir River main stem, reaches 12 and 22 are the lower reaches of the Gil Gil and Mehi distributaries, respectively, and reaches 11 and 21 are geographically equivalent to Reach 5 but accounted for in a different manner. Conclusions follow:

- Most of the gains in the main stem are well gauged and about 70 to 90 percent of inflows into successive reaches appear to be gauged. The reach that includes Copeton Dam (Reach 1) and the last reaches on the two distributaries (Reach 12 – Gil Gil/Carole Creek and Reach 22 – Mehi River) are exceptions: less than 50 percent of apparent gains are gauged in these reaches. These are associated with ungauged tributary inflows.
- Losses are generally reasonably well gauged at the reach level (50 to over 90 percent, with two reaches at about 30 percent gauged). In reaches 2 to 4 more than 90 percent of losses are gauged. Reach 7 is also relatively well gauged (79 percent). Important ungauged losses occur in reaches 6 and 8 (26 to 32 percent of losses gauged). Losses from the whole system, however, are less well gauged, at only 40 percent of losses. Overall, for each reach 48 to 77 percent of the water balance was gauged, although 87 to 91 percent was gauged in reaches 2, 3 and 4 (Gwydir River between Copeton Dam and Pallamallawa).
- 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 upstream reaches. Least attribution was achieved in the Copeton Dam reach (Reach 1, 58 percent of total water balance attributed), due to the large storage that is incorporated in this reach and for which dam storage data are available but not used in accounting. Lesser attribution was also achieved in the two distributaries (reaches 12 and 22, 69 to 78 percent attributed) where much of the diversions for irrigation, break-outs and wetlands occur.

The hydrological system is reasonably well instrumented and understood in the upper reaches but less so in the lower parts of the catchment.

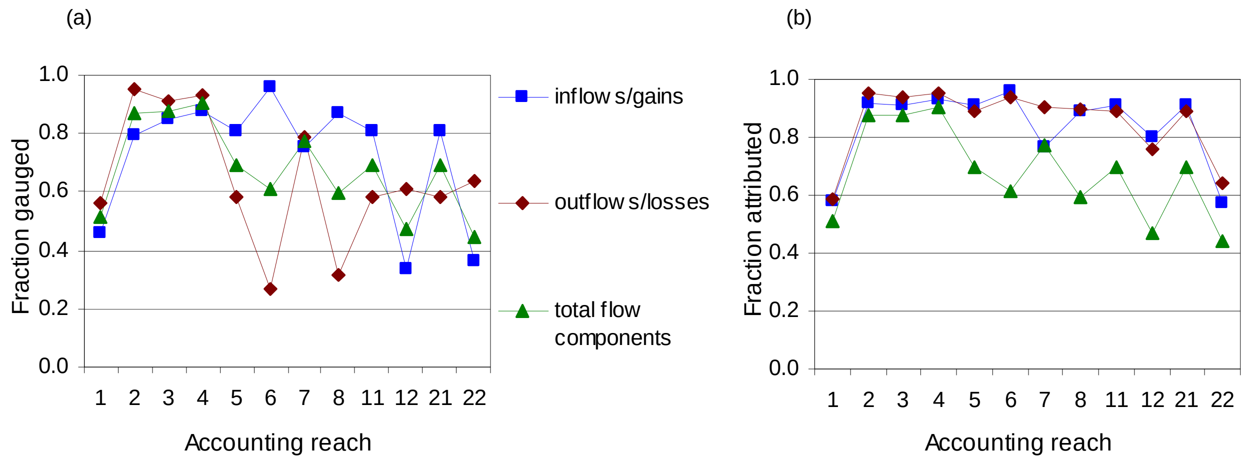

Figure 5-3. The fraction of inflows/gains, outflows/losses and the total of water balance components that is (a) gauged or (b) could be attributed in the water accounts

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. The general picture is that the upper part of the region receives the most runoff, is well gauged and loses little water. The model performs reasonably well in this part of the region. The lower part of the region receives less runoff, is less well gauged and losses much water to the floodplain and wetlands. Model performance is poorer. There is considerable uncertainty and possibly measurement error in many elements of the water balance. Interpretation follows:

- The upper reaches of the Gwydir river system are gaining reaches. The system starts to lose more water than it gains below Pallamallawa where most of the break-outs and irrigation extractions occur (Appendix C).
- Groundwater exchanges in water accounting were not estimated due to the generally small usage and lack of direct data. It was estimated at 3 GL/year by the river model.
- Modelled main stem inflows (into Reach 1 from the Gwydir upstream of Bundarra) are 96 GL/year (38 percent) greater than observed inflows.
- Tributary inflows simulated by the model into the remainder of the reaches are 122 GL/year less than gauged inflows, corresponding to a difference of -65 percent.
- Modelled local inflows (584 GL/year) were greater (by 142 GL/year or 32 percent) than the sum of local inflows that could be accounted for with SIMHYD estimates, but inflows appear to include considerable measurement noise.
- Gauged water balance terms (975 GL/year, including diversions) represented 37 percent of the total water balance (2636 GL/year, including measurement noise), whereas another 916 GL/year (35 percent) could be attributed using SIMHYD estimates and remote sensing estimates of wetland and floodplain losses.
- Ungauged gains (including measurement noise) for the entire accounted system that could not be attributed to a process represent 438 GL/year or 33 percent of total apparent gains. Ungauged losses (including measurement noise) that could not be attributed to a process represent 307 GL/year or 23 percent of total apparent losses. Their sum represents 745 GL/year or 28 percent of the total water balance.
- End-of-system outflow (the sum of outflows from Gwydir, Gil Gil and Mehi, reaches 8, 12 and 22) simulated by the model was 62 GL/year (-26 percent) lower than observed combined streamflow. This can partially be explained by the fact that there were no simulated outflows for the Gwydir River at Millewa (Reach 8), representing 27 GL/year of gauged outflows.
- Simulated diversions for the accounting period were 4 percent or 12 GL/year less than recorded diversions.
- The sum of modelled unspecified losses and distributary outflows (532 GL/year) was slightly larger (57 GL/year or 12 percent) than the sum of accounted river and floodplain losses and distributary outflows (475 GL/year). They were also reasonably similar on a reach-by-reach basis, with the exception of Reach 4, where 57 GL/year of unspecified losses were simulated. Only 2 GL/year of river and wetland losses could be accounted.

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

Water balance (Jul 1990 – Jun 2006)	Model (A)	Accounts	Difference	Difference
		GL/y		percent
Inflows (gains)				
Main stem inflows	346	250	96	38%
Tributary inflows	66	189	-123	-65%
Local inflows	584	441	143	32%
Total	**996**	**880**	**116**	**13%**
Unattributed gains and noise	0	438	-438	-100%
Outflows (losses)				
End of system outflows	177	238	-62	-26%
Distributary outflows	266	0	266	NA
Net diversions	285	298	-12	-4%
River flux to groundwater	3	0	3	NA
River and floodplain losses	0	475	-475	-100%
Unspecified losses	266	0	266	NA
Total	**997**	**1011**	**-15**	**-1%**
Unattributed losses and noise	0	307	-307	-100%

NA: not available.

Climate range

The calibration period for most river model components was from 1989 to 2004 (Section 5.3.2). The number of years in the entire 111-year record used in modelling that were drier than those included in this calibration period was four. Four years were wetter. The region-average rainfall range in the calibration period was 388 to 929 mm/year, compared to 345 to 1100 mm/year for the 111-year period. The average annual rainfall in these calibration years was 6 percent higher than the long-term average. By comparison, the historical 111-year rainfall record had four years that were drier and four years that were wetter than the extremes during the period of water accounting 1990 to 2006.

The calibration period for the Gwydir River model appears to provide a very good representation of long-term climate variability, as does the water accounting period 1990 to 2006.

Performance of the river model in explaining historical flow patterns

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

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. Reaches 1 to 8 are located on the Gwydir River main stem (modelled data was not available for reaches 5 to 8 in the timeframe of this project), 12 and 22 are the lower reaches of the Gil Gil and Mehi distributaries, respectively, and 11 and 21 are geographically equivalent to Reach 5 but accounted for in a different manner. Observations follow:

- Performance was good (monthly and annual normal NSME 0.51–0.84) for the Gwydir River between Pinegrove and Pallamallawa (reaches 2, 3 and 4). Performance was better for monthly than for annual flows, which can be attributed to the slight bias that has greater effect on annual totals: average flows were over estimated by 8 to 15 percent (51 to 78 GL/year) for these reaches.
- The overall performance of the model was moderate to reasonable (monthly and annual normal NSME 0.49–0.72) for the distributaries Carole and Gil Gil creeks and the lower Mehi River (reaches 12, 22 and 11). Model performance in simulating flows in the upper Mehi River at Combadello was poor (Reach 21, monthly and annual normal NSME <0.09) where modelled flows are systematically greater than those recorded.

- In several cases ranked NSME is greater than normal NSME, particularly for annual totals (Figure 5-4). This indicates that the model reproduces patterns well but has a bias.
- 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 Table 5-4).

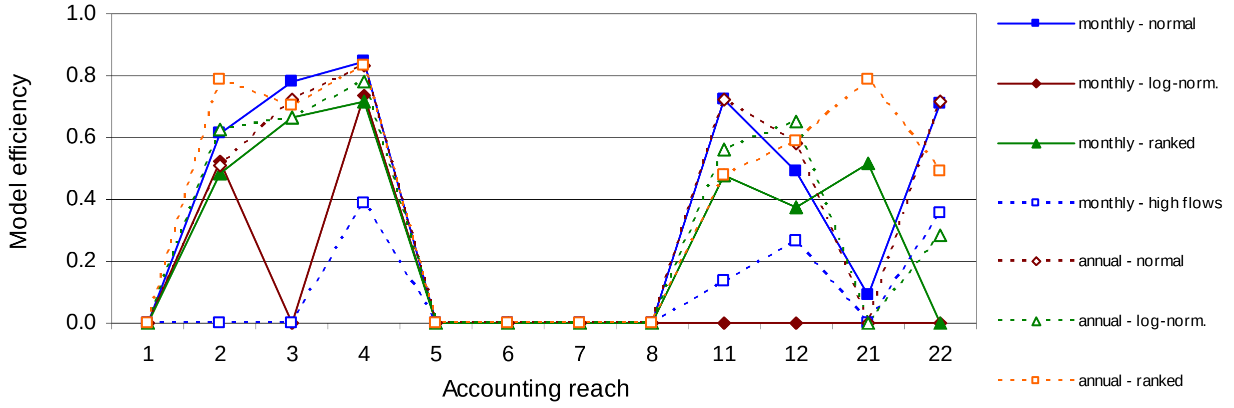

Figure 5-4. Changes in the model efficiency (the relative performance of the river model in explaining observed streamflow patterns) along the length of the river. Modelled results for reaches 5 to 8 were not available in the timeframe of this study, so model efficiencies were not calculated for these reaches.

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 Figure 5-5 b, respectively. Reaches 1 to 8 are located on the Gwydir River main stem (modelled data was not available for reaches 5 to 8), reaches 12 and 22 are the lower reaches of the Gil Gil and Mehi distributaries, respectively, and reaches 11 and 21 are geographically equivalent to Reach 5 but accounted for in a different manner. The results suggest that:

- The projected changes from pre-development to current flow patterns is greater than model uncertainty by a reasonable to high margin in the upper Gwydir (above Pallamallawa, reaches 2, 3 and 4) (CUR=3.1–7.1), and by a weak to reasonable margin in the lower Gwydir system, including its distributaries (CUR=0.6–3.2). The modelling suggests flow patterns would be different without development. Low flows would be lower in the upper Gwydir River, considerably higher in Mehi River, and affected in different ways in Carole and Gil Gil creeks.
- The projected change in Scenario Cwet is generally greater than model uncertainty by a fair to high margin ($1.8 < CUR < 4.6$) in the upper reaches and by a low to fair margin ($0.6 < CUR < 2.2$) in the lower reaches, for annual flow and monthly patterns. The projected changes in the Scenario Cdry are greater than model uncertainty in all reaches by margins that vary from moderate to fair ($1.2 < CUR < 2.5$) in both monthly and annual patterns, except for the outflow at Reach 21 where the margin was very low to low ($0.4 < CUR < 0.5$). The projected changes in Scenario Cmid are greater than model uncertainty by low margins ($0.9 < CUR < 1.5$). This can be attributed to the models' tendency to over estimate streamflow in parts of the system. The extreme wet and dry scenarios generally 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 reaches.

The magnitude of projected changes in flow under future scenarios is generally greater, but only by moderate amounts, than the uncertainty in the model predictions for most scenarios in most reaches, and a little less than the uncertainty in the model predictions for the remaining reaches (Figure 5-5).

Generally, therefore, moderate confidence can be placed in the predictions of change for most reaches. However, the model does provide greater confidence in the evidence for different flow patterns under pre-development conditions.

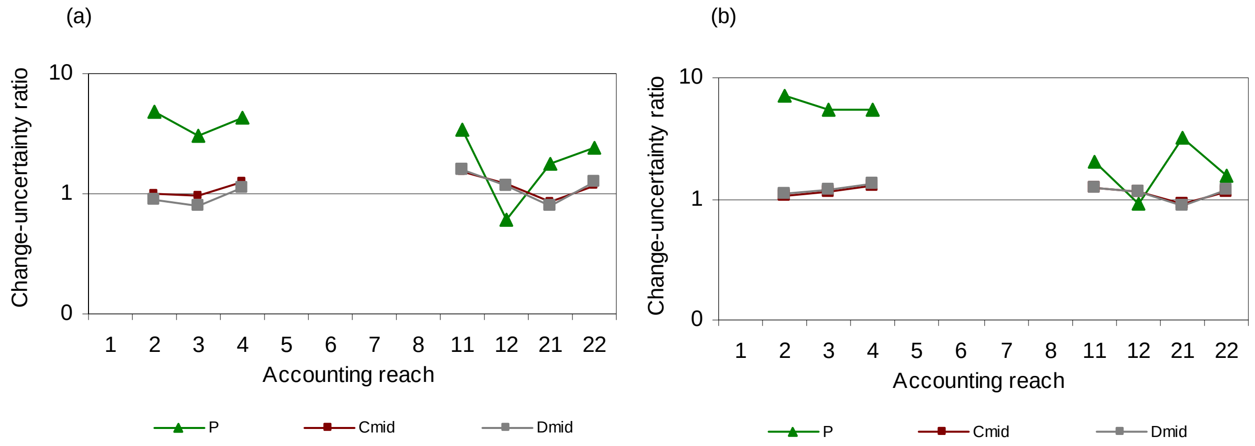

Figure 5-5. Pattern along the river of the ratio of the projected change over the river model uncertainty for scenarios P, C and D modelled for (a) monthly and (b) annual flows

5.4 Discussion of key findings

5.4.1 Completeness of the gauging network

The spatial density of streamflow gauging in the Gwydir region is similar to that of the MDB average (Section 5.3.1). In setting up and calibrating the model, the quantity and quality of gauging was not identified as a major issue (Section 5.3.2). The main uncertainty in gauging arises from the considerable losses on the lower reaches, which are largely ungauged (Section 5.3.3). Water accounting estimated that 40 percent of all apparent losses in the Gwydir was gauged, with most ungauged losses in the lower, net losing end of the system (below Pallamallawa). These losses (60 percent) were attributed to river and floodplain losses using remote sensing information (Section 5.3.3).

5.4.2 Conceptual understanding of regional surface hydrology

The conceptual understanding of the hydrology of the Gwydir region is reasonably good. The greatest uncertainty is associated with the distributary systems in the lower part of the system where wetland and floodplain losses are important (Section 5.3.2). The model performance assessment also suggested that this was where the greatest uncertainties arose (Section 5.3.3). Overall patterns in streamflow, storage levels, diversions and planted areas are simulated well by the model, giving greater confidence that the system is well understood (Section 5.3.2).

The influence of groundwater on hydrology is discussed in Chapter 6. The river model results suggested that under baseline conditions less than 0.3 percent of reach streamflow is lost to the groundwater system, totalling only 3 GL/year for the accounted reaches (Appendix C). As such, surface–groundwater interactions would seem to be of small significance to regional hydrology.

5.4.3 Performance and uncertainty in aspects of the river model

Review of a prior model performance assessment suggested that the model performs well to very well (Section 5.3.2). The climate range over the calibration period of the model was assessed to be very good.

Comparison with observations and water accounts largely confirmed this for the upper reaches. Flows in the Mehi River and Carole and Gil Gil creeks were reproduced less well with some bias (<10 percent) in average flows appeared to exist in many cases.

As a consequence, normal model efficiency was less than might be expected, and sometimes less than performance of the model in simulating the relative magnitude (ranking) of flows. This led to weak to modest change-uncertainty ratios. The 10 percent lowest flows were reproduced poorly, particularly for the lower reaches.

5.4.4 Implications for use of these results

Overall, the model appears adequate to confirm the direction and magnitude of change under the pre-development scenario. Only moderate confidence can be placed in the predictions of change for most reaches. Internal model uncertainty was considerable when compared to the uncertainty in the climate change and development scenarios. This can partially be attributed to bias between the model and observations; flow patterns over time generally agreed better. On this basis, the model may be still adequate to provide estimates of relative flow changes, though this could not be verified. Particular caution is recommended when interpreting projected changes in low flows and changes in flows in the Mehi River, and flows in the other distributaries.

5.5 References

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6 Groundwater assessment

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

- a summary
- a description of the groundwater management units in the region
- 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
- an assessment of conjunctive water use indicators
- a discussion of key findings.

6.1 Summary

6.1.1 Issues and observations

There are seven groundwater management units (GMUs) that cover the entire Gwydir region.

An existing numerical groundwater model underpins the assessments for the Lower Gwydir Alluvium GMU and parts of the Great Artesian Basin (GAB) Alluvial GMU. Simpler water balance analyses were conducted for the remaining GMUs.

6.1.2 Key messages

Total groundwater extraction in the Gwydir Region for 2004/05 is estimated at 46.2 GL. This represents 2.8 percent of the groundwater use in the MDB (excluding confined aquifers of the GAB). About 77 percent of this extraction was from the Lower Gwydir Alluvium GMU. Extraction in this GMU currently exceeds the long-term average extraction limit (LTAEL), due to usage under supplementary licences for which the entitlements will decrease to zero by 2015.

Current groundwater extraction represents 12 percent of total water use in the region on average and 55 percent in the years of minimal surface water diversion.

Groundwater extraction across the whole region is expected to rise from 12 to 36 percent of total water use on average and increase from 55 to 85 percent of total water use in the years of minimal surface water diversion.

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

Groundwater modelling of the Lower Gwydir area

Under the historical climate with extraction at the LTAEL:

- Extraction in the modelled area (33 GL/year) represents 63 percent of total groundwater recharge including lateral inflow, and 74 percent excluding lateral inflow. This is a moderate to high level of development.
- Extraction from the Lower Gwydir Alluvium GMU on the current spatial pattern can be sustained and would avoid reversals of gradients that might otherwise lead to groundwater salinisation.
- In the west of the Lower Gwydir Alluvium GMU and in the GAB Alluvial GMU, groundwater is more saline and the current rates of recharge and extraction will lead to rising watertables. In this area the majority of the irrigated area relies on surface water. Irrigation exceeds crop water use to ensure leaching and to avoid surface salinisation. This is leading to rising watertables.
- Neither extraction nor irrigation recharge will have a large impact on future streamflow in the Gwydir River. The time lag between extraction and stabilisation of surface–groundwater fluxes appears to be very short.

Under the best estimate 2030 climate with extraction at the LTEAL there would be small impacts on surface–groundwater exchanges: the streamflow loss to groundwater would decrease by 0.2 GL/year and this would be offset by a 0.3 GL/year reduction in the inflow to the river from groundwater.

Under 2030 climate with future catchment development (farm dams) and with extraction at the LTAEL there would be negligible additional impacts on the groundwater balance. The extraction level would remain sustainable.

Water balance analyses outside of the Lower Gwydir area

- Extraction is expected to increase 12-fold overall by 2030, with the increase in the New England Fold Belt GMU assessed to be a 24-fold increase.
- For some GMUs these increases would lead to a high level of extraction. For example, in the Miscellaneous Alluvium of Barwon Region GMU extraction would almost equal rainfall recharge.
- The total impact of these future levels of extraction outside of the Lower Gwydir area would be an estimated 37 GL/year reduction in streamflow. This is 14 times the ultimate impact of prolonged groundwater extraction at 2004/05 levels.

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 watertable 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 bring the groundwater system to a 'dynamic equilibrium' over the first 111 years, and then for the second 111 years to run in sequence with surface water models to provide input to surface–groundwater 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 watertables gradually fall. This suggests that the modelled spatial pattern of extraction is not sustainable.

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

The ranking criteria in the first instance are based on the following 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) the complexity of process representation; (iv) the availability of field data independent of calibration; (v) the explicit representation of surface–groundwater connectivity; and (vi) the 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 Lower Gwydir Alluvium, the model did not have a steady-state pre-development calibration. This model has been used to prepare groundwater sharing plans and had a high level of scrutiny. Historical monitoring and extraction data to support the model is not good and calibration occurred over a short period of time. Lateral flows are about 15 percent of the water balance, which is relatively high. The Lower Gwydir Alluvium model has been assessed as moderate, which makes it fit for the purpose of this project. The model would be barely adequate for providing groundwater balances that support some of the conclusions in this chapter. The model could be improved with further calibration. Future work is warranted 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 Gwydir Alluvium 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.

Using the water balance approach, the ratio of extraction to rainfall recharge indicates the level of extraction compared to rainfall recharge. There may be other forms of recharge including recharge from streams. A rating of 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 Gwydir region are divided into seven GMUs for management purposes (Table 6-1). The GMUs are three-dimensional because of the layering of geological formations at different depths. The level of development of the groundwater in 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 for the project and the assessment ranking for this project. The priority ranking focuses on efforts on those GMUs that affect the overall groundwater or surface water resource in the MDB. It 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 and reflect the availability of data and analysis tools as well as the priority of the GMU. They range from 'minimal' to 'very thorough'. For the GMUs in the Gwydir region a 'simple' ranking denotes a simple water balance approach. A 'moderate' ranking denotes use of a poorly calibrated and poorly conceptualised numerical groundwater model – in the context of this project. The assessment and priority rankings are consistent for all the GMUs except for the Lower Gwydir 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 of the Gwydir region together with estimated current and future extraction, and extraction limits for each unit

Code	Name	Priority	Assessment ranking	Total entitlement	Current extraction (2004/05)[3]	Long-term average extraction limit[4]	Maximum likely extraction without plan revision[2]
					GL/y		
N03	Lower Gwydir Alluvium	high	moderate	33.0[1]	35.52	32.3[1] (plus basic landholder rights)	32.3[1] (plus basic landholder rights)
N23	Miscellaneous Alluvium of the Barwon Region	low	simple	1.54	0.87	0.89	1.54
N63	GAB Alluvial	low	simple	3.79	2.6	43.01	25.81
N601	GAB Intake Beds	very low	simple	2.59	1.85	4.02	4.02
N604	Gunnedah Basin	very low	simple	0	0	0.45	0.32
N803	Inverell Basalt	low	simple	2.19	1.4	9.05	4.52
N805	New England Fold Belt	low	simple	5.49	4	158.85	95.31

(1) Source: DIPNR, 2006
(2) This value incorporates all sources of recharge in Water Sharing Plan areas but represents only rainfall recharge in Macro Groundwater Sharing Plan areas. Where indicated the recharge volume does not include the amount of groundwater available for basic rights, which is an additional volume. The volume of recharge does not include recharge to national park areas, which has generally been allocated to environmental purposes and is not available for consumptive use.
(3) Data for the Lower Gwydir Alluvium GMU is metered data. 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). Data quality is variable depending on the location of bores and the frequency of meter reading.
(4) For Macro Groundwater Sharing Plan areas, these limits are draft, as plans for these areas are not yet gazetted.

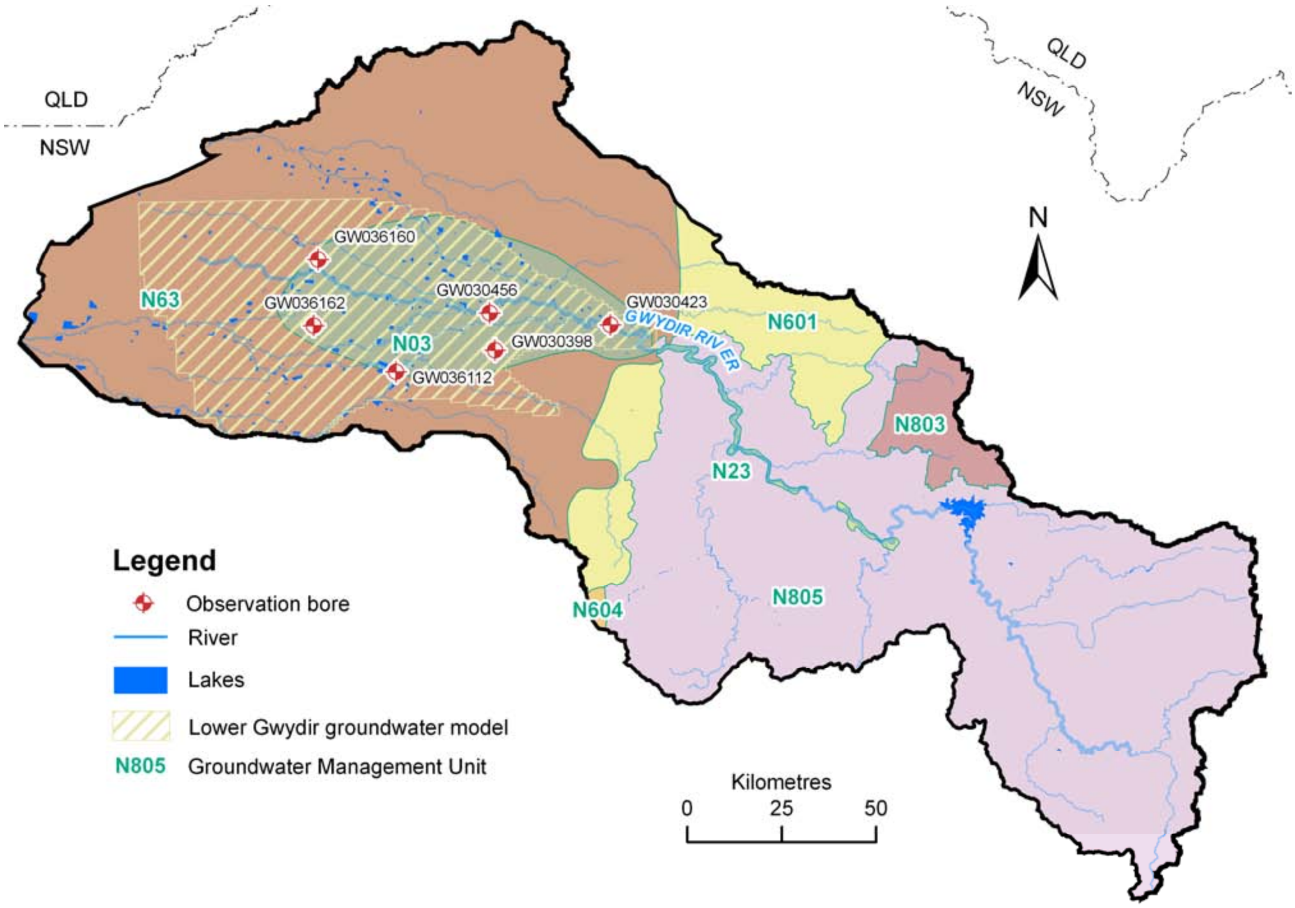

Figure 6-1. Map of groundwater management units, key indicator bores and modelled zone in the Gwydir region

6.2.3 Hydrogeological context

The hydrogeological context is outlined in Chapter 2. Some additional detail is provided below.

The hydrogeology in the highland reaches of the region is dominated by fractured rock aquifers in a range of different geologies including Palaeozoic and Mesozoic granites, basalts, consolidated sediments and metasediments. Groundwater salinities in the fractured rock aquifers range from 1200 to 3600 mg/L with yields of 1 to 2 L/s. Recharge to the fractured rocks occurs mainly on hilltops and slopes with discharge areas at the break-of-slope and as baseflow to adjacent streams and valley floors. The basalts receive recharge throughout the landscape and have recharge and permeability that results in highly flushed systems containing low salinity groundwater.

There are also local deposits of unconsolidated sediment forming aquifers of alluvium in the valley floors. Recharge to these systems depends on the frequency of flooding and the type of soil and weathered rock above the watertable. Discharge occurs to streams at the break-of-slope and at the base of terraces. The streams in this upper part of the valley are highly dependent on baseflow.

Multi-layered sandstones and mudstones of the GAB occur across much of the western part of the region and outcrop in many areas on the western flanks of the highlands. These outcrops allow recharge to the GAB from rainfall and river flow. Groundwater flow in the region is initially to the west. Water quality decreases further along the flow path with fresh to marginal groundwater occurring in the upper aquifers becoming more saline with depth to the west. The water resources of these aquifers are not considered in this assessment except where intake beds of the GAB outcrop within the region. Groundwater in these areas has the potential to be connected with surface water systems and shallow groundwater systems.

The GAB is represented in the region by the following hydrogeological units:

- the deep Jurassic sandstone confined aquifers that extend beneath the western part of the reporting region and outcrop in the central parts
- the Cretaceous sandstone confined aquifers and shale confining layers which lie conformably above the Jurassic aquifers. The Cretaceous confining layers separate the deeper confined aquifers from the surficial aquifers
- the GAB Intake Beds and GAB Alluvial.

The GAB hydrogeological units correspond to GMUs as follows:

- the deep Jurassic and Cretaceous sandstone confined aquifers and Cretaceous confining layers which are administered under the New South Wales Great Artesian Basin Groundwater Sources Water Sharing Plan (WSP) (DWE, 2007) (N601 GAB Surat Zone)
- the GAB Intake Beds that occur where the Jurassic and Cretaceous sandstone aquifers outcrop. This GMU is also administered under the same WSP (N601 Eastern Recharge Zone)
- the GAB alluvium is a thick sequence of Cainozoic alluvium covering the GAB sequence in the western portion of the region (N63 GAB Alluvial).

The deeper GAB Jurassic and Cretaceous confined sandstone aquifers provide a limited groundwater resource to the region.

The groundwater within these aquifers is separated from the surface aquifers by thick confining beds. This means there is little interaction with the overlying surface water or groundwater contained in near-surface aquifers. The water resources within these confined aquifers are not considered further in this assessment.

The region's primary groundwater resource is in the alluvial aquifers associated with the main rivers and prior channels of the western floodplain. Groundwater from these aquifers supplies irrigation, stock, domestic and town water. The aquifers form a three-layered system composed of the Cubbaroo Formation, overlain by the Gunnedah Formation and, in turn, by the Narrabri Formation. The Cubbaroo Formation is restricted to the deepest parts of the alluvial sequence and comprises coarse-grained palaeochannels. The Gunnedah Formation extends across the region and is slightly finer grained than the Cubbaroo Formation. The dominant proportion of useable low-salinity groundwater resources in the Gwydir region are in the Lower Gwydir Alluvium GMU. It lies at the eastern end of the broad alluvial floodplain where the Gwydir River emerges from the slightly higher relief landscape of the eastern valley. The GMU is defined by the extent of groundwater quality and bore yields suitable for irrigation.

Groundwater within the Lower Gwydir GMU is largely extracted from the deeper Gunnedah Formation. The Narrabri Formation is composed of shallow alluvial fan sediments deposited by creeks draining the adjacent highlands. Groundwater is contained in small discontinuous sand lenses and varies in quality and yield. Recharge is via rainfall infiltration, flooding events and irrigation in the area.

Recharge to the fractured rock systems within the highland areas of the Gwydir region 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. 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 if streamflow persists. Watertables are found closer to the surface at the far western edge of the alluvial plain 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 flow direction is reversed.

Groundwater levels in the Gunnedah Formation generally reflect climatic conditions upstream of the irrigated areas on the western floodplain.

Groundwater levels within irrigated areas show large seasonal fluctuations associated with pumping and display a consistent downward trend of 3 to 5 m in the Gunnedah Formation from 1977 to 1996. Groundwater levels have stabilised since then.

There is evidence of periodic recharge from flooding events within the Narrabri Formation but the long-term groundwater level trend is consistently downward. Groundwater levels fell from 1987 to 1996 then recovered from 1996 to 2000 and have since displayed a falling trend. Groundwater salinity in the Narrabri Formation can be high. Saline water may leak to the underlying Gunnedah Formation due to an increased downward hydraulic gradient caused by depletion of the Gunnedah Formation.

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 sustainable yield within the WSPs. The available extraction from each system will be gradually reduced from current levels to the sustainable yield over the ten years of the WSP.

The LTAEL values used in this project for all of the relevant regions are the sustainable yield estimates – that is, they are the levels of extraction to be achieved by the end of the WSP. This forms the assumed levels of extraction under scenarios A and D for the Lower Gwydir.

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 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 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 2.9 m at Yarraman Bridge (stream gauge 418004) compared to the depth range of 0.3 to 3.8 m for the period of record (1982 to 2007). It is only the variations in the relative (not absolute) groundwater fluxes from or to the river that are considered. The fact that it was an unusually low flow period does not affect the connectivity analyses.

An average aquifer thickness of 20 m was used for all river reaches. Hydraulic conductivity values varied across the region between 0.1 to 50 m/day. The upper Narrabri Formation in the western parts of the region had hydraulic conductivities generally between 1 to 10 m/day. Hydraulic conductivity generally decreased in the eastern parts of the region with values less than 1 m/day common in the upper catchment region.

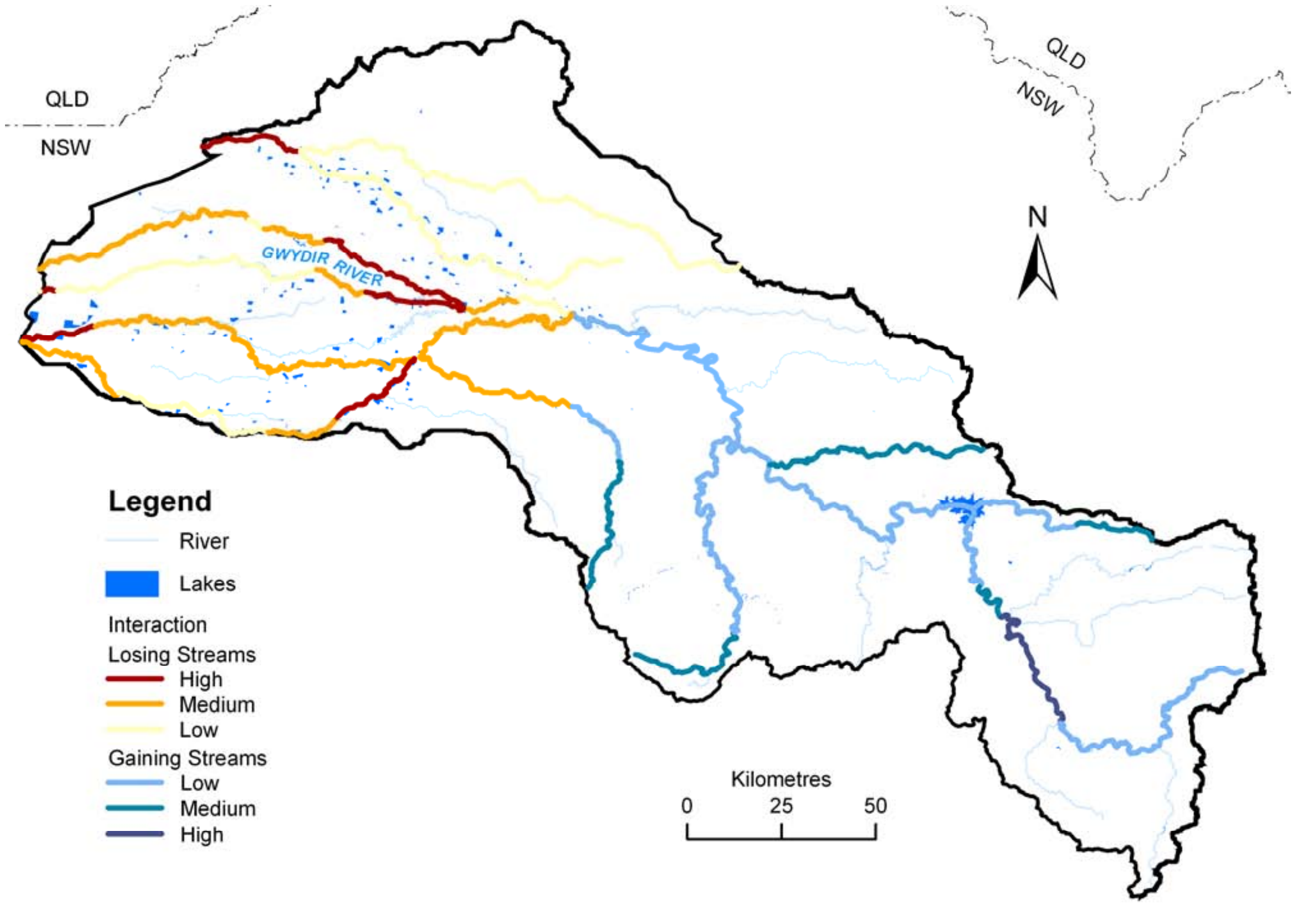

Figure 6-2. Map of surface–groundwater connectivity showing gaining streams in the upper reaches and losing streams in the lower catchment

Nearly all reaches in the Lower Gwydir are losing and range from the 'low losing' reaches of Gil Gil and Carole creeks to the 'high losing' reaches of the Gwydir River and Gingham Channel near Moree. The 'high losing' reaches are associated with a high hydraulic conductivity zone (5 to 50 m/day). Most other reaches fall into the 'medium losing' category. There is a single gaining reach of the Gwydir River at the eastern edge of the Narrabri Formation.

All reaches in the Upper Gwydir region were classified as 'gaining'. Most reaches fell into the 'low gaining' category. Fluxes were typically higher for reaches in the headwaters of tributaries such as the Horton River and Tycannah, Myall and Copes creeks. The greater fluxes in these areas are mostly due to high topographic gradients. There is also a section of the Gwydir River near Bundarra with higher fluxes into the surface water system. Relatively high hydraulic conductivity (0.5 to 10 m/day) and topographic gradients (0.02 to 0.05 m/m) are important controls on these fluxes.

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 show how these fluxes change with time. Groundwater levels retained the same relative relationship with river stage in most reaches studied. This indicated that the nature of the surface–groundwater connection remained essentially stable over time. This was tempered by observations that gaining conditions could be reversed over a short time in some river reaches due to flood events, indicating a more episodic influence on connectivity.

6.4 Groundwater modelling

About 77 percent of the current (2004/05) groundwater extraction in the Gwydir region occurs in the Lower Gwydir. This area was analysed using a numerical groundwater model (Bilge H, 2002) that was developed previously by the New South Wales government. The model covers all of the Lower Gwydir Alluvium GMU as well as a part of the GAB Alluvial GMU to the west. The original groundwater model was modified for the purposes of this project.

6.4.1 Model description

The model includes representation of two aquifers overlying a low-permeability basement. There is no significant interaction in the model between these aquifers and the GAB which underlies the modelled aquifer system. The numerical model uses MODFLOW and is constructed using a variety of specialised software. The model was calibrated previously against observed hydrographs over the period 1 July 1993 to 30 June 1998. The model was run for the period 1 July 1993 to 20 June 1998 in this project and is consistent with the original calibration. The length of the calibration period is insufficient to ensure reliable model predictions.

The eastern and western boundaries in the model area are flow boundaries where either groundwater potential or flow-rates can be prescribed as a function of time and position. Fluxes across these boundaries are expected to be significant due to connectivity with adjoining aquifers. Regional flow is considered to be approximately parallel to the northern and southern boundaries in the model and groundwater flow is negligible to the north and the south.

The major sources of aquifer recharge are identified as rainfall, irrigation deep drainage, groundwater inflows from the east and inflow from the rivers in the region. These rivers include the Gwydir River, the Gingham Watercourse, the Mehi River, Carole Creek, Mallowa Creek, Moomin Creek, Tycannah Creek and Marshal Ponds Creek.

Discharge from the aquifer occurs primarily as groundwater extraction in irrigation bores, discharge of groundwater to rivers and lateral groundwater flow out through the western boundary of the model.

6.4.2 Scenario implementation

The objective of the numerical modelling is to assess groundwater and surface water impacts under a range of groundwater extraction scenarios in the Lower Gwydir. The groundwater impacts are characterised by resource condition indicators. The surface water impacts are characterised by river losses to groundwater. Groundwater extraction for the Lower Gwydir Alluvium GMU area was set at 33 GL/year for all scenarios. This is the LTAEL (including 0.7 GL/year for basic rights) defined in the Lower Gwydir Groundwater Source WSP (DIPNR, 2006). Small extraction volumes were also included for the remainder of the modelled area in the GAB Alluvial GMU.

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 recharge scaling factors (RSF). The method used to estimate the RSFs 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 river model (as implemented for the Lower Gwydir Groundwater WSP) would implicitly include surface–groundwater exchanges within the unattributed losses and gains term. The calibration period for the groundwater model broadly coincides with the latter part of the surface water model calibration period (generally 1980 to 1995). Hence the changes in surface–groundwater exchanges in the groundwater model outputs for the calibration period are assumed to be the same as the changes in groundwater exchanges that are within the unattributed gains and losses of the river model. In all cases annual extraction rates were assumed to be constant.

The different scenarios were run for a 222-year period. This was implemented by using a 111-year climate series for two consecutive runs. The second run used the final condition from the first run as its initial condition. The second 111-year run provided ‘dynamic equilibrium’ conditions and most of the results are drawn from this second 111-year period.

6.4.3 Recharge modelling

Recharge Scaling Factors (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 Gwydir region. The RSFs are used to multiply these values to provide estimates of dryland recharge under different climate scenarios to be used in further analyses. The RSF is 1.0 by definition for Scenario A. 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.

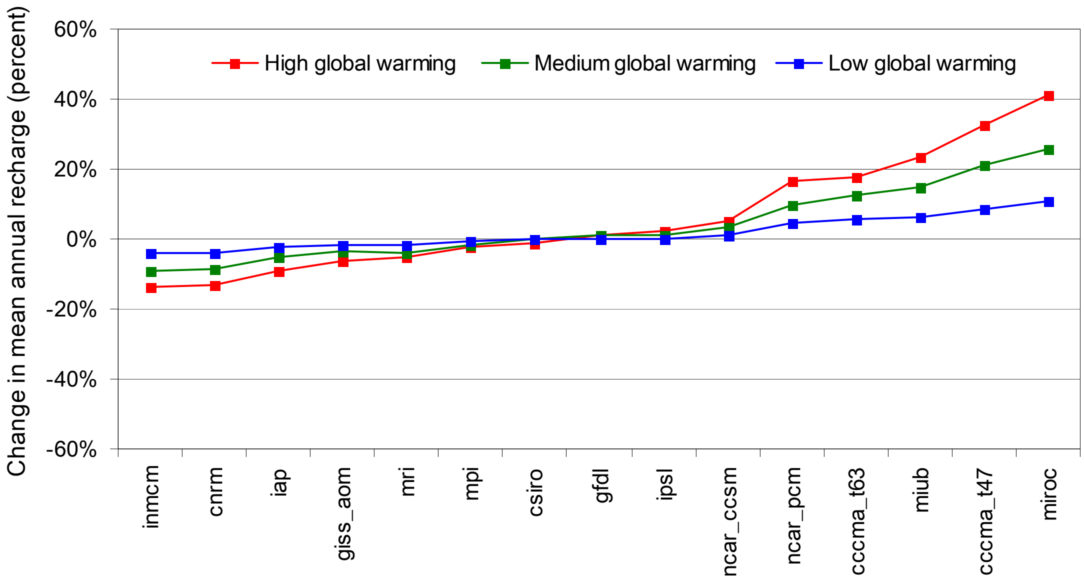

Figure 6-3. Percentage change in mean annual recharge from the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A recharge

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

High global warming			Medium global warming			Low global warming		
GCM	Rainfall	Recharge	GCM	Rainfall	Recharge	GCM	Rainfall	Recharge
inmcm	-8%	-14%	inmcm	-5%	-9%	inmcm	-2%	-4%
cnrm	-10%	-13%	cnrm	-6%	-9%	cnrm	-3%	-4%
iap	-3%	-9%	iap	-2%	-5%	iap	-1%	-2%
giss_aom	**-10%**	**-6%**	mri	-4%	-4%	mri	-2%	-2%
mri	-6%	-5%	giss_aom	-6%	-3%	giss_aom	-3%	-2%
mpi	-7%	-2%	mpi	-4%	-2%	mpi	-2%	-1%
csiro	-4%	-1%	csiro	-3%	0%	ipsl	0%	0%
gfdl	-6%	1%	gfdl	-4%	1%	gfdl	-2%	0%
ipsl	0%	2%	**ipsl**	**0%**	**1%**	csiro	-1%	0%
ncar_ccsm	2%	5%	ncar_ccsm	1%	3%	ncar_ccsm	1%	1%
ncar_pcm	6%	16%	ncar_pcm	4%	10%	ncar_pcm	2%	4%
cccma_t63	5%	18%	cccma_t63	3%	13%	cccma_t63	1%	5%
miub	6%	24%	miub	4%	15%	miub	2%	6%
cccma_t47	**11%**	**32%**	cccma_t47	7%	21%	cccma_t47	3%	8%
miroc	12%	41%	miroc	8%	26%	miroc	3%	11%

Figure 6-3 shows the percentage change in the modelled mean annual recharge averaged over the Gwydir region for Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual 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 GCMs and scenarios regarding climate change in the Gwydir region. Just over half the scenarios predict less or equal recharge and the remainder predict greater recharge. The high global warming scenario predicts both the highest and lowest change in recharge for the Gwydir region.

In subsequent modelling and reporting only the dry, mid and wet Scenario C variants are shown. These variants are based on the runoff modelling and are indicated in Table 6-2 in bold type. The choice of GCMs for surface runoff is comparable to those that would be chosen if recharge formed the basis of choice. The second highest, second lowest and median results for surface runoff are respectively the second highest, sixth lowest and the median of the 45 results for RSFs. The large variability in RSFs is related to the large variability in rainfall produced by the various GCMs. Rainfall and RSFs are not perfectly correlated.

Some GCMs that indicate reductions in rainfall lead to RSFs greater than 1.0. This is due to the more frequent extreme events despite of a reduction in mean annual 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. Summary results of the scenarios for modelling for each groundwater management unit in the Gwydir region. Numbers show percentage change in mean annual recharge under Scenario C relative to Scenario A

Name	Cdry	Cmid	Cwet
	percent change from Scenario A		
Lower Gwydir Alluvium	-1%	22%	32%
Miscellaneous Alluvium of the Barwon Region	-4%	-10%	43%
GAB Alluvial	-3%	2%	32%
GAB Intake Beds	-2%	-1%	32%
Gunnedah Basin	-2%	-1%	33%
Inverell Basalt	-2%	2%	30%
New England Fold Belt	-3%	-6%	32%

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

Model Zone	Cdry	Cmid	Cwet
	percent change from Scenario A		
Lower Gwydir Zone 2	6%	35%	44%
Lower Gwydir Zone 3	-18%	4%	12%
Lower Gwydir Zone 4	-11%	12%	25%
Lower Gwydir Zone 5	-4%	16%	27%

6.5 Modelling results

6.5.1 Time lags following development

Groundwater extraction takes a finite amount of time to reach an equilibrium impact on streamflow. Figure 6-4 indicates that there is a period of only a few years at the start of the scenario run before the interaction between the river and groundwater stabilises at about 25 GL/year. Net river loss slowly decreases as the average groundwater level increases in the model. A long-term equilibrium condition is not reached over that time. The rate of change in net river loss appears to decrease during the period from an initial loss of between 25 and 30 GL/year to a loss of between 20 and 25 GL/year.

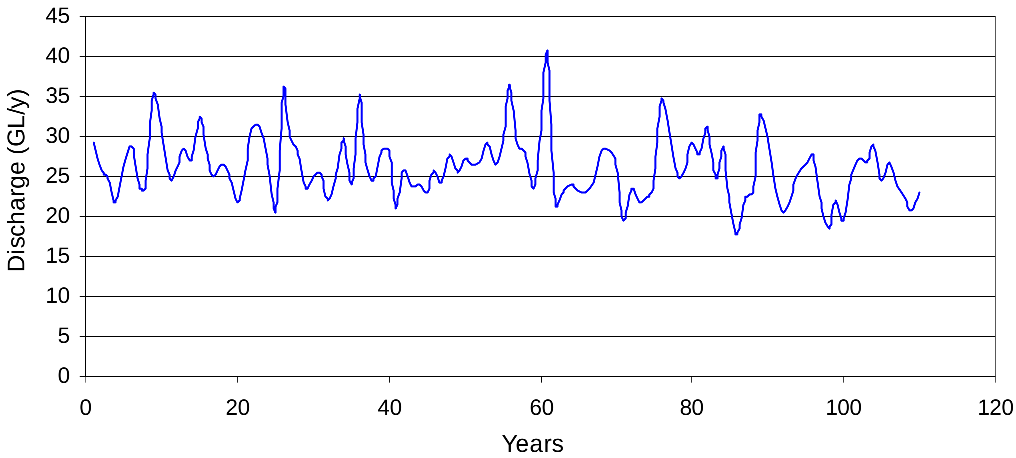

Figure 6-4. Modelled annual net river loss for the Lower Gwydir model zone over the first 111-year period of simulation under Scenario A

The dry scenarios lead to less flow into the river than the wet scenarios because there is less rainfall recharge in areas where the groundwater level around the river is generally higher than the river. The watertable is lower as a result. The wet scenarios have the greatest loss of water from river to groundwater in areas where the groundwater level is below the base of the river in the model because the higher river water levels under the wet scenarios provide more gradient for water loss than the dry scenarios. These patterns in net river loss were observed along different reaches of the Gwydir River system.

6.5.2 Groundwater levels

Twelve observation bores were selected to indicate the water level changes under the scenarios in both the shallow aquifer and the deep aquifer along an east–west transect. Data for groundwater levels in the key indicator bores are given in Table 6-5 for the second 111-year simulation period.

There is some spatial variability in levels across the modelled area. All bores show lower water levels in scenarios Cdry and Ddry relative to Scenario A and higher levels under mid and wet scenarios.

Some modelled bore hydrographs show a slow rise in water level of up to 5 m under Scenario A over the simulation period. The model also predicts that watertables would reach to within 2 m of the surface in some areas.

Table 6-5. Median groundwater level under Scenario A and changes in median levels under scenarios C and D relative to Scenario A for key indicator bores and average for the two main aquifers

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	m AHD			m			
Shallow aquifer	189.7	-0.4	0.4	1.4	-0.5	0.4	1.3
Deep aquifer	186.3	-0.3	0.2	0.9	-0.3	0.2	0.8
Average	**188.0**	**-0.4**	**0.3**	**1.1**	**-0.4**	**0.3**	**1.1**
Key indicator bores							
GW036162_3	167.4	-0.5	0.5	1.7	-0.5	0.5	1.7
GW036162_1	167.7	-0.5	0.6	1.9	-0.5	0.5	1.9
GW036160_3	162.1	-0.3	0.3	1.0	-0.3	0.2	1.0
GW036160_1	167.2	-0.5	0.4	1.7	-0.5	0.4	1.6
GW036112_3	184.7	-0.1	0.1	0.3	-0.1	0.0	0.3
GW036112_1	185.1	-0.1	0.0	0.3	-0.1	0.0	0.3
GW030456_3	189.6	-0.7	0.4	1.6	-0.8	0.4	1.5
GW030456_1	192.6	-0.7	0.5	1.6	-0.8	0.4	1.6
GW030423_2	221.3	-0.1	0.0	0.1	-0.1	0.0	0.1
GW030423_1	221.6	-0.1	0.0	0.1	-0.1	0.0	0.1
GW030398_3	192.4	-0.1	0.1	0.4	-0.2	0.1	0.4
GW030398_1	203.7	-0.7	1.1	2.6	-0.7	1.1	2.6

6.5.3 Groundwater balance

Total annual groundwater recharge was calculated as the sum of rainfall recharge, irrigation recharge, lateral groundwater flow into the model and flow of water from rivers to groundwater. Figure 6-5 shows total recharge both for the Lower Gwydir Alluvium GMU and for the entire modelled area together with groundwater extraction for the second 111-year period under Scenario A.

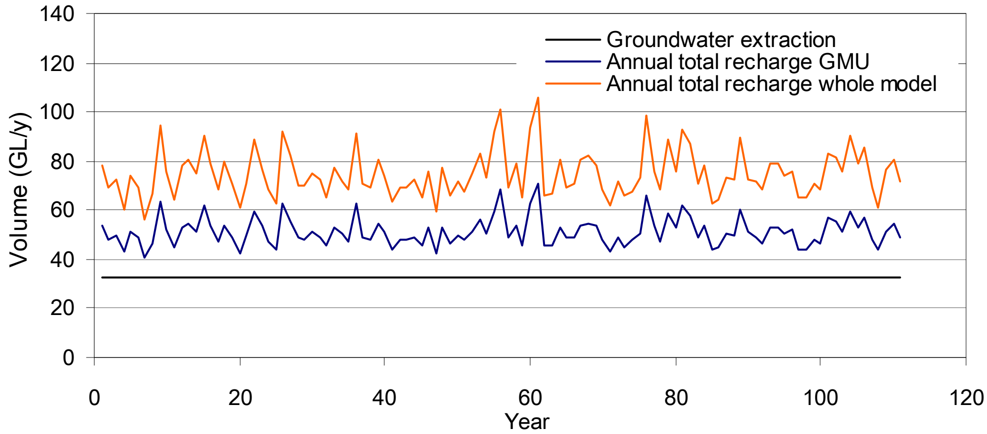

Figure 6-5. Annual total recharge for the whole model zone and for the Lower Gwydir Alluvium GMU as compared to groundwater extraction under Scenario A

Total recharge always exceeds groundwater extraction (Figure 6-5). All of the components of groundwater inflow and outflow are summarised in Table 6-6 for the entire modelled area and in Table 6-7 for the Lower Gwydir Alluvium GMU.

Table 6-6. Modelled average annual groundwater balance for the Lower Gwydir model zone (second 111-year period) under scenarios A, C and D

Average annual water balance components	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (gains)							
Rainfall	26	24	30	35	24	30	35
Irrigation	10	10	10	10	10	10	10
River system	32	32	31	31	31	31	30
Lateral flow	7	7	7	6	7	7	6
Total	**75**	**73**	**77**	**82**	**73**	**77**	**82**
Discharge (losses)							
Extraction	32	32	33	33	32	33	33
To rivers	6	5	6	7	5	6	7
Lateral flow	19	18	20	22	18	20	22
Total	**57**	**56**	**58**	**62**	**56**	**58**	**61**
Change in Storage	**18**	**17**	**18**	**20**	**17**	**18**	**20**

Table 6-7. Modelled average annual groundwater balance for the Lower Gwydir Alluvium GMU under the second 111-year period under scenarios A, C and D

Average annual water balance components	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y						
Recharge (gains)							
Rainfall	14.8	13.6	16.7	19.7	13.6	16.7	19.7
Irrigation	6.5	6.5	6.5	6.5	6.5	6.5	6.5
River system	22.2	22.3	21.4	21.1	22.1	21.2	21.0
Lateral flow	7.7	7.9	7.5	7.0	8.0	7.6	7.1
Total	**51.2**	**50.3**	**52.1**	**54.4**	**50.2**	**52.0**	**54.3**
Discharge (losses)							
Extraction	32.4	32.5	32.5	32.6	32.5	32.5	32.6
To rivers	5.3	5.0	5.6	6.5	5.0	5.6	6.4
Lateral flow	10.5	10.0	10.8	11.7	10.0	10.7	11.7
Total	**48.2**	**47.5**	**48.9**	**50.8**	**47.5**	**48.8**	**50.8**
Change in Storage	**3.0**	**2.8**	**3.2**	**3.5**	**2.7**	**3.1**	**3.5**

The distribution of recharge over the full period of simulation is shown for each of the model scenarios in Figure 6-6. The data shows that the median recharge over the 111-year period is about 50 GL/year for the Lower Gwydir Alluvium GMU area and 72 GL/year for the entire modelled area under Scenario A. Recharge varies from 60 GL/year to between 95 and 110 GL/year for the entire modelled area. It varies from 40 GL/year to between 70 and 80 GL/year for the Lower Gwydir Alluvium GMU area. This large dynamic range provides some information as to the utility of managing the aquifer through drier periods.

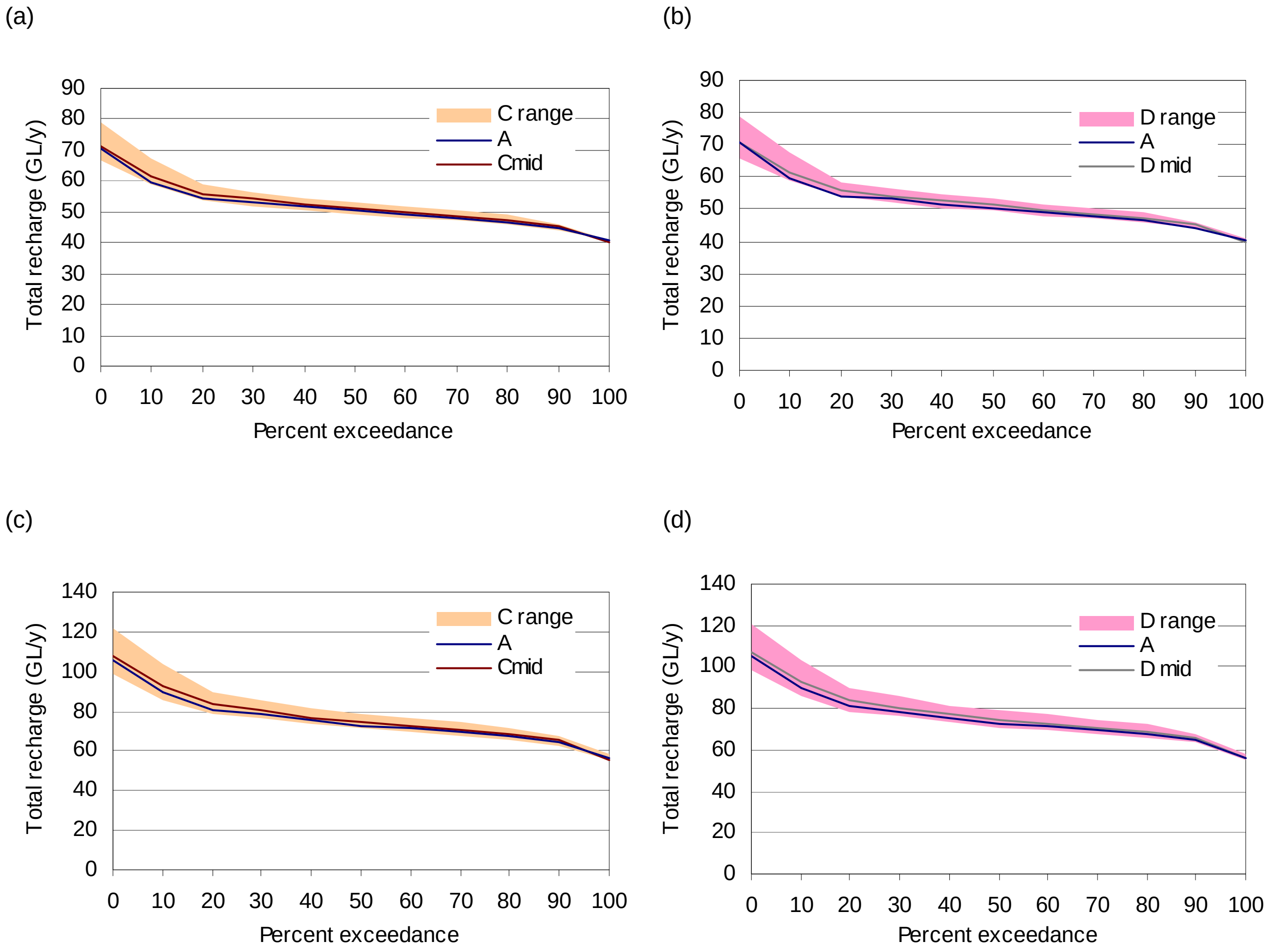

Figure 6-6. Annual total recharge exceedence curves for the Lower Gwydir Alluvium GMU under (a) Scenario C and (b) Scenario D; and the entire model zone under (c) Scenario C and (d) Scenario D

A large area of land irrigated by surface water occurs in the modelled area of the GAB Alluvial to the west. Irrigation deep drainage accounts for about 10 GL/year of total recharge. River leakage occurs in the modelled area of the GAB Alluvial to the west. Figure 6-6 indicates that recharge tends to increase under most scenarios except for Scenarios Cdry and Ddry where there is a slight decrease.

The LTAEL in the Lower Gwydir Groundwater Source WSP for the Lower Gwydir Alluvium GMU is 32.3 GL/year (excluding basic rights) and is based on total recharge to the GMU of 38 GL/year. The groundwater balance for the entire modelled area indicates total recharge minus lateral flows would be around 42 to 43 GL/year. Groundwater extraction can only occur in the 'fresher' groundwater within the GMU. The main limit to groundwater extraction is the need to ensure throughflow to avoid groundwater salinisation so recharge within the GMU should be greater than extraction. The area of recharge that can be balanced against the groundwater extraction could be defined by the area of the drawdown cone associated with pumping but its shape at the end of each simulation is not known.

6.5.4 Groundwater indicators

Groundwater resource condition indicators are described in Table 6-8. The results (Table 6-9) show that groundwater resource security is high under all scenarios. The difference between the indicators given in the table and recharge shown in the exceedence curves (Figure 6-6) is that the groundwater security indicator includes recharge averaged over a moving ten-year period. The environmental indicator values are relatively constant across all scenarios and indicate a level of about 35 percent of non-extracted water.

Table 6-8. Definition of groundwater indicators

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

The drought indicator values show a range of responses in groundwater level. Most changes are small (less than 5 m) indicating that the future scenarios would not place much additional stress on aquifer water levels.

Table 6-9. Groundwater indicators under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Security indicator	100%	100%	100%	100%	100%	100%	100%
Environmental indicator				ratio			
Entire model zone	0.4	0.5	0.4	0.4	0.5	0.4	0.4
Lower Gwydir Alluvium GMU	0.6	0.6	0.7	0.6	0.6	0.7	0.6
Drought indicator				m			
Average	-1.2	-1.5	-0.9	-0.2	-1.5	-0.9	-0.3
Observation bore							
GW036162_3	-3.1	-3.5	-2.7	-1.7	-3.5	-2.7	-1.7
GW036162_1	-3.4	-3.8	-3.0	-1.8	-3.8	-3.0	-1.9
GW036160_3	-1.0	-1.2	-0.8	-0.3	-1.2	-0.8	-0.3
GW036160_1	-1.7	-2.1	-1.3	-0.4	-2.1	-1.4	-0.4
GW036112_3	-0.4	-0.5	-0.3	-0.1	-0.5	-0.3	-0.1
GW036112_1	-0.2	-0.3	-0.2	0.0	-0.4	-0.2	0.0
GW030456_3	-0.6	-1.3	-0.1	0.9	-1.4	-0.2	0.9
GW030456_1	-0.4	-1.1	0.1	1.2	-1.2	0.0	1.1
GW030423_2	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2	-0.1
GW030423_1	-0.2	-0.3	-0.2	-0.1	-0.3	-0.2	-0.1
GW030398_3	-1.3	-1.4	-1.2	-1.1	-1.4	-1.2	-1.1
GW030398_1	-2.6	-3.1	-1.8	-0.8	-3.1	-3.1	-0.8

6.6 Water balances for lower priority groundwater management units

Simple water balance analyses were undertaken for the lower priority GMUs in the Gwydir region (Table 6-1). 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: 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 streamflow either directly through the channel bed or through the floodplain during floods. Extration 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 reported 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 Gwydir region is shown in Table 6-10. The estimates of current extraction are based on metered data and on an average extraction estimate of 1.5 ML/year for each stock and domestic bore (DWE, pers. comm.) for areas controlled by New South Wales macro groundwater plans.

The macro groundwater plan program is a broad-scale planning process covering areas of New South Wales not covered by 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. LTAELs are based on the estimation of rainfall recharge to each GMU.

Table 6-10. Estimated current and future groundwater extraction levels and current entitlements for the lower priority groundwater management units in the Gwydir region

Code	Name	Current extraction* 2004/05	Total entitlement	Future extraction
			GL/y	
N23	Miscellaneous Alluvium of the Barwon Region	0.9	1.5	1.5
N63	GAB Alluvial	2.6	3.8	25.8
N601	GAB Intake Beds	1.9	2.6	4.0
N604	Gunnedah Basin	0.0	0.0	0.3
N803	Inverell Basalt	1.4	2.2	4.5
N805	New England Fold Belt	4.0	5.5	95.3
	Total	**10.7**	**15.6**	**131.5**

*Current groundwater extraction for macro groundwater plan areas is based on metered and estimated data provided by NSW DWE. Data quality is variable depending on the location of bores and the frequency of meter reading.
** Determined from values supplied by DWE from DWE (2007). Future extraction will equal the LTAEL.

Groundwater extraction within the Gwydir 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 was not determined but it is expected that full growth will be achieved by 2030. 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 and the total additional stock and domestic requirement was calculated assuming usage rates of 2.25 ML/year for domestic bores and 0.0088 ML/ha/year for stock bores.

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. One-dimensional modelling of recharge was used to produce point estimates of root zone drainage from which RSFs were calculated to transform recharge figures. RSFs under Scenario D are identical to Scenario C with the addition of groundwater management rules applied 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 6-11.

Table 6-11. Scaled recharge under scenarios A and C for lower priority groundwater management units in the Gwydir region under scenario A and C

Code	Name	Recharge	Scaled recharge		
		A	Cdry	Cmid	Cwet
		GL/y			
N23	Miscellaneous Alluvium of the Barwon Region	1.8	1.7	1.6	2.5
N63	GAB Alluvial	99.8	96.5	102.2	131.3
N601	GAB Intake Beds	73.2	71.4	72.6	96.8
N604	Gunnedah Basin	0.6	0.6	0.6	0.9
N803	Inverell Basalt	18.1	17.8	18.4	23.5
N805	New England Fold Belt	317.7	309.0	299.3	418.2
	Total	**511.2**	**497.0**	**494.7**	**673.1**
	Average scaling factor		1.0	1.0	1.3

The ratio of current (2004/05) groundwater extraction to recharge is shown in Table 6-13. The E/R ratio is an indicator of potential stress on the aquifer. Where E/R exceeds 1.0 groundwater is being extracted at a rate greater than the rate of recharge. New South Wales macro groundwater plans allocate 30 to 50 percent of rainfall recharge to environmental purposes (E/R of 0.5 to 0.7).

Groundwater extraction is most substantial within the Miscellaneous Alluvium of the Barwon Region GMU. Extraction in this GMU is about half of rainfall recharge and E/R is predicted to increase slightly because climate change is expected to reduce recharge. Development in this GMU under Scenario D is expected to lift E/R to a level of high development. It is unclear how much water may be derived from streams to help maintain this extraction rate.

Table 6-12. Comparison of groundwater extraction with scaled rainfall recharge for lower priority groundwater management units in the Gwydir region under scenario A and C

Code	GMU	Current extraction 2004/05	E/R			
			A	Cdry	Cmid	Cwet
		GL/y	ratio			
N23	Miscellaneous Alluvium of the Barwon Region	0.9	0.5	0.5	0.6	0.3
N63	GAB Alluvial	2.6	<0.1	<0.1	<0.1	<0.1
N601	GAB Intake Beds	1.9	<0.1	<0.1	<0.1	<0.1
N604	Gunnedah Basin	0.0	0.0	0.0	0.0	0.0
N803	Inverell Basalt	1.4	0.1	0.1	0.1	0.1
N805	New England Fold Belt	4.0	<0.1	<0.1	<0.1	<0.1

The GAB Alluvial and New England Fold Belt GMUs are predicted to experience significant growth in groundwater extraction. The predicted growth would lead to higher E/R values. However, considering the relatively low current level of groundwater extraction, the increases would not be significant and remain within the environmental guidelines outlined by the New South Wales government.

The Great Artesian Basin Groundwater Sources WSP will significantly reduce licensed groundwater extraction from the Eastern Recharge Zone, the portion of the GAB outcropping within the region. These reductions will lower the ratio of extraction to rainfall recharge.

Table 6-13. Comparison of groundwater extraction with scaled rainfall recharge for lower priority groundwater management units in the Gwydir region under Scenario D

Code	Name	Future extraction	Scaled E/R		
			Ddry	Dmid	Dwet
		GL/y	ratio		
N23	Miscellaneous Alluvium of the Barwon Region	1.5	0.9	1.0	0.6
N63	GAB Alluvial	25.8	0.3	0.3	0.2
N601	GAB Intake Beds	4.0	0.1	0.1	0.0
N604	Gunnedah Basin	0.3	0.5	0.5	0.4
N803	Inverell Basalt	4.5	0.3	0.3	0.2
N805	New England Fold Belt	95.3	0.3	0.3	0.2

6.6.3 Impact of extraction on streamflow

The future impact of lower priority GMU extraction on streamflow is assumed to be the difference between the likely maximum use as defined in the macro groundwater plan and the current entitlement multiplied by a connectivity factor. Table 6-14 shows future groundwater use, connectivity factors and impacts of future groundwater use on streamflow.

Table 6-14. Estimation of the impacts of current and future groundwater extraction on streamflow outside of the Lower Gwydir Alluvium GMU

Code	Name	Connectivity**	Impact of extraction on streamflow (2004/05)	Impact of extraction on streamflow at 2030	Time lag to reach full impact*
		percent	GL/y		years
N23	Miscellaneous Alluvium of the Barwon Region	52%	0.45	0.8	10 to 50
N63	GAB Alluvial	17%	0.44	4.39	1 to 10
N601	GAB Intake Beds	0%	0	0	>100
N604	Gunnedah Basin	26%	0	0.08	10 to 50
N803	Inverell Basalt	35%	0.49	1.58	1 to 10
N805	New England Fold Belt	32%	1.28	30.5	50 to 100
	Total	–	**2.66**	**37.35**	–

*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), and are expressed as the percent of groundwater extraction derived from streamflow.

These calculations assume that GAB pumping causes impacts on streamflow in the region. Future groundwater pumping is assumed not to increase and current pumping has occurred long enough to be included within the calibration period of the river models. Current use is assumed to be at entitlement levels for the macro groundwater plan areas. The effect of this assumption is to decrease estimated impacts to be less than 2 GL/year. The calculations use connectivity data supplied by state agencies and reported in MDBC (2007). The effects of current use relative to the calibration period for the river model are ignored (scenarios A and C), hence only Scenario D is relevant. Future extraction figures are the 'likely maximum use without plan revision' figures from the macro groundwater plan data supplied by DWE. It is assumed that extracted groundwater does not return to aquifers (for example, via irrigation of crops), that the full impacts of extraction on streams will occur within 100 years, and that the impact of current extraction on streams has already occurred.

The impacts of groundwater extraction on streamflow listed in Table 6-14 are distributed to the relevant surface water subcatchments or stretches of river.

Streamflow losses of less than 2 GL/year in a subcatchment would be difficult to observe in reality. Only subcatchments where the estimated impact from groundwater extraction exceeds a 2 GL/year reduction in streamflow are considered further and included in river modelling (Chapter 4). This cut-off discounts about 24 GL/year of impact reducing the total estimated impact from about 37 GL/year (Table 6-14) to about 13 GL/year.

Table 6-15. Estimates of impacts of groundwater pumping in lower priority groundwater management units in the Gwydir region on subcatchments where impacts exceed 2 GL/year

Station no.	Location	Estimated impact
		GL/y
4180150	Horton River @ Rider (Killara)	5.5
4180290	Gwydir River @ Yarrowyck	5.6
4180351	Gwydir River @ Copeton Dam storage gauge	2.2
	Total	**13.3**

The estimated losses in each subcatchment were used to modify daily flow duration curves (Figure 6-7) and Scenario D inflows for the relevant subcatchments in the river model (Chapter 4). The percentage of low flows decreases by 20 to 30 percent in the affected subcatchments. These reductions in baseflow would make flow in these streams even more ephemeral affecting near-river ecosystems and flow in the main channel.

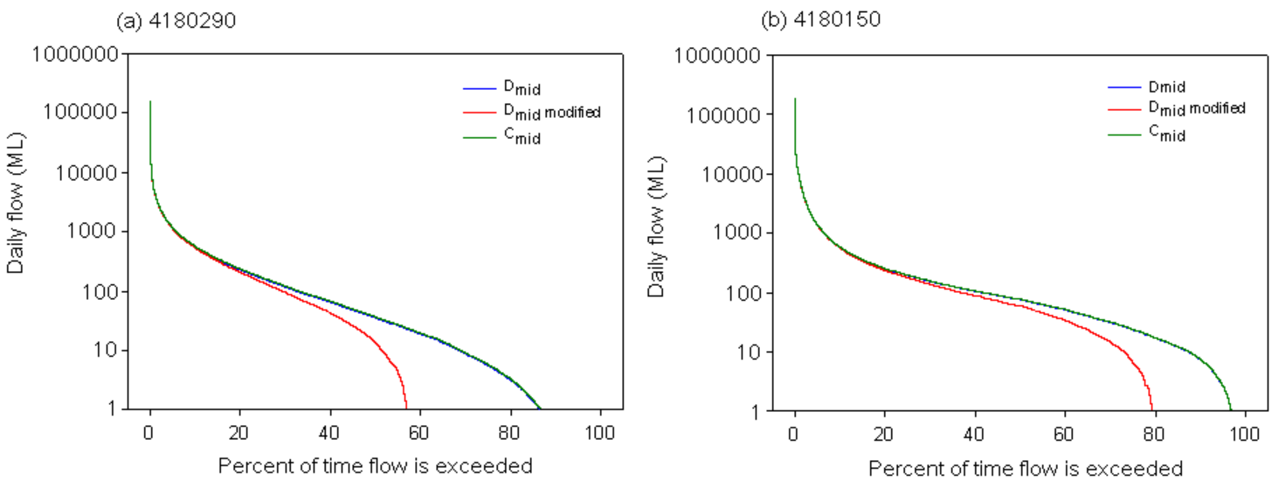

Figure 6-7. Daily flow duration curves for gauges (a) 4180290 and (b) 4180150 The scenarios shown are Cmid (climate change and current farm dam development), Dmid (climate change, future farm development and current groundwater development) Dmid modified (climate change, future farm development and future groundwater development)

6.7 Conjunctive water use indicators

Groundwater can provide a secure water source during drier periods. Irrigators may elect to change from surface water to groundwater during years of low flow where such 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 6-16 shows these ratios as percentages for different dry conditions as well as average values.

Average groundwater extraction under current conditions represents 12 percent of total water use or 55 percent of the lowest one-year total surface water diversions in the Gwydir region. This is similar under Scenario Cmid but considerably different for Scenario Cdry (15 and 73 percent) and Scenario Cwet (10 and 46 percent).

There is expected to be an almost four-fold increase in groundwater extractions under Scenario D mainly for stock and domestic use from the fractured rock aquifers. This would lead to a decrease in river flows as described above but the exchange is not one for one. Some of the extracted water would have otherwise been used for plant transpiration, or would have moved to another groundwater system, and this is expressed as a connectivity factor of less than 1.0.

Average groundwater extraction as a percentage of total water use under Scenario D in the lowest one-year case changes to 30 and 78 percent Scenario Dmid, 41 and 91 percent under Scenario Ddry and 30 and 78 percent under Scenario Dwet.

These results show that groundwater represents a minor water resource overall but that it 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 in low flow years in general. The increased significance represents a trend towards increasing groundwater use for stock and domestic supply.

Table 6-16. Groundwater extraction to total water (surface and groundwater) for low surface water use periods under scenarios A, C and D

	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
Lowest 1-year period	55%	73%	58%	46%	91%	85%	78%
Lowest 3-year period	33%	50%	33%	21%	81%	66%	52%
Lowest 5-year period	23%	38%	28%	17%	72%	61%	44%
Average	12%	15%	13%	10%	41%	36%	30%

6.8 Discussion of key findings

6.8.1 Connectivity

The key features of the connectivity analysis (Figure 6-2) are:

- The gaining reaches in the Upper Gwydir are generally low fluxes except for the headwaters and a high permeability zone near Bundurra.
- The losing reaches in the Lower Gwydir – apart from a single gaining reach near the eastern edge of the Narrabri Formation – have more variable fluxes with higher fluxes near Moree.

The evaluation was done during a dry period. While values will change over time 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 Gwydir Alluvium GMU

The major fraction of current groundwater extraction within the Gwydir region occurs in the Lower Gwydir Alluvium GMU. Groundwater extraction from this GMU (~33 GL/year) is still much smaller than the average annual diversion of surface water for irrigation (~320 GL/year). The need for a leaching fraction means the level of groundwater extraction will be offset by leaching under the irrigation areas. The groundwater extraction will also lead to increased leakage from rivers, again offsetting the drawdown caused by the groundwater extraction. Total recharge for the modelled area exceeds groundwater extraction leading to rising watertables.

The area of the GMU is smaller than the area of surface water irrigation and is related to the low salinity and higher transmissivity of the aquifer in that area. Water quality decreases to the west.

There is the potential for reversal of gradients and hence salinisation of the groundwater resource should groundwater extraction in the GMU exceed recharge within the drawdown zone. The Lower Gwydir Groundwater Source WSP aims to keep extraction in the GMU below the recharge in the GMU. The groundwater modelling shows that westerly gradients are mostly maintained. However, this strategy does place a limit on groundwater extraction and the level of protection that extraction provides in controlling rising watertables.

This suggests that sustainability of the resource is sensitive to controlling groundwater salinisation and preventing land salinisation caused by rising watertables. This project was not set up to consider either issue.

6.8.3 Impacts of groundwater extraction around the catchment

Most of the future development in the Gwydir region is expected to occur away from the main aquifers. Under the New South Wales groundwater sharing plans, a 'maximum likely groundwater extraction without plan revision' is defined. This limit may not be realised for a number of reasons, including groundwater quality, transmissivity, land suitability and pumping regulations. Scenario D is therefore not intended as a prediction of conditions that will eventuate, but as a scenario of consequences that might arise if no management changes were made and the resource was fully developed according to current predictions. Consequently, results highlight pressure points in the system into the future. This assessment does not elaborate on what management actions might be taken to address any of these pressure points.

Ignoring impacts of less than 2 GL/year in any subcatchment has meant that at a catchment scale 60 percent of the potential impact is ignored in the river modelling. Current impacts on streams assume that current use is equal to entitlements and that the full impacts of this are realised. Thus while the projected development may represent an upper limit, the assessment of this impact is likely to be an underestimate. The total impacts of extraction outside the Lower Gwydir Alluvium GMU are estimated to be ~37 GL/year. While this estimate has a large uncertainty, it does show the importance of the development in these parts of the region. The local impact on streamflow can also be important with the number of zero flow days increasing by as much as 30 percent of the total time.

The GAB Intake Beds are assigned zero connectivity in New South Wales. This connectivity is assumed within the context of the very low recharge rates assigned to the Intake Beds (about 0.5 percent of rainfall). The low recharge rates are derived within the context that "recharge is often rejected back to the surface for stream baseflow" (M. Williams, pers comm.). The low connectivity may be thought to apply 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. This makes sense when it is considered that 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. If this connectivity is accepted, then 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. That is, 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 rate to the Intake Beds is much higher than the quoted 0.5 percent rate allowing for the volume of recharge that is rejected.

6.8.4 Miscellaneous Alluvium of the Barwon Region GMU

The E/R ratio indicates that this GMU is moderately developed under current and future climate scenarios and highly developed under projected extraction scenarios. It is likely that some recharge occurs directly from the stream. These smaller alluvia are flagged in a number of regions by high E/R values. For such a high level of development, it is important to have a good understanding of the overall groundwater balance and the importance of other sources of water such as rivers and lateral movement from adjacent GMUs. Further work would be required to assess the long-term implications of this extraction.

6.9 References

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7 Environment

This chapter describes the major environmental assets in the Gwydir region. It has four sections:

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

7.1 Summary

7.1.1 Issues and observations

- The Gwydir River is regulated by Copeton Dam and is affected by major water extractions.
- The Gwydir Wetlands on the floodplain of the lower river are of regional, national and international importance. There are two main wetland areas: the Lower Gwydir Watercourse and the Gingham Watercourse. There are four components to the Gwydir Wetlands Ramsar site: three on the Gingham Watercourse and one on the Lower Gwydir Watercourse. The Gwydir Wetlands support large colonial waterbird breeding events and an appreciable assemblage of rare, endangered and vulnerable species. The wetlands are showing a high level of ecological stress.
- The Water Sharing Plan for the Gwydir Regulated River Water Source (DIPNR, 2004) has environmental water provisions including an environmental contingency allowance held in Copeton Dam and restrictions on extraction on supplementary flow events, with the latter providing the main inflows to the Gwydir Wetlands.

7.1.2 Key messages

- As a result of water resource development there has been a large (more than 75 percent) increase in the average period between flood events that inundate 20,000 ha (or about 20 percent) of the Gwydir Wetlands. There has also been a large (64 percent) increase in the maximum period between events which has risen from 7 to 11.5 years. The average annual above-threshold flood volume has also been reduced (by 42 percent). However on average, individual flood events are now 8 percent larger in terms of flooding volume because of the reduction in flood frequency. These changes are consistent with the stressed ecological condition of the wetlands.
- Under the best estimate 2030 climate the average and the maximum period between inundation events would not change greatly. However, the average annual flooding volume would fall by 20 percent relative to current conditions to be less than half the pre-development event volume. The change in flooding volume would be likely to have additional effects on the vegetation condition and structure in the wetlands and affect their use by waterbirds for breeding.
- Under the dry 2030 climate extreme there would be a large increase in the average period between flows (52 percent relative to current conditions) such that flooding would only occur every 3.5 years on average, instead of every 15 months under pre-development conditions. Although the average size of individual events would increase, the average annual flooding volume would be half of the current average annual volume and only 29 percent of the pre-development average annual volume. These changes would be likely to have serious consequences for all aspects of the Gwydir Wetlands ecology with possible losses of some important elements.
- Under the wet extreme 2030 climate the frequency of flood events would almost return to the pre-development frequency, and the average annual flooding volume would be very close to the pre-development value.
- Future development (farm dams and growth in groundwater extractions) would have limited additional impact on the hydrology of the Gwydir Wetlands.

7.1.3 Uncertainty

The main uncertainties involving analysis and reporting include the following:

- 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 asset 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 Gwydir region and on the assessment of hydrologic indicators defined by prior studies for information 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 Summary of environmental flow rules

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

- a limit on the long-term average annual amount of water that can be extracted from the water source. This limit is equal to the amount of water that could have been extracted under 1999/2000 levels of water resource development and the management rules in the water sharing plan. This amount is currently estimated to be 388 GL/year over the long term. This rule is estimated to reserve about 66 percent of the long-term average annual flow term for the environment
- a minimum flow rule which passes up to 500 ML/day of inflows from tributaries downstream of Copeton Dam, through to the Gwydir Wetlands
- up to 90 GL (at general security) to be reserved in Copeton Dam as an environmental contingency allowance (ECA) which can be released for a wide variety of environmental purposes
- scope for access licences to be committed for environmental purposes
- 50 percent of the volume of supplementary water events to be protected from extraction when inflows are greater than 500ML/day.

Changes in the total environmental water share, end-of-system flows and the availability and reliability of the ECA under different scenarios are reported in Chapter 4. The hydrological indicators defined and reported below relate primarily to the supplementary flow events rule given above.

7.2.2 Environmental assets and indicators

The following information is primarily provided by Environment Australia (2001), unless otherwise cited.

The Gwydir Wetlands (NSW008, Figure 7-1 and Figure 7-2) are nationally important wetlands and cover an area of about 100,000 ha on the lower floodplain of the Gwydir River downstream of Moree. The wetlands are in two main areas: the Lower Gwydir Watercourse and Gingham Watercourse just to the north. In 1999 four privately owned portions received Ramsar listing, recognising their international importance. These portions are 'Windella', 'Crinolyn' and 'Goddard's Lease' on the Gingham Watercourse and 'Old Dromana' on the Lower Gwydir Watercourse. These portions cover some 823 ha and were the first privately owned areas in Australia nominated for Ramsar listing.

Widespread inundation of the wetlands occurs during large floods sourced in the upper catchment. Flooding has been affected by upstream water resource development. The Gwydir Raft – an accumulation of timber and debris established since the 1940s – altered the flow distribution between the two watercourses.

The primary ecological features of the wetlands are large expanses of vegetation (approximately 60,000 ha) including large areas of Coolibah (*Eucalyptus coolabah*) woodland and Water Couch (*Paspalum distichum*). The wetlands represent one of the largest areas of Water Couch in New South Wales. The largest stand of Marsh Club-rush (*Bolboschenus fluviatilis*) in New South Wales (about 1300 ha) is in the Gwydir Watercourse. The Gingham Watercourse provide virtually permanent water and is an important waterbird habitat.

The wetlands are an important breeding site for colonial waterbirds, including Straw-necked Ibis (*Threskiornis spinicollis*), Intermediate Egret (*Ardea intermedia*) and Rufous Night Heron (*Nycticorax caledonicus*). Very large colonies of these species (exceeding 100,000 pairs) bred in the wetlands in the late 1990s. The wetlands are used by a range of state-listed vulnerable or endangered species including the Magpie Goose (*Anseranas semipalmata*), Blue-billed Duck (*Oxyura australis*), Freckled Duck (*Stictonetta naevosa*), Brolga (*Grus rubicundus*), Painted Snipe (*Rostratula benghalensis*) and Jabiru (*Xenorhynchus asiaticus*). The wetlands provide habitat for waterbirds listed under international treaties.

Land tenure in the wetlands is freehold. Grazing and cropping (including irrigation) are the main land uses. There are many levee banks distributed through the wetlands, mostly to protect crops from flooding.

In addition to the impacts of land use change, large areas of the wetlands have been invaded by weeds, particularly Water Hyacinth (*Eichornia crassipes*) and Lippia (*Phyla canescens*).

Figure 7-1. Location map of environmental assets

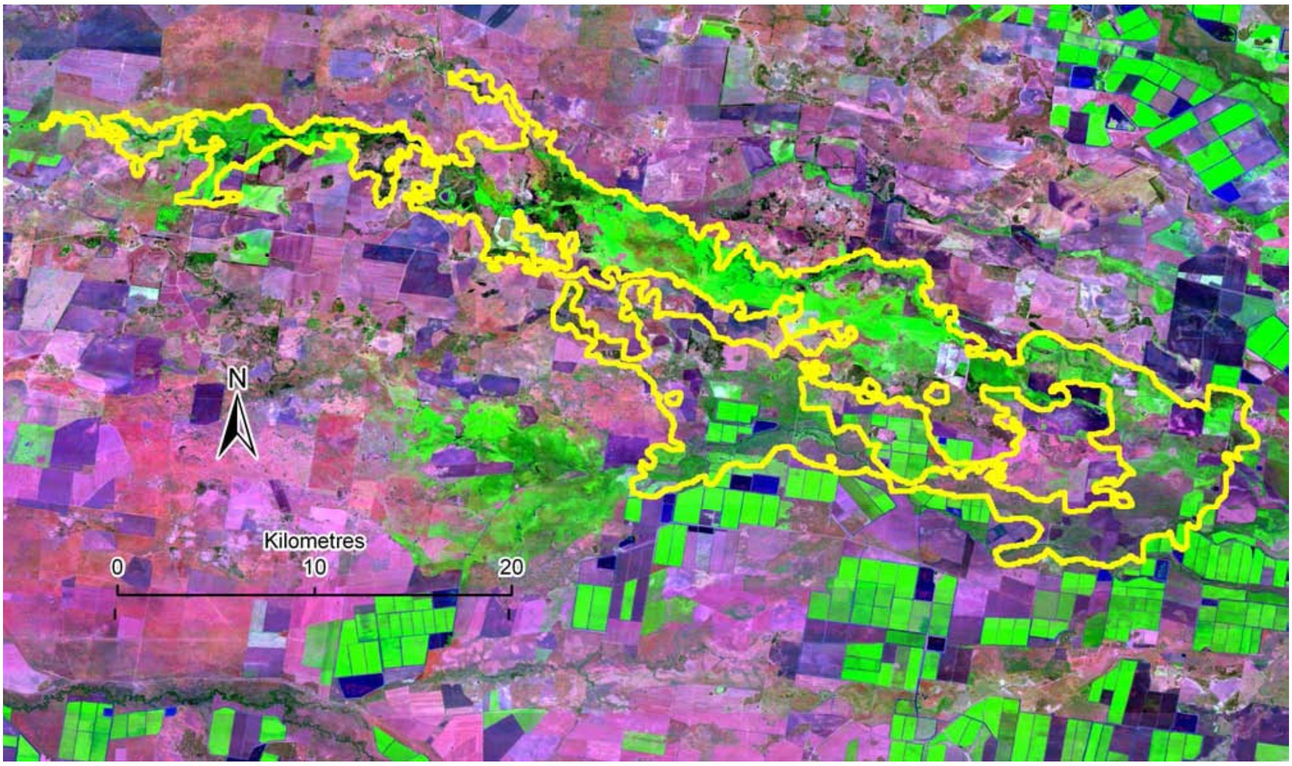

Figure 7-2. Satellite image indicating (yellow polygons) the extent of the Gwydir Wetlands as defined in Environment Australia (2001)

In the early 1990s a number of studies were undertaken to identify inundation requirements of the Gwydir Wetlands. McCosker and Duggin (1993) used a water budget approach to determine an estimated requirement of 3 to 6 ML/ha to initially flood the areas of Water Couch and *Bolboschenous* vegetation. Bennett and Green (1993) used streamflow records and satellite imagery of inundation events and estimated that a flow of 100 GL/month at the Yarraman gauge was needed to flood 20,000 ha. This area largely comprises the two watercourse areas (Green and Bennett, 1991; cited in Bennett and McCosker (1994)). Bennett and McCosker (1994) further outline the approaches taken in the two studies.

Powell (2005) has undertaken a more recent study of flooding and vegetation responses in the Gwydir Wetlands, but does not provide hydrological indicators which could be used for the analysis required in this report. The 100 GL/month flow at the Yarraman gauge was therefore adopted for use in this project, and was used to define two indicators of flood frequency and two indicators of flooding volume (Table 7-1).

Table 7-1. Definition of environmental indicators

Gwydir Wetlands indicators	Description
Average period between events	Average period between flows exceeding 100 GL/month at Yarraman gauge
Maximum period between events	Maximum period between flows exceeding 100 GL/month at Yarraman gauge
Average flooding volume per year	Average annual volume above 100 GL/month at Yarraman gauge
Average flooding volume per event	Average event volume above 100 GL/month at Yarraman gauge

7.3 Results

The projected changes in the flood frequency and volume indicators under the various scenarios (including the pre-development Scenario P) are listed in Table 7-2. These were assessed using scenario outputs for the Yarraman gauge from the Gwydir River model (Chapter 4).

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

Indicators	P	A	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	years		percent change from Scenario A					
Average period between events	1.3	2.3	52%	-1%	-39%	53%	-1%	-38%
Maximum period between events	7.0	11.5	65%	-4%	-53%	65%	-4%	-52%
	GL							
Average flooding volume per year	211	123	-50%	-20%	72%	-51%	-22%	69%
Average flooding volume per event	316	342	43%	-20%	19%	-39%	-20%	17%

7.4 Discussion of key findings

As a result of water resource development there has been a decrease in both the frequency of flood events and the total flooding volume for the Gwydir River wetlands. There has been a large (more than 75 percent) increase in the average period between assessed flood events and a large (64 percent) increase in the maximum period between events which has risen from 7 to 11.5 years. On average, flood events are now 8 percent larger in terms of flooding volume as the smaller events no longer occur. However, the large reduction in frequency means that the average annual flooding volume has been reduced by 42 percent. Webb, McKeown and Associates (2007) reported a 24 percent reduction in mean annual inflows (not above-threshold flows) to the wetlands as measured at Yarraman for the period 1922 to 2000. The large reductions in flooding of the Gwydir Wetlands as a result of water resource development are one of the primary reasons for their current stressed condition (BRGCMA, 2007).

Under the best estimate 2030 climate, the average and the maximum period between inundation events would not change greatly. However, the average annual flooding volume would fall by 20 percent relative to current conditions to be less than half the pre-development event volume. The average flooding volume per event would be 20 percent less than the current average volume, or 13 percent lower than the pre-development average volume. These changes in flood volume would be likely to have additional effects on the vegetation condition and structure in the wetlands and affect their use by waterbirds for breeding.

Under the dry 2030 climate extreme there would be large increases in the average period between flows (52 percent relative to current conditions) such that flooding would only occur every 3.5 years on average, instead of every 15 months under pre-development conditions. The maximum period between events would increase by 65 percent (relative to current conditions) to nearly 19 years, compared to 7 years under pre-development conditions. Although the average size of individual events would increase, this would again be due to the loss of all the smaller events, and the average annual flooding volume would be half of the current average annual volume and only 29 percent of the pre-development average annual volume. These changes would be likely to have serious consequences for all aspects of the Gwydir Wetlands ecology with possible losses of some important elements.

Under the wet extreme 2030 climate the frequency of flood events would almost return to the pre-development frequency, and the average annual flooding volume would be very close to the pre-development value.

Future development (farm dams and growth in groundwater extractions) would have limited additional impact on the hydrology of the Gwydir Wetlands.

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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					
4160271	447	511	1580	18	4%	1%	-10%	-28%	0%	-4%	9%	22%
4160540	3303	551	1556	20	4%	6%	-10%	-29%	0%	-6%	9%	21%
4180011	1180	642	1487	28	4%	3%	-10%	-29%	0%	-8%	10%	24%
4180021	414	583	1528	21	4%	1%	-10%	-32%	0%	-8%	10%	29%
4180050	236	821	1346	77	9%	2%	-10%	-28%	0%	-7%	13%	35%
4180062	183	601	1518	24	4%	0%	-10%	-31%	0%	-7%	10%	28%
4180071	124	575	1534	22	4%	0%	-10%	-30%	0%	-7%	9%	21%
4180081	512	741	1339	54	7%	3%	-10%	-29%	0%	-9%	13%	36%
4180123	238	756	1410	44	6%	1%	-10%	-31%	0%	-10%	13%	37%
4180124	317	740	1421	42	6%	1%	-10%	-30%	0%	-10%	13%	37%
4180133	501	688	1472	38	6%	2%	-10%	-30%	0%	-12%	13%	36%
4180134	161	675	1487	31	5%	0%	-10%	-31%	0%	-10%	13%	38%
4180135	290	665	1478	42	6%	1%	-10%	-28%	0%	-8%	12%	31%
4180136	166	738	1461	45	6%	1%	-10%	-31%	0%	-10%	13%	37%
4180150	1957	775	1411	113	15%	22%	-10%	-25%	0%	-8%	13%	28%
4180160	535	689	1439	42	6%	2%	-10%	-27%	0%	-7%	10%	25%
4180170	870	732	1421	39	5%	3%	-10%	-30%	0%	-11%	13%	37%
4180180	557	740	1387	40	5%	2%	-10%	-31%	0%	-11%	13%	38%
4180210	344	795	1285	80	10%	3%	-10%	-29%	0%	-11%	13%	33%
4180220	524	818	1293	81	10%	4%	-10%	-28%	0%	-9%	13%	35%
4180230	669	848	1298	85	10%	6%	-10%	-28%	0%	-9%	13%	36%
4180250	147	745	1429	45	6%	1%	-10%	-31%	0%	-11%	13%	37%
4180290	1989	752	1305	59	8%	12%	-10%	-31%	-2%	-12%	13%	34%
4180311	775	482	1575	15	3%	1%	-10%	-30%	0%	-9%	9%	26%
4180320	880	684	1470	33	5%	3%	-10%	-30%	0%	-12%	13%	39%
4180330	189	761	1323	62	8%	1%	-10%	-30%	-1%	-11%	13%	37%
4180351	790	775	1379	68	9%	5%	-10%	-28%	0%	-6%	13%	34%
4180373	359	571	1532	19	3%	1%	-10%	-31%	0%	-9%	12%	34%
4180374	170	565	1538	19	3%	0%	-10%	-32%	0%	-9%	10%	26%
4180521	570	555	1547	20	4%	1%	-10%	-30%	0%	-7%	9%	21%
4180551	2724	503	1563	15	3%	4%	-10%	-30%	0%	-6%	10%	29%
4180603	1027	579	1522	20	3%	2%	-10%	-31%	0%	-9%	13%	39%
4180810	977	501	1572	17	3%	2%	-10%	-30%	0%	-7%	9%	25%
4220044	825	509	1575	18	4%	1%	-10%	-28%	0%	-5%	9%	22%
	24947	**644**	**1469**	**41**	**6%**	**100%**	**-10%**	**-28%**	**0%**	**-9%**	**12%**	**31%**

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		
4160271	18	0	312	0.7	-30%	-6%	19%
4160540	20	0	2449	0.7	-31%	-8%	19%
4180011	28	0	844	0.7	-30%	-10%	22%
4180021	21	0	286	0.7	-34%	-10%	26%
4180050	77	0	130	0.6	-29%	-8%	34%
4180062	24	0	102	0.6	-32%	-9%	26%
4180071	22	0	70	0.6	-31%	-8%	19%
4180081	54	0	303	0.6	-30%	-11%	34%
4180123	44	0	35	0.1	-32%	-11%	36%
4180124	42	0	78	0.2	-31%	-11%	36%
4180133	38	0	237	0.5	-31%	-13%	35%
4180134	31	0	34	0.2	-31%	-11%	38%
4180135	42	0	203	0.7	-29%	-9%	29%
4180136	45	0	34	0.2	-31%	-11%	36%
4180150	113	0	584	0.3	-25%	-9%	28%
4180160	42	0	254	0.5	-28%	-8%	24%
4180170	39	0	262	0.3	-31%	-12%	36%
4180180	40	0	129	0.2	-32%	-12%	37%
4180210	80	0	180	0.5	-30%	-12%	32%
4180220	81	0	296	0.6	-29%	-10%	34%
4180230	85	0	349	0.5	-29%	-10%	35%
4180250	45	0	18	0.1	-31%	-11%	36%
4180290	59	0	1278	0.6	-32%	-13%	33%
4180311	15	0	598	0.8	-32%	-11%	24%
4180320	33	0	668	0.8	-32%	-14%	37%
4180330	62	0	129	0.7	-31%	-12%	36%
4180351	68	0	336	0.4	-28%	-7%	33%
4180373	19	0	242	0.7	-33%	-11%	31%
4180374	19	0	91	0.5	-33%	-11%	24%
4180521	20	0	376	0.7	-32%	-9%	18%
4180551	15	0	2048	0.8	-31%	-9%	27%
4180603	20	0	758	0.7	-32%	-11%	36%
4180810	17	0	745	0.8	-31%	-9%	23%
4220044	18	0	655	0.8	-30%	-7%	19%
	41	**0**	**15113**	**0.6**	**-29%**	**-10%**	**30%**

Appendix B River modelling reach mass balances

Subcatchment 4180011

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period								
Inflows								
Subcatchments								
Directly gauged	757.7	757.7	35%	-10%	-30%	32%	-13%	-32%
Indirectly gauged	65.2	65.2	24%	-8%	-29%	22%	-10%	-30%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**822.9**	**822.9**	**34%**	**-10%**	**-29%**	**31%**	**-12%**	**-32%**
Diversions								
Licensed private diversions								
General security	1.1	1.1	2%	3%	-2%	1%	1%	-9%
High security	9.5	9.5	0%	3%	7%	0%	3%	7%
Supplementary flow access	0.0	0.0	0%	0%	0%	0%	0%	0%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.1	0.1	0%	0%	0%	0%	0%	0%
Sub-total	**10.7**	**10.7**	**1%**	**3%**	**6%**	**0%**	**3%**	**6%**
Outflows								
End of catchment flows	744.8	746.5	33%	-10%	-29%	31%	-12%	-32%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	1.7	0.0	17%	7%	3%	15%	5%	0%
Sub-total	**746.5**	**746.5**	**33%**	**-10%**	**-29%**	**31%**	**-12%**	**-32%**
Net evaporation								
Public storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Unattributed fluxes								
River unattributed loss	65.6	65.7	46%	-13%	-36%	44%	-15%	-38%
Net evaporation – private storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Irrigator rainfall harvesting	0.3	0.3	47%	3%	-31%	48%	3%	-31%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180021

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	0.0	0.0	23%	-19%	-26%	23%	-19%	-109%
Inflows								
Subcatchments								
Directly gauged	281.9	282.7	26%	-6%	-26%	23%	-9%	-29%
Indirectly gauged	15.2	15.2	29%	-8%	-32%	26%	-10%	-34%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**297.0**	**297.9**	**26%**	**-7%**	**-27%**	**23%**	**-9%**	**-30%**
Diversions								
Licensed private diversions								
General security	1.6	1.6	28%	-11%	-34%	25%	-14%	-38%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.3	0.3	12%	-4%	-14%	10%	-6%	-16%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**1.9**	**1.9**	**26%**	**-8%**	**-31%**	**23%**	**-13%**	**-35%**
Outflows								
End of catchment flows	294.4	296.0	27%	-6%	-27%	24%	-9%	-30%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.7	0.0	-100%	-33%	49%	-100%	-29%	53%
Sub-total	**295.1**	**296.0**	**26%**	**-7%**	**-26%**	**23%**	**-9%**	**-29%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Net evaporation – private storages	0.4	0.4	3%	3%	3%	3%	2%	2%
Irrigator rainfall harvesting	0.8	0.9	6%	-1%	-11%	7%	0%	-11%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180062

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	0.0	0.0	215%	10%	22%	161%	10%	22%
Inflows								
Subcatchments								
Directly gauged	744.8	746.5	33%	-10%	-29%	31%	-12%	-32%
Indirectly gauged	0.0	0.0	0%	0%	0%	0%	0%	0%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**744.8**	**746.5**	**33%**	**-10%**	**-29%**	**31%**	**-12%**	**-32%**
Diversions								
Licensed private diversions								
General security	2.7	2.7	20%	-7%	-29%	18%	-11%	-33%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.0	0.0	33%	8%	14%	34%	2%	26%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**2.7**	**2.7**	**20%**	**-7%**	**-29%**	**18%**	**-10%**	**-32%**
Outflows								
End of catchment flows	735.2	736.9	33%	-10%	-29%	30%	-12%	-32%
Subcatchment effluent	6.8	6.8	84%	-29%	-50%	81%	-30%	-51%
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**742.0**	**743.7**	**33%**	**-10%**	**-29%**	**31%**	**-12%**	**-32%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Net evaporation – private storages	0.9	0.9	26%	1%	-26%	23%	-5%	-31%
Irrigator rainfall harvesting	0.8	0.8	40%	3%	-28%	40%	3%	-29%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180071

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	0.0	0.0	-61%	6%	46%	-47%	21%	46%
Inflows								
Subcatchments								
Directly gauged	460.2	461.0	38%	-12%	-31%	35%	-14%	-33%
Indirectly gauged	23.4	23.4	21%	-7%	-30%	19%	-9%	-31%
Effluent return								
River groundwater gains	1.5	0.0	2%	3%	-2%	4%	4%	-1%
Sub-total	**485.1**	**484.3**	**37%**	**-12%**	**-31%**	**35%**	**-14%**	**-33%**
Diversions								
Licensed private diversions								
General security	15.8	15.7	30%	-11%	-34%	27%	-15%	-37%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	6.6	6.6	21%	-10%	-20%	20%	-11%	-20%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**21.5**	**21.5**	**26%**	**-8%**	**-29%**	**24%**	**-13%**	**-32%**
Outflows								
End of catchment flows	427.0	426.2	37%	-12%	-31%	34%	-14%	-33%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**427.0**	**426.2**	**37%**	**-12%**	**-31%**	**34%**	**-14%**	**-33%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	35.8	35.8	44%	-14%	-36%	41%	-17%	-37%
Net evaporation – private storages	8.1	8.2	10%	0%	-14%	9%	-3%	-16%
Irrigator rainfall harvesting	4.0	4.0	19%	3%	-24%	19%	4%	-24%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180081

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period								
Inflows								
Subcatchments								
Directly gauged	134.7	134.7	34%	-12%	-31%	28%	-18%	-36%
Indirectly gauged	236.9	236.9	35%	-9%	-28%	34%	-10%	-29%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**371.5**	**371.5**	**35%**	**-10%**	**-29%**	**32%**	**-13%**	**-32%**
Diversions								
Licensed private diversions								
General security	0.0	0.0	0%	0%	0%	0%	0%	0%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.0	0.0	0%	0%	0%	0%	0%	0%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End of catchment flows	332.3	332.3	36%	-11%	-30%	33%	-14%	-32%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**332.3**	**332.3**	**36%**	**-11%**	**-30%**	**33%**	**-14%**	**-32%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	39.3	39.3	26%	-5%	-23%	22%	-9%	-26%
Net evaporation – private storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Irrigator rainfall harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180124

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period								
Inflows								
Subcatchments								
Directly gauged	378.1	378.2	35%	-11%	-30%	33%	-13%	-32%
Indirectly gauged	96.8	96.8	37%	-11%	-31%	37%	-11%	-32%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**475.0**	**475.0**	**36%**	**-11%**	**-30%**	**33%**	**-13%**	**-32%**
Diversions								
Licensed private diversions								
General security	0.0	0.0	0%	0%	0%	0%	0%	0%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.0	0.0	0%	0%	0%	0%	0%	0%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	3.0	3.0	0%	0%	0%	0%	0%	0%
Sub-total	**3.0**	**3.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End of catchment flows	471.9	472.0	36%	-11%	-30%	34%	-13%	-33%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**471.9**	**472.0**	**36%**	**-11%**	**-30%**	**34%**	**-13%**	**-33%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Net evaporation – private storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Irrigator rainfall harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180135

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period								
Inflows								
Subcatchments								
Directly gauged	471.9	472.0	36%	-11%	-30%	34%	-13%	-33%
Indirectly gauged	304.7	304.7	30%	-9%	-27%	28%	-11%	-29%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**776.6**	**776.7**	**34%**	**-10%**	**-29%**	**31%**	**-12%**	**-31%**
Diversions								
Licensed private diversions								
General security	0.0	0.0	0%	0%	0%	0%	0%	0%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.0	0.0	0%	0%	0%	0%	0%	0%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.7	0.7	0%	0%	0%	0%	0%	0%
Sub-total	**0.7**	**0.7**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End of catchment flows	757.7	757.7	35%	-10%	-30%	32%	-13%	-32%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**757.7**	**757.7**	**35%**	**-10%**	**-30%**	**32%**	**-13%**	**-32%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	18.3	18.3	0%	0%	0%	0%	0%	0%
Net evaporation – private storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Irrigator rainfall harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180311

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	-0.1	-0.1	-11%	0%	0%	-9%	0%	0%
Inflows								
Subcatchments								
Directly gauged	427.0	426.2	37%	-12%	-31%	34%	-14%	-33%
Indirectly gauged	0.0	0.0	0%	0%	0%	0%	0%	0%
Effluent return								
River groundwater gains	0.0	0.0	-51%	16%	65%	-40%	33%	204%
Sub-total	**427.0**	**426.2**	**37%**	**-12%**	**-31%**	**34%**	**-14%**	**-33%**
Diversions								
Licensed private diversions								
General security	24.4	24.4	22%	-7%	-30%	20%	-11%	-33%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	17.2	17.2	19%	-8%	-20%	18%	-9%	-20%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**39.8**	**39.8**	**20%**	**-3%**	**-25%**	**18%**	**-9%**	**-28%**
Outflows								
End of catchment flows	5.1	5.2	57%	-15%	-39%	54%	-16%	-40%
Subcatchment effluent	246.7	246.6	39%	-13%	-33%	37%	-15%	-34%
River groundwater loss	0.8	0.0	0%	-29%	-58%	-6%	-42%	-63%
Sub-total	**252.6**	**251.8**	**39%**	**-14%**	**-33%**	**37%**	**-15%**	**-34%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	132.8	132.8	37%	-9%	-29%	34%	-12%	-31%
Net evaporation – private storages	16.8	16.8	12%	0%	-14%	10%	-4%	-17%
Irrigator rainfall harvesting	8.5	8.5	24%	2%	-25%	24%	2%	-25%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180351

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – Copeton Dam								
Change over period	-4.6	-4.6	-35%	2%	18%	-29%	8%	23%
Inflows								
Subcatchments								
Directly gauged	332.3	332.3	36%	-11%	-30%	33%	-14%	-32%
Indirectly gauged	85.4	85.4	34%	-7%	-28%	33%	-8%	-29%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**417.7**	**417.7**	**36%**	**-10%**	**-29%**	**33%**	**-12%**	**-32%**
Diversions								
Licensed private diversions								
General security	0.0	0.0	0%	0%	0%	0%	0%	0%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.0	0.0	0%	0%	0%	0%	0%	0%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End of catchment flows	378.1	378.2	35%	-11%	-30%	33%	-13%	-32%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0.0	0%	0%	0%	2.1	2.1	2.1
Sub-total	**378.1**	**378.2**	**35%**	**-11%**	**-30%**	**33%**	**-13%**	**-32%**
Net evaporation								
Public storages	23.3	23.3	-126%	-140%	-147%	-128%	-143%	-149%
Unattributed fluxes								
River unattributed loss	20.9	20.9	36%	-10%	-29%	33%	-12%	-32%
Net evaporation – private storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Irrigator rainfall harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180373

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	0.0	0.0	13%	-19%	-26%	13%	-19%	-88%
Inflows								
Subcatchments								
Directly gauged	294.4	296.0	27%	-6%	-27%	24%	-9%	-30%
Indirectly gauged	46.9	46.9	37%	-11%	-31%	34%	-13%	-32%
Effluent return								
River groundwater gains	2.6	0.0	42%	14%	-14%	42%	13%	-15%
Sub-total	**343.9**	**342.9**	**28%**	**-7%**	**-27%**	**25%**	**-10%**	**-30%**
Diversions								
Licensed private diversions								
General security	3.4	3.4	33%	-14%	-36%	30%	-18%	-39%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.8	0.8	26%	-12%	-29%	25%	-13%	-31%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**4.0**	**4.0**	**31%**	**-8%**	**-35%**	**28%**	**-17%**	**-37%**
Outflows								
End of catchment flows	309.2	308.1	27%	-7%	-27%	25%	-9%	-29%
Subcatchment effluent	0.0		0.0	0.0	0.0	0.0	0.0	0.0
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**309.2**	**308.1**	**27%**	**-7%**	**-27%**	**25%**	**-9%**	**-29%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	30.4	30.5	33%	-8%	-32%	30%	-10%	-35%
Net evaporation – private storages	1.2	1.2	4%	1%	-2%	3%	-1%	-3%
Irrigator rainfall harvesting	2.0	2.0	3%	2%	-9%	4%	3%	-9%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180521

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	-0.1	-0.1	-64%	-1%	-1%	-44%	-1%	-1%
Inflows								
Subcatchments								
Directly gauged	113.4	113.4	31%	-13%	-32%	29%	-15%	-34%
Indirectly gauged	7.0	7.0	21%	-8%	-30%	18%	-9%	-32%
Effluent return								
River groundwater gains	0.1	0.0	-18%	49%	72%	-1%	65%	88%
Sub-total	**120.5**	**120.4**	**31%**	**-12%**	**-32%**	**29%**	**-14%**	**-34%**
Diversions								
Licensed private diversions								
General security	32.9	32.9	26%	-12%	-34%	24%	-15%	-37%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	13.4	13.4	18%	-10%	-17%	17%	-10%	-16%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**46.1**	**46.1**	**23%**	**-11%**	**-29%**	**22%**	**-14%**	**-31%**
Outflows								
End of catchment flows	52.4	52.4	31%	-11%	-31%	29%	-13%	-32%
Subcatchment effluent	0.0		0.0	0.0	0.0	0.0	0.0	0.0
River groundwater loss	0.1	0.0	91%	-26%	-77%	74%	-42%	-91%
Sub-total	**52.5**	**52.4**	**31%**	**-11%**	**-31%**	**29%**	**-13%**	**-32%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	21.7	21.7	44%	-17%	-41%	42%	-19%	-43%
Net evaporation – private storages	14.7	14.8	11%	-3%	-17%	8%	-6%	-20%
Irrigator rainfall harvesting	5.8	5.8	23%	6%	-24%	23%	7%	-23%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180551

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	-0.1	-0.1	-85%	25%	80%	-84%	25%	88%
Inflows								
Subcatchments								
Directly gauged	309.2	308.1	27%	-7%	-27%	25%	-9%	-29%
Indirectly gauged	36.5	36.5	39%	-9%	-31%	36%	-11%	-32%
Effluent return								
River groundwater gains	0.1	0.0	96%	42%	13%	102%	52%	25%
Sub-total	**345.9**	**344.7**	**29%**	**-7%**	**-27%**	**26%**	**-10%**	**-30%**
Diversions								
Licensed private diversions								
General security	96.6	96.5	18%	-8%	-29%	16%	-12%	-32%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	48.6	48.5	21%	-7%	-21%	19%	-8%	-23%
Floodplain harvesting	7.7	7.7	15%	-10%	-26%	13%	-11%	-28%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**148.3**	**148.2**	**18%**	**-5%**	**-26%**	**16%**	**-10%**	**-29%**
Outflows								
End of catchment flows	102.3	102.3	37%	-5%	-26%	34%	-7%	-29%
Subcatchment effluent	0.0		0.0	0.0	0.0	0.0	0.0	0.0
River groundwater loss	0.9	0.0	22%	-3%	-20%	17%	-10%	-28%
Sub-total	**103.2**	**102.3**	**37%**	**-5%**	**-26%**	**34%**	**-7%**	**-28%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	89.9	89.6	36%	-8%	-29%	33%	-11%	-32%
Net evaporation – private storages	72.5	72.5	8%	2%	-7%	7%	0%	-8%
Irrigator rainfall harvesting	90.7	90.7	19%	2%	-13%	2%	-13%	-25%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4180810

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period								
Inflows								
Subcatchments								
Directly gauged	187.8	187.8	46%	-14%	-33%	43%	-16%	-35%
Indirectly gauged	0.0	0.0	0%	0%	0%	0%	0%	0%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**187.8**	**187.8**	**46%**	**-14%**	**-33%**	**43%**	**-16%**	**-35%**
Diversions								
Licensed private diversions								
General security	0.0	0.0	0%	0%	0%	0%	0%	0%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	0.0	0.0	0%	0%	0%	0%	0%	0%
Floodplain harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**0.0**	**0.0**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Outflows								
End of catchment flows	34.0	34.0	27%	-6%	-23%	24%	-8%	-25%
Subcatchment effluent	54.5		79.7	46.7	35.7	78.4	45.7	35.0
River groundwater loss	0.2	0.0	18%	-16%	-39%	9%	-28%	-50%
Sub-total	**88.7**	**88.6**	**39%**	**-11%**	**-30%**	**36%**	**-13%**	**-32%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	99.1	99.1	52%	-17%	-36%	49%	-18%	-37%
Net evaporation – private storages	0.0	0.0	0%	0%	0%	0%	0%	0%
Irrigator rainfall harvesting	0.0	0.0	0%	0%	0%	0%	0%	0%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Subcatchment 4160271

River system model average annual water balance	A	A0	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Model start date	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895	Jul-1895
Model end date	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006	Jun-2006
	GL/y		percent change from Scenario A					
Storage volume – private storages								
Change over period	-0.1	-0.1	-5%	1%	4%	-2%	3%	4%
Inflows								
Subcatchments								
Directly gauged	104.9	104.9	26%	-9%	-30%	24%	-11%	-32%
Indirectly gauged	0.0	0.0	0%	0%	0%	0%	0%	0%
Effluent return								
River groundwater gains	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**138.9**	**138.9**	**26%**	**-8%**	**-28%**	**24%**	**-10%**	**-30%**
Diversions								
Licensed private diversions								
General security	16.6	16.6	25%	-10%	-32%	23%	-13%	-36%
High security	0.0	0.0	0%	0%	0%	0%	0%	0%
Supplementary flow access	13.1	13.1	11%	-4%	-14%	10%	-5%	-15%
Floodplain harvesting	0.4	0.4	35%	-25%	-70%	32%	-27%	-71%
Urban								
Town water supply	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**29.8**	**29.7**	**19%**	**-6%**	**-24%**	**17%**	**-9%**	**-26%**
Outflows								
End of catchment flows	81.5	81.6	26%	-7%	-27%	24%	-9%	-28%
Subcatchment effluent	0.0	0.0	0%	0%	0%	0%	0%	0%
River groundwater loss	0.0	0.0	0%	0%	0%	0%	0%	0%
Sub-total	**81.5**	**81.6**	**26%**	**-7%**	**-27%**	**24%**	**-9%**	**-28%**
Net evaporation								
Public storages								
Unattributed fluxes								
River unattributed loss	27.1	27.1	34%	-12%	-37%	31%	-14%	-39%
Net evaporation – private storages	13.3	13.2	12%	-1%	-16%	9%	-5%	-20%
Irrigator rainfall harvesting	3.3	3.3	24%	6%	-26%	24%	7%	-26%
Mass balance								
Mass balance error (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix C River system model uncertainty assessment by reach

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

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

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

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

Downstream gauge	418026 Gwydir River @ D/S Copeton Dam	Reach 1
Upstream gauge	418008 Gwydir River @ Bundarra	

Reach length (km)	48
Area (km^2)	1214
Outflow/inflow ratio	1.22
Net gaining reach	

This is a gaining reach. Inflows are dominated by runoff immediately following rain. Outflows are dominated by releases from Copeton Dam

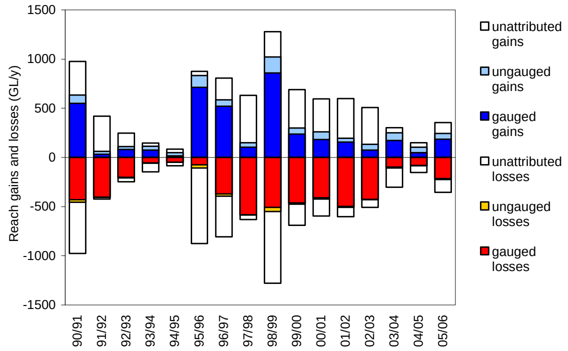
Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains but a moderate adjustment was required. There are no recorded diversions.

Model results are not available for this reach. Accounting does not explain monthly flows, because the dam operation determines outflows. Accounting only explains long term flow totals.

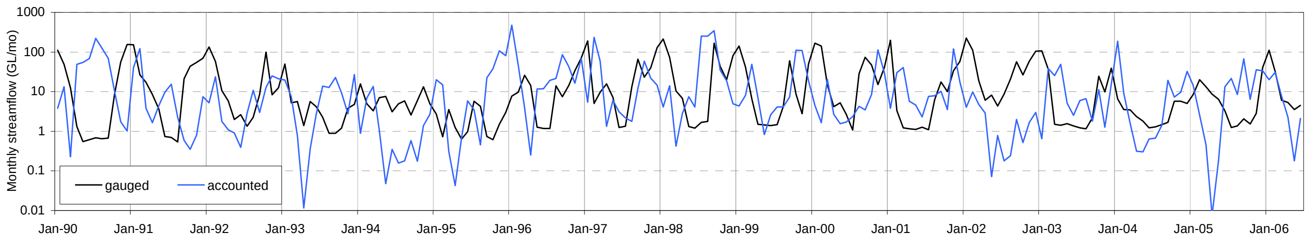
Land use	ha	%
Dryland	116,680	96
Irrigable area	-	-
Open water*	-	-
River and wetlands	4,730	4
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.46	0.56	0.51
Attributed	0.58	0.58	0.58
Fraction of variance			
Gauged	0.64	0.32	0.48
Attributed	0.64	0.38	0.51



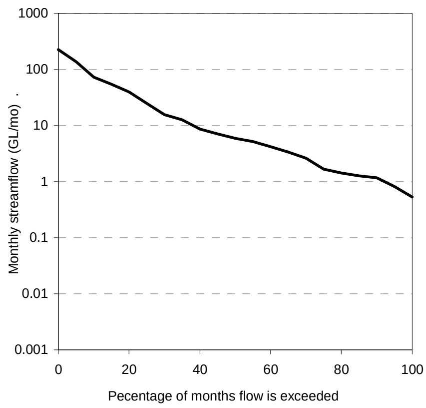
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.15	-0.35	**-0.97**	**-0.74**	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.95**	**-0.84**	-0.09	-0.37	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.09	-0.16	**-0.77**	**-0.60**	Adjusted -24.0%



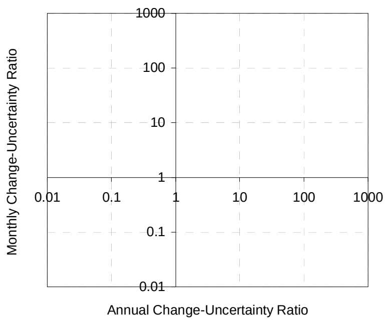
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	250	-250
Tributary inflows	0	0	0
Local inflows	0	66	-66
Unattributed gains and noise	-	226	-226
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	304	-304
Distributary outflows	0	0	0
Net diversions	0	0	0
River flux to groundwater	0	-	0
River and floodplain losses	0	13	-13
Unspecified losses	0	-	0
Unattributed losses and noise	-	226	-226

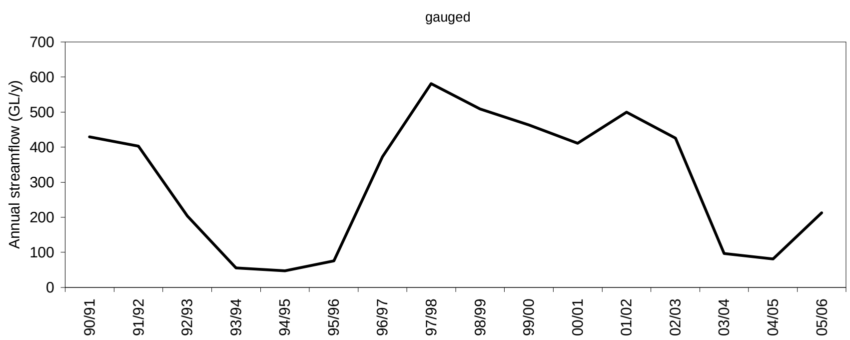
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	<0
Log-normalised	-	-
Ranked	<0	<0
Low flows only	<0	<0
High flows only	<0	<0
Annual		
Normal	<0	<0
Log-normalised	-	-
Ranked	<0	<0

Definitions:
- low flows (flows<10% percentile) : 1.2 GL/mo
- high flows (flows>90% percentile) : 73.2 GL/mo



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





Downstream gauge	**418012 Gwydir River @ Pinegrove**	**Reach 2**
Upstream gauge	**418026 Gwydir River @ D/S Copeton Dam**	

Reach length (km)	57
Area (km^2)	1112
Outflow/inflow ratio	1.20
Net gaining reach	

Land use	ha	%
Dryland	111,150	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

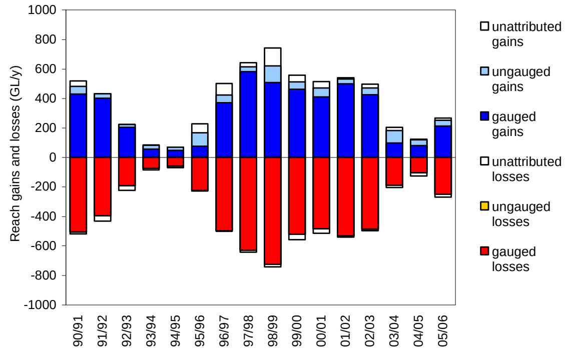
This is a gaining reach. Flows are dominated by inflows from Copeton Dam releases.

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

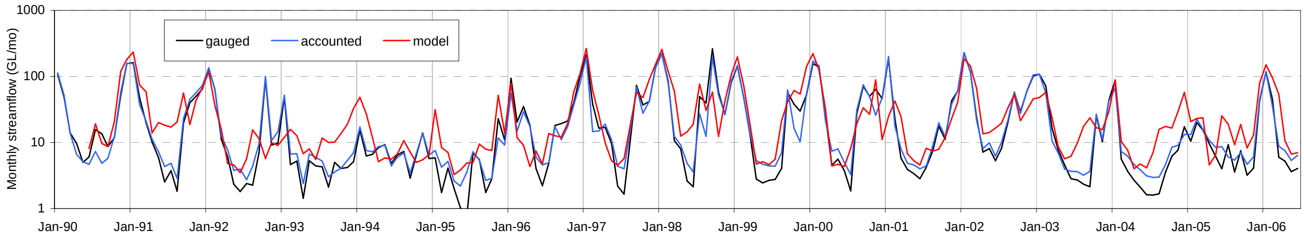
Baseline model performance is moderate. Accounting explains observed flows very well.

The projected changes are generally simliar to the uncertainty of modelling.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.79	0.95	0.87
Attributed	0.92	0.95	0.94
Fraction of variance			
Gauged	0.93	1.00	0.96
Attributed	0.97	1.00	0.99



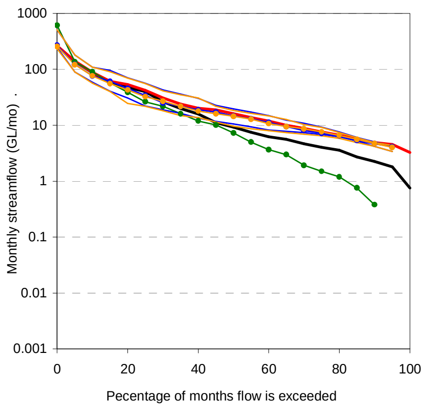
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.10	-0.01	-0.47	-0.39	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.37	-0.34	-0.38	-0.30	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.89**	**-0.76**	-0.08	-0.27	



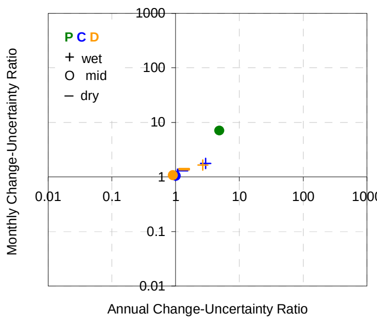
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	346	304	42
Tributary inflows	0	0	0
Local inflows	77	49	28
Unattributed gains and noise	-	31	-31
Losses	GL/y	GL/y	GL/y
Main stem outflows	420	366	54
Distributary outflows	0	0	0
Net diversions	3	0	3
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	18	-18

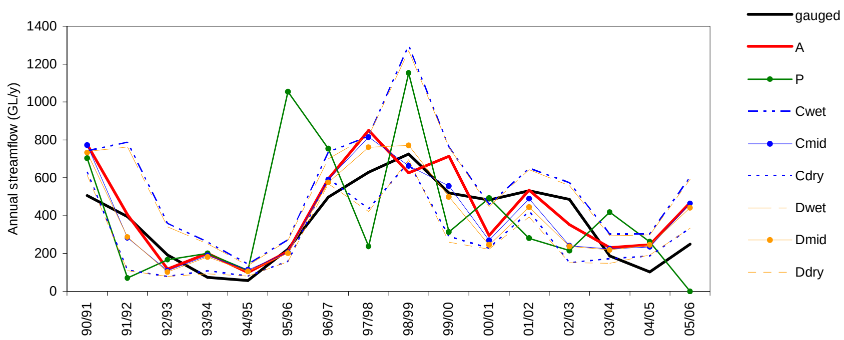
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.61	0.97
Log-normalised	0.52	0.92
Ranked	0.49	0.94
Low flows only	<0	<0
High flows only	<0	0.85
Annual		
Normal	0.51	0.96
Log-normalised	0.63	0.98
Ranked	0.79	0.95

Definitions:
- low flows (flows<10% percentile) : 2.3 GL/mo
- high flows (flows>90% percentile) : 86.5 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.8		3.0	1.0	1.3	2.7	0.9	1.4
Monthly streamflow	7.1		1.8	1.0	1.3	1.7	1.1	1.4





Downstream gauge	418013 Gwydir River @ Gravesend	Reach 3
Upstream gauge	418012 Gwydir River @ Pinegrove	

Reach length (km)	48
Area (km^2)	1652
Outflow/inflow ratio	1.55
Net gaining reach	

Land use	ha	%
Dryland	165,200	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

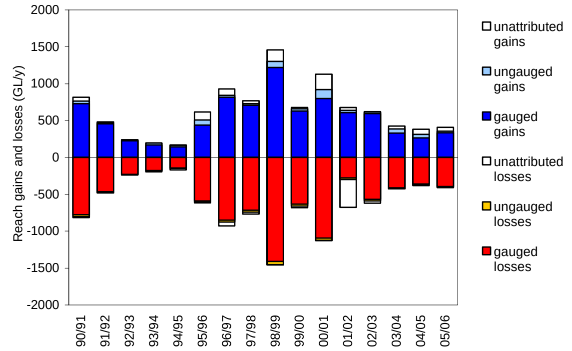
This is a gaining reach. Flows are dominated by runoff immediately following rain.

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains without adjustment. There is a small amount of recorded diversion and ungauged losses are small.

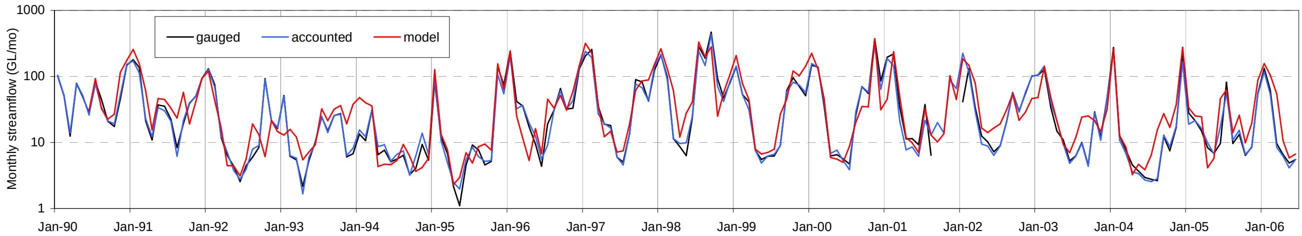
Baseline model performance is good. Accounting explains observed flows very well.

The projected changes are generally similar to or less than the uncertainty in the modelling, except for the P, Cwet and Dwet scenarios in which the modelled changes are greater than the uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.85	0.91	0.88
Attributed	0.91	0.94	0.93
Fraction of variance			
Gauged	0.94	0.95	0.94
Attributed	0.97	0.96	0.96



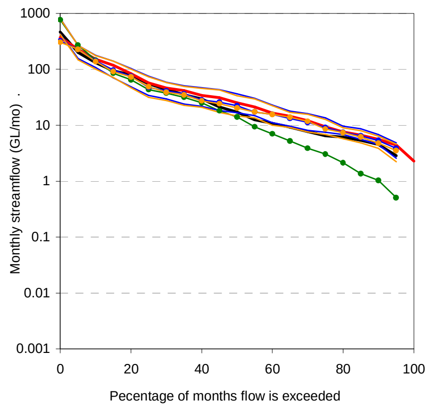
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.13	-0.08	-0.40	-0.46	
Tributary inflows	**-0.80**	**-0.56**	-0.02	-0.19	
Main gauge outflows	**-0.71**	-0.41	-0.02	-0.11	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.90**	**-0.63**	-0.01	-0.24	Adjusted -44.0%



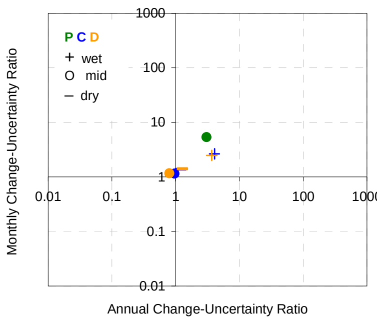
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	420	366	54
Tributary inflows	0	163	-163
Local inflows	246	40	206
Unattributed gains and noise	-	56	-56
Losses	GL/y	GL/y	GL/y
Main stem outflows	647	569	78
Distributary outflows	0	0	0
Net diversions	1	0	1
River flux to groundwater	0	-	0
River and floodplain losses	0	19	-19
Unspecified losses	18	-	18
Unattributed losses and noise	-	37	-37

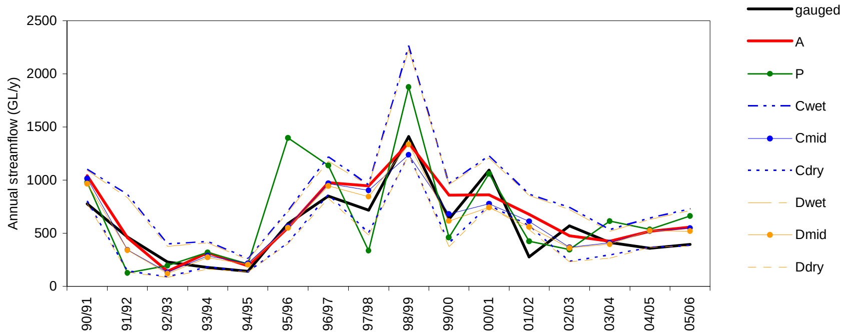
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.78	0.91
Log-normalised	-	-
Ranked	0.66	0.86
Low flows only	<0	<0
High flows only	<0	0.67
Annual		
Normal	0.72	0.89
Log-normalised	0.67	0.87
Ranked	0.71	0.87

Definitions:
- low flows (flows<10% percentile) : 4.5 GL/mo
- high flows (flows>90% percentile) : 132.2 GL/mo



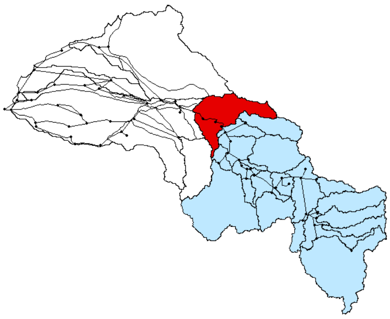
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.1		4.1	1.0	1.2	3.7	0.8	1.3
Monthly streamflow	5.3		2.7	1.2	1.4	2.5	1.2	1.4





Downstream gauge	418001 Gwydir River @ Pallamallawa	Reach 4
Upstream gauge	418013 Gwydir River @ Gravesend	

Reach length (km)	30
Area (km^2)	1180
Outflow/inflow ratio	1.07
Net gaining reach	



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

Most of the inflows are gauged. Estimated local runoff explains most of the ungauged gains without adjustment. There are some recorded diversions and ungauged losses are small.

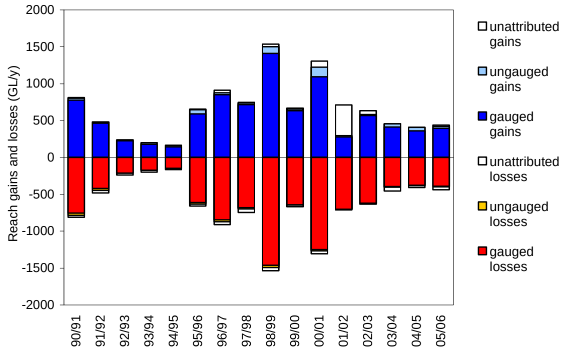
Baseline model performance is good. Accounting also explains observed flows very well.

The projected changes are generally similar to or less than the uncertainty in the modelling, except for the P, Cwet and Dwet scenarios in which the modelled changes are greater than the uncertainty.

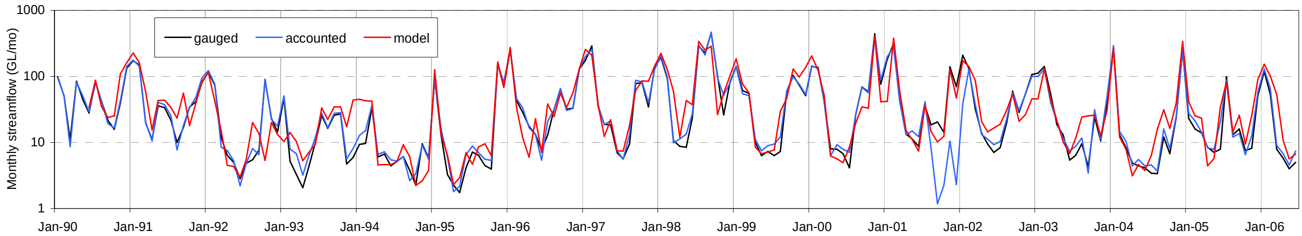
Land use	ha	%
Dryland	117,970	100
Irrigable area	-	-
Open water*	-	-
River and wetlands	-	-
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.88	0.93	0.91
Attributed	0.93	0.95	0.94
Fraction of variance			
Gauged	0.94	0.99	0.97
Attributed	0.95	1.00	0.98



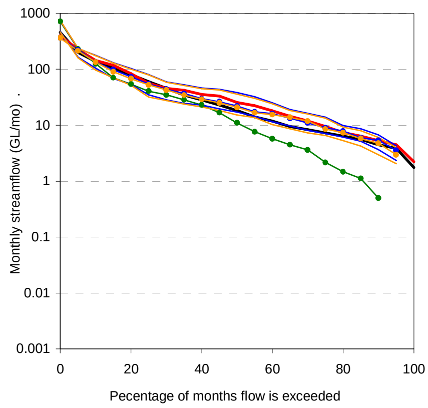
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.21	-0.13	-0.36	-0.35	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.45	-0.34	-0.25	-0.23	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.45	-0.37	-0.02	-0.00	



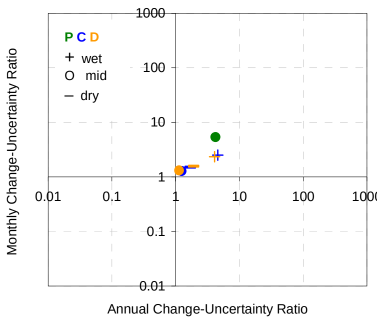
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	647	569	78
Tributary inflows	0	0	0
Local inflows	78	37	41
Unattributed gains and noise	-	43	-43
Losses	GL/y	GL/y	GL/y
Main stem outflows	657	606	51
Distributary outflows	0	0	0
Net diversions	10	11	-1
River flux to groundwater	2	-	2
River and floodplain losses	0	2	-2
Unspecified losses	57	-	57
Unattributed losses and noise	-	30	-30

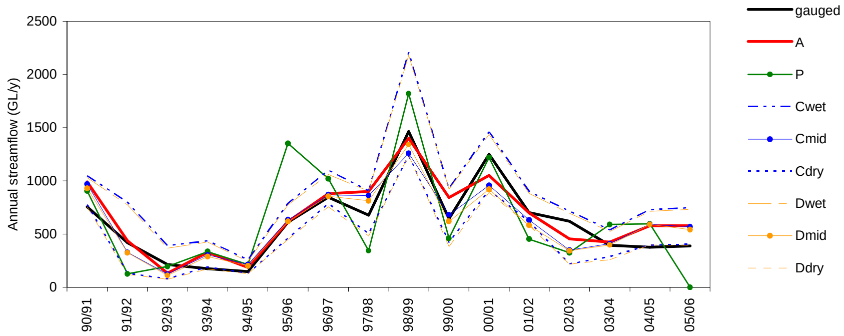
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.84	0.94
Log-normalised	0.74	0.87
Ranked	0.71	0.88
Low flows only	<0	<0
High flows only	0.39	0.76
Annual		
Normal	0.84	0.91
Log-normalised	0.78	0.88
Ranked	0.83	0.78

Definitions:
- low flows (flows<10% percentile) : 4.5 GL/mo
- high flows (flows>90% percentile) : 139.2 GL/mo



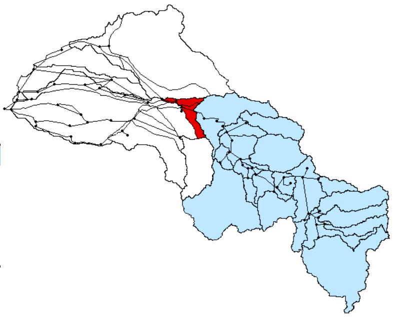
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	4.2		4.6	1.2	1.7	4.1	1.1	1.9
Monthly streamflow	5.4		2.5	1.3	1.5	2.4	1.3	1.6





Downstream gauge	418004 Gwydir River @ Yaraman Bridge	Reach 5
Upstream gauge	418001 Gwydir River @ Pallamallawa	

Reach length (km)	22
Area (km^2)	2700
Outflow/inflow ratio	0.43
Net losing reach	



This reach had two other outflows in gauged distributaries, reach 11 and reach 21. Water accounts are also done using those as the outflow gauge, but there is just one underlying account.

This is a losing reach. Flows are dominated by infows from upstream and losses to distributaries and diversions.

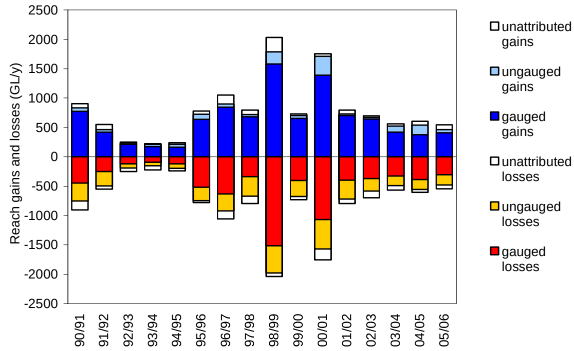
Most of the inflows are gauged. Estimated local runoff is small. There are large recorded diversions and ungauged losses.

Model results were not reported for this gauge. Accounting explains observed flows very well.

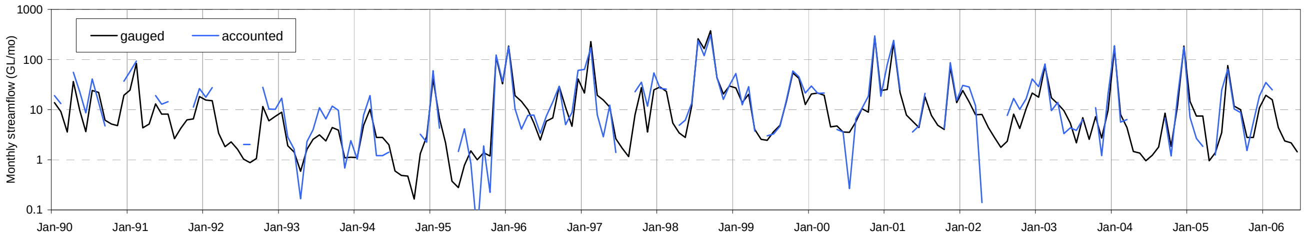
Land use	ha	%
Dryland	264,270	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	5,720	2
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.81	0.58	0.69
Attributed	0.91	0.89	0.90
Fraction of variance			
Gauged	0.94	0.90	0.92
Attributed	0.98	0.98	0.98



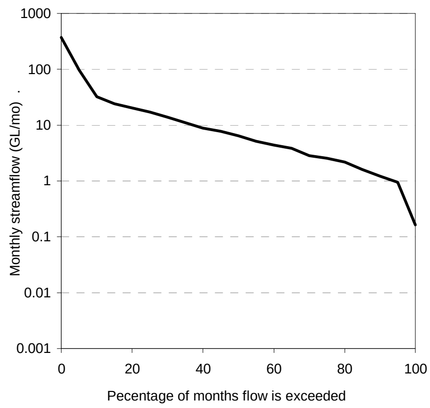
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.46	-0.12	**-0.56**	**-0.73**	
Tributary inflows	-0.34	-0.21	-0.06	-0.09	
Main gauge outflows	**-0.58**	-0.22	-0.13	**-0.54**	
Distributary outflows	**-0.61**	-0.21	-0.39	**-0.61**	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.39	-0.23	-0.10	-0.29	



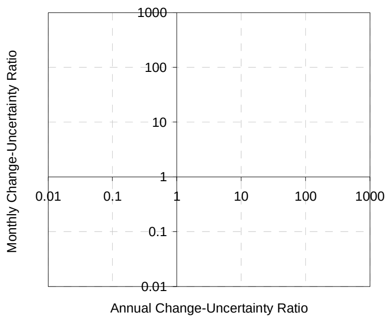
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	606	-606
Tributary inflows	0	25	-25
Local inflows	0	83	-83
Unattributed gains and noise	-	68	-68
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	259	-259
Distributary outflows	0	195	-195
Net diversions	0	84	-84
River flux to groundwater	0	-	0
River and floodplain losses	0	159	-159
Unspecified losses	0	-	0
Unattributed losses and noise	-	84	-84

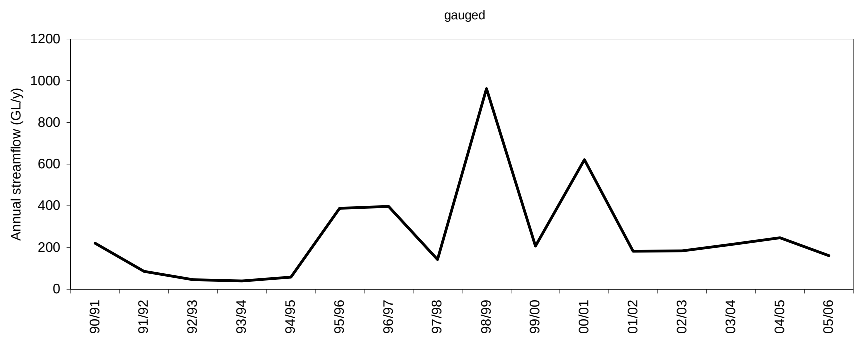
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.94
Log-normalised	-	-
Ranked	<0	0.68
Low flows only	<0	<0
High flows only	<0	0.94
Annual		
Normal	<0	0.97
Log-normalised	-	-
Ranked	<0	0.91

Definitions:
- low flows (flows<10% percentile) : 1.2 GL/mo
- high flows (flows>90% percentile) : 32.3 GL/mo



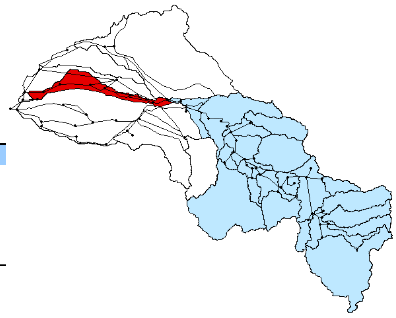
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow								
Monthly streamflow								





Downstream gauge	418063 Gwydir River @ D/S Tyreel	Reach 6
Upstream gauge	418004 Gwydir River @ Yaraman Bridge	

Reach length (km)	21
Area (km^2)	775
Outflow/inflow ratio	0.28
Net losing reach	



This is a strongly losing reach. Flows are dominated by inflows and losses in distributaries.

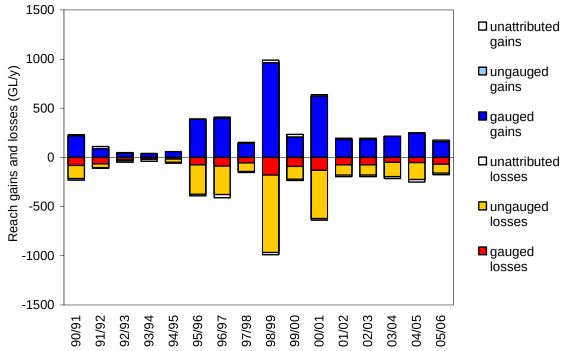
most of the inflows are gauged. Estimated local runoff is small. There are some recorded diversions and ungauged losses are large

Model results were not reported for this gauge. Accounting explains observed flows poorly.

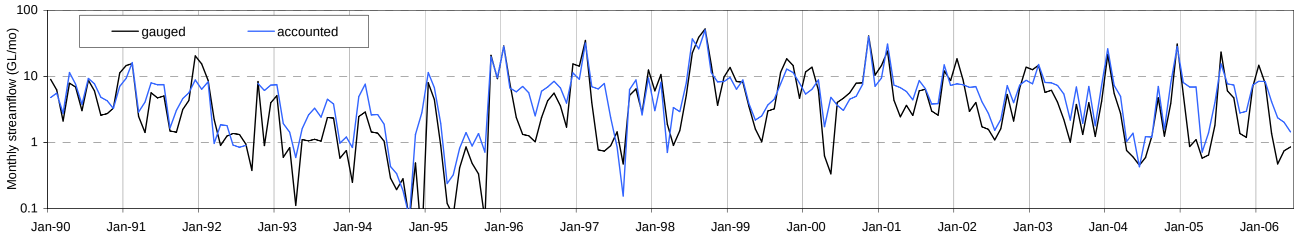
Land use	ha	%
Dryland	63,280	82
Irrigable area	-	-
Open water*	-	-
River and wetlands	14,190	18
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.96	0.26	0.61
Attributed	0.96	0.94	0.95
Fraction of variance			
Gauged	1.00	0.25	0.63
Attributed	1.00	1.00	1.00



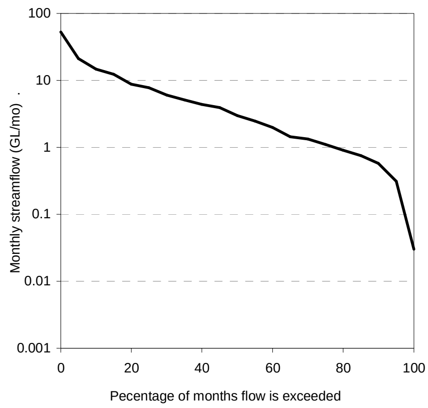
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.03	-0.04	**-1.00**	**-0.91**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.09	-0.07	**-0.84**	**-0.71**	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.20	-0.03	-0.21	-0.49	Adjusted -90.0%



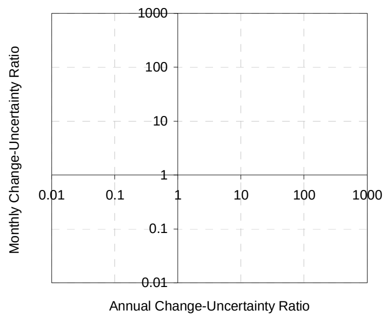
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	259	-259
Tributary inflows	0	0	0
Local inflows	0	1	-1
Unattributed gains and noise	-	11	-11
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	71	-71
Distributary outflows	0	0	0
Net diversions	0	6	-6
River flux to groundwater	0	-	0
River and floodplain losses	0	176	-176
Unspecified losses	0	-	0
Unattributed losses and noise	-	17	-17

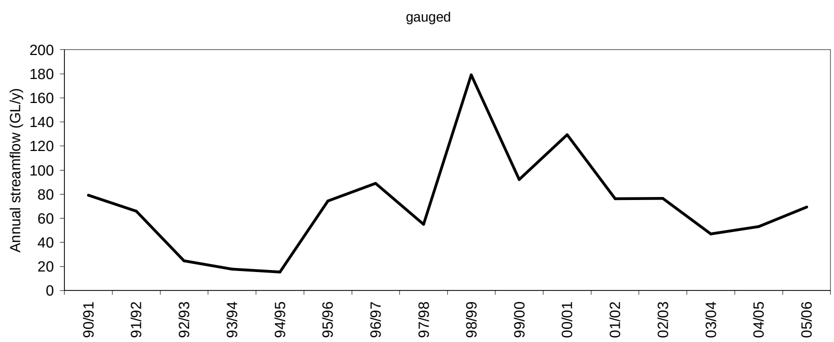
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.83
Log-normalised	-	-
Ranked	<0	0.76
Low flows only	<0	<0
High flows only	<0	0.83
Annual		
Normal	<0	0.89
Log-normalised	-	-
Ranked	<0	0.81

Definitions:
- low flows (flows<10% percentile) : 0.6 GL/mo
- high flows (flows>90% percentile) : 14.7 GL/mo



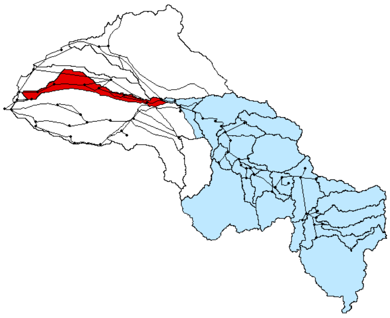
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow								
Monthly streamflow								





Downstream gauge	418053 Gwydir River @ Brageen Crossing	Reach 7
Upstream gauge	418063 Gwydir River @ D/S Tyreel	

Reach length (km)	25
Area (km^2)	775
Outflow/inflow ratio	1.04
Net gaining reach	



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

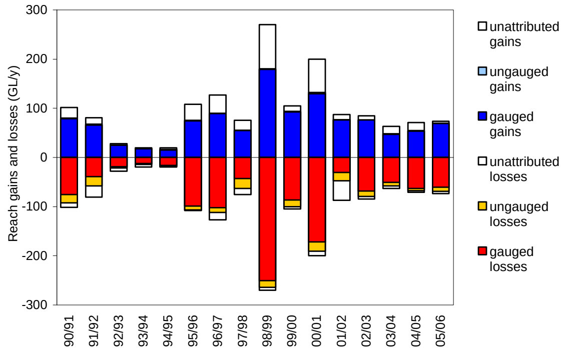
Most of the inflows are gauged. Estimated local runoff is small and was adjusted. There are some recorded diversions; ungauged losses are small.

Model performance was not available for this reach. Accounting explains observed flows quite well.

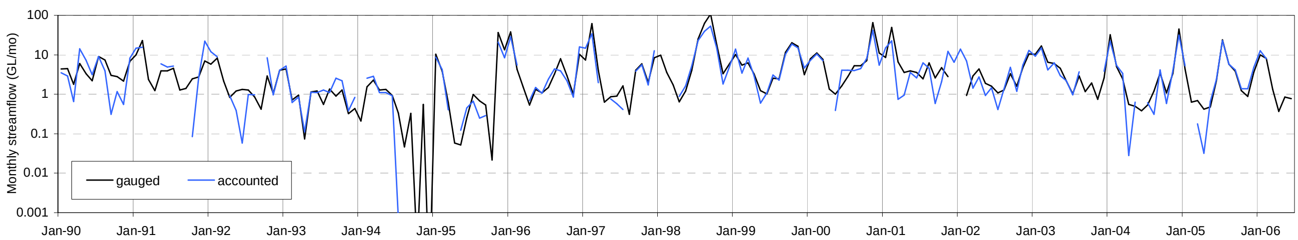
Land use	ha	%
Dryland	63,280	82
Irrigable area	-	-
Open water*	-	-
River and wetlands	14,190	18
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.76	0.79	0.77
Attributed	0.77	0.90	0.83
Fraction of variance			
Gauged	0.80	0.96	0.88
Attributed	0.81	0.97	0.89



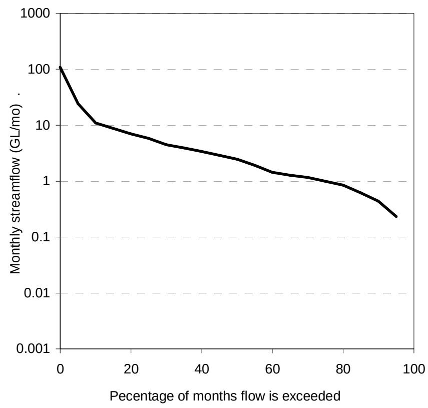
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	**-0.77**	-0.35	-0.28	-0.40	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.95**	-0.49	-0.06	-0.14	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.14	-0.37	-0.10	-0.05	Adjusted -90.0%



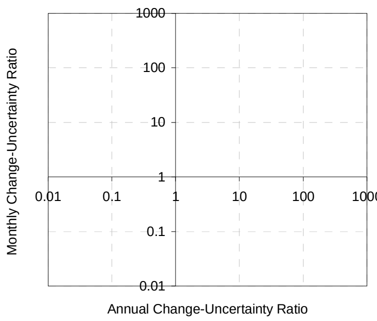
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	71	-71
Tributary inflows	0	0	0
Local inflows	0	1	-1
Unattributed gains and noise	-	22	-22
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	74	-74
Distributary outflows	0	0	0
Net diversions	0	11	-11
River flux to groundwater	0	-	0
River and floodplain losses	0	0	0
Unspecified losses	0	-	0
Unattributed losses and noise	-	9	-9

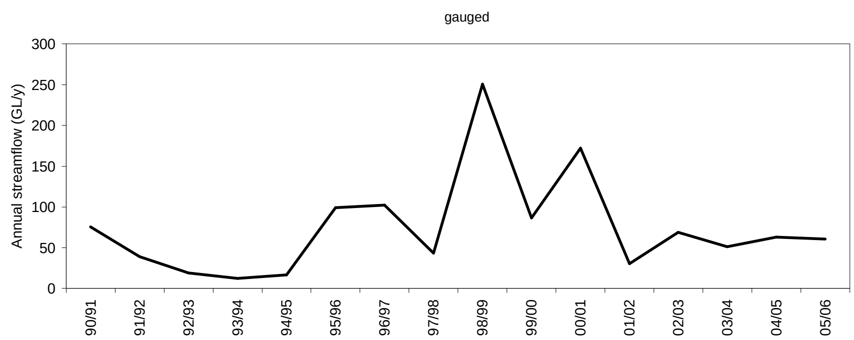
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.75
Log-normalised	-	-
Ranked	<0	0.61
Low flows only	<0	<0
High flows only	<0	0.76
Annual		
Normal	<0	0.77
Log-normalised	-	-
Ranked	<0	0.89

Definitions:
- low flows (flows<10% percentile) : 0.4 GL/mo
- high flows (flows>90% percentile) : 11.0 GL/mo



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



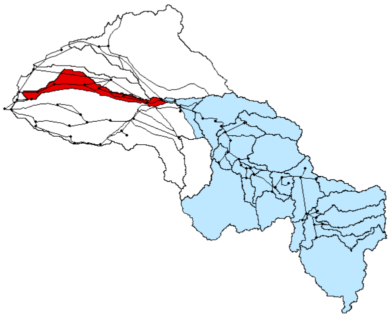


Downstream gauge	418066 Gwydir River @ Millewa	Reach 8
Upstream gauge	418053 Gwydir River @ Brageen Crossing	

Reach length (km)	22
Area (km^2)	775
Outflow/inflow ratio	0.36
Net losing reach	

Land use	ha	%
Dryland	63,280	82
Irrigable area	-	-
Open water*	-	-
River and wetlands	14,190	18
Open water*	-	-

* averages for 1990–2006



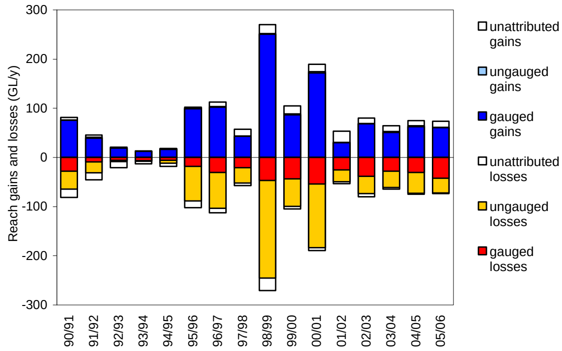
This is a losing reach. Flows are dominated by infows and an ungauged tributary inflow and by diversions.

Most of the inflows are ungauged. Estimated local runoff is large, and there other occasional unattributed inflows. There are large recorded diversions and some ungauged losses.

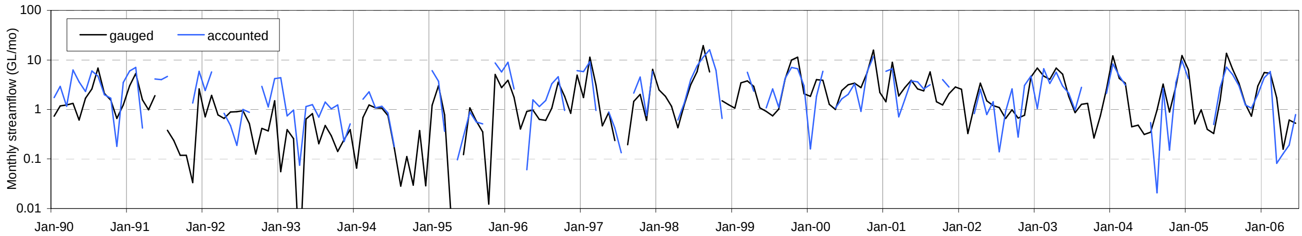
Baseline model performance is moderate. Accounting explains observed flows reasonably well.

The projected changes are less than or similar to model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.87	0.32	0.59
Attributed	0.89	0.89	0.89
Fraction of variance			
Gauged	0.99	0.28	0.63
Attributed	0.99	0.99	0.99



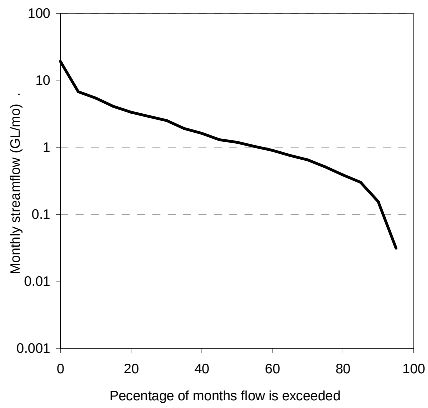
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.07	-0.13	**-0.98**	**-0.83**	
Tributary inflows	-	-	-	-	
Main gauge outflows	-0.10	-0.19	**-0.57**	-0.40	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.01	-0.06	-0.17	-0.41	Adjusted -90.0%



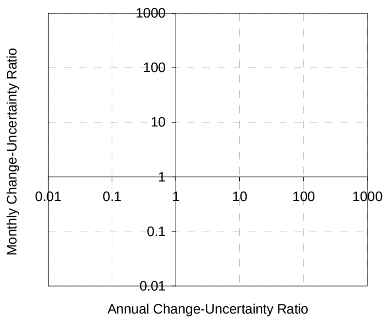
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	0	73	-73
Tributary inflows	0	0	0
Local inflows	0	1	-1
Unattributed gains and noise	-	9	-9
Losses	GL/y	GL/y	GL/y
Main stem outflows	0	27	-27
Distributary outflows	0	0	0
Net diversions	0	12	-12
River flux to groundwater	0	-	0
River and floodplain losses	0	36	-36
Unspecified losses	0	-	0
Unattributed losses and noise	-	9	-9

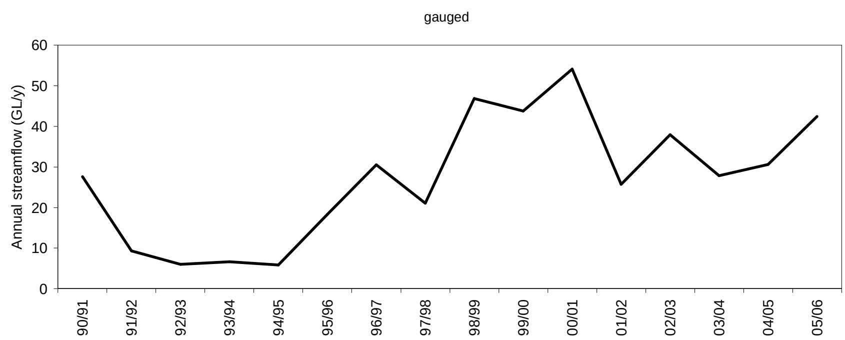
Model efficiency	Model (A)	Accounts
Monthly		
Normal	<0	0.37
Log-normalised	-	-
Ranked	<0	0.27
Low flows only	<0	<0
High flows only	<0	0.40
Annual		
Normal	<0	0.57
Log-normalised	-	-
Ranked	<0	0.62

Definitions:
- low flows (flows<10% percentile) : 0.2 GL/mo
- high flows (flows>90% percentile) : 5.5 GL/mo



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



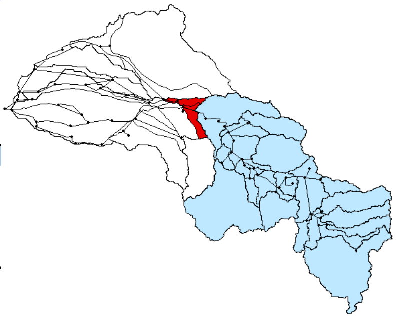


Downstream gauge	418052 Carol Ck near Garah	Reach 11
Upstream gauge	418001 Gwydir River @ Pallamallawa	

Reach length (km)	22
Area (km^2)	2700
Outflow/inflow ratio	0.10
Net losing reach	

Land use	ha	%
Dryland	264,270	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	5,720	2
Open water*	-	-

* averages for 1990–2006



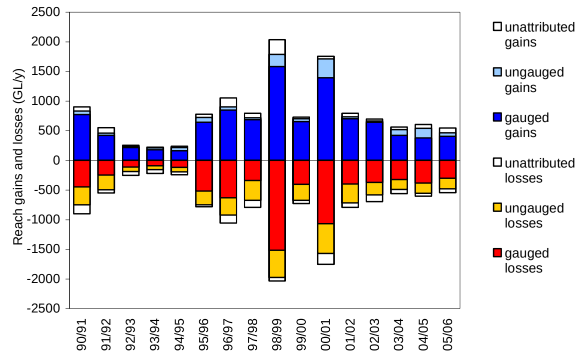
This is the same reach balance as reach 5, Yarraman Bridge, but here we examine the outflow at another of the three distributary outflow gauges.

This is a losing reach. Flows are dominated by infows and outflows in the main stem, and by diversions.

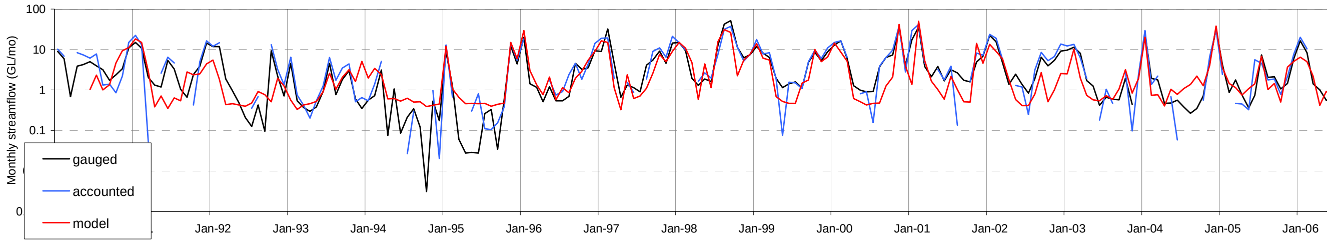
Most of the inflows are gauged. Estimated local runoff is small. There are large recorded diversions and ungauged losses.

Baseline model performance is reasonable. Accounting explains observed flows very well. The projected changes are similar to model uncertainty for most scenarios.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.81	0.58	0.69
Attributed	0.91	0.89	0.90
Fraction of variance			
Gauged	0.94	0.90	0.92
Attributed	0.98	0.98	0.98



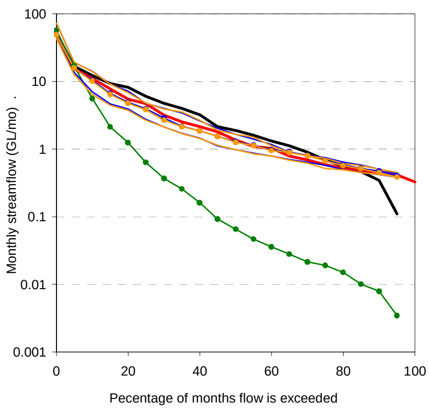
Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.46	-0.12	-0.56	-0.73	
Tributary inflows	-0.34	-0.21	-0.06	-0.09	
Main gauge outflows	-0.64	--	-0.45	--	
Distributary outflows	-0.60	-0.23	-0.20	-0.59	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.39	-0.23	-0.10	-0.29	



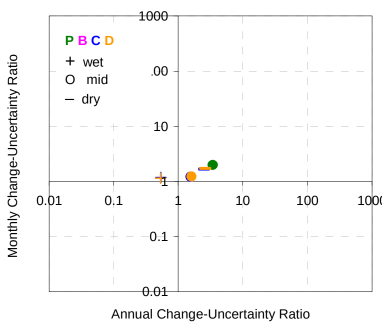
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	657	606	51
Tributary inflows	0	25	-25
Local inflows	98	83	15
Unattributed gains and noise	-	68	-68
Losses	GL/y	GL/y	GL/y
Main stem outflows	50	60	-10
Distributary outflows	554	395	159
Net diversions	77	84	-7
River flux to groundwater	1	-	1
River and floodplain losses	0	159	-159
Unspecified losses	77	-	77
Unattributed losses and noise	-	84	-84

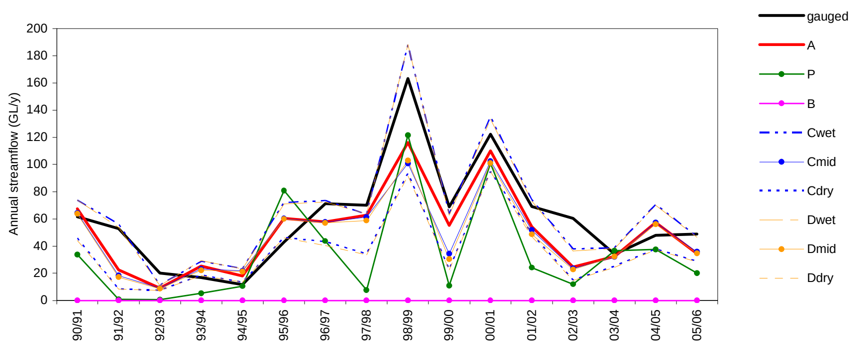
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.72	0.87
Log-normalised	-	-
Ranked	0.48	0.72
Low flows only	<0	<0
High flows only	0.13	0.70
Annual		
Normal	0.72	0.94
Log-normalised	0.56	0.94
Ranked	0.48	0.86

Definitions:
- low flows (flows<10% percentile) : 0.3 GL/mo
- high flows (flows>90% percentile) : 12.3 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	3.4		0.5	1.5	2.5	0.5	1.6	2.6
Monthly streamflow	2.0		1.2	1.2	1.7	1.1	1.2	1.7



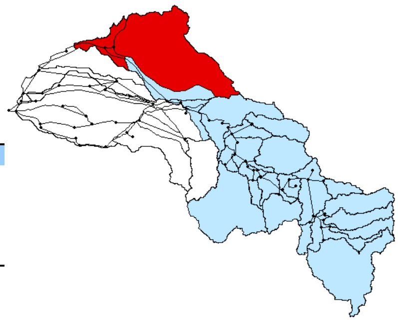


Downstream gauge	416027 Gil Gil @ Weemelah	Reach 12
Upstream gauge	418052 Carole Ck near Garah	

Reach length (km)	50
Area (km^2)	3750
Outflow/inflow ratio	1.83
Net gaining reach	

Land use	ha	%
Dryland	370,490	99
Irrigable area	-	-
Open water*	-	-
River and wetlands	4,510	1
Open water*	-	-

* averages for 1990–2006



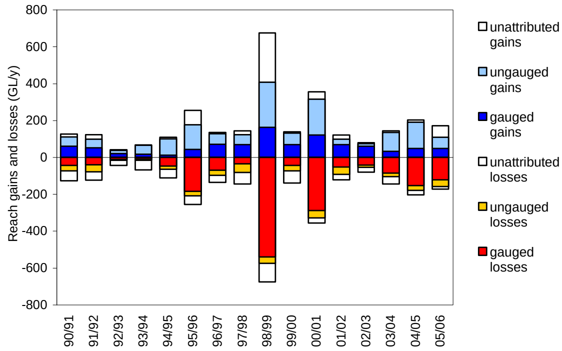
This is a losing reach. Flows are dominated by infows and an ungauged tributary inflow and by diversions.

Most of the inflows are ungauged. Estimated local runoff is large, and there other occasional unattributed inflows. There are large recorded diversions and some ungauged losses.

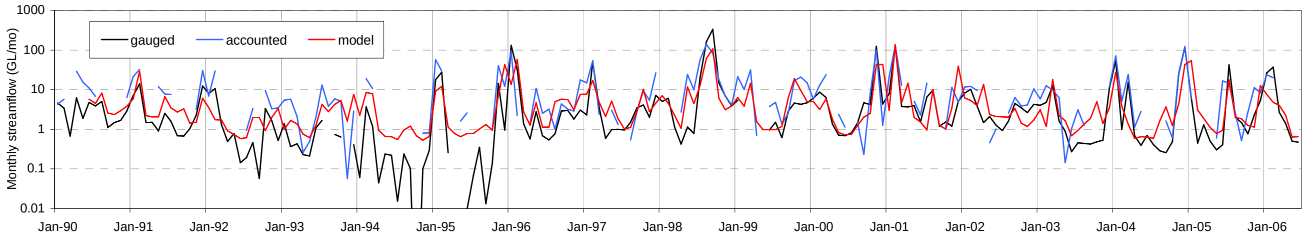
Baseline model performance is moderate. Accounting explains observed flows reasonably well.

The projected changes are less than or similar to model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.33	0.61	0.47
Attributed	0.80	0.76	0.78
Fraction of variance			
Gauged	0.35	0.96	0.65
Attributed	0.69	0.96	0.82



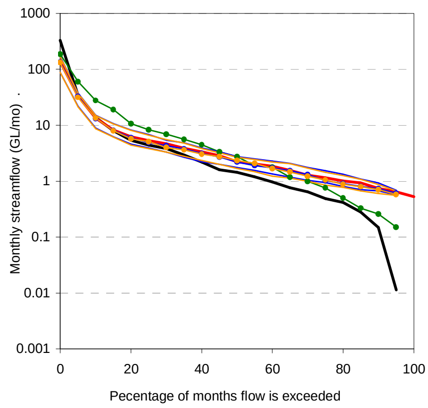
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	**-0.74**	-	-0.33	-	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.99**	**-0.56**	-0.08	-0.12	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	**-0.65**	-0.48	-0.09	-0.00	Adjusted -0.2%



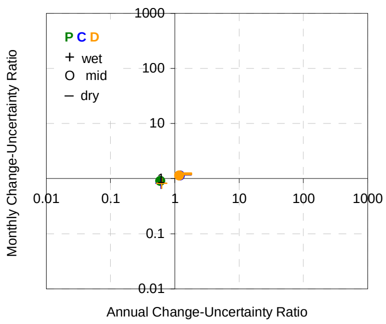
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	117	60	56
Tributary inflows	0	0	0
Local inflows	29	84	-55
Unattributed gains and noise	-	36	-36
Losses	GL/y	GL/y	GL/y
Main stem outflows	83	110	-27
Distributary outflows	0	0	0
Net diversions	30	22	8
River flux to groundwater	0	-	0
River and floodplain losses	0	5	-5
Unspecified losses	33	-	33
Unattributed losses and noise	-	44	-44

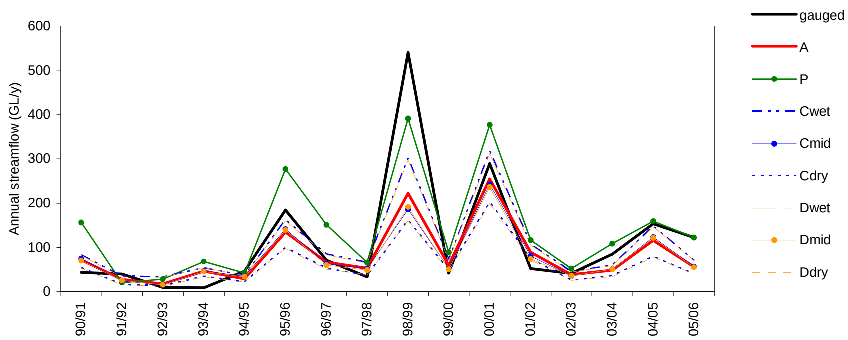
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.49	0.61
Log-normalised	-	-
Ranked	0.37	0.28
Low flows only	<0	<0
High flows only	0.26	0.42
Annual		
Normal	0.58	0.84
Log-normalised	0.65	0.54
Ranked	0.59	0.68

Definitions:
- low flows (flows<10% percentile) : 0.1 GL/mo
- high flows (flows>90% percentile) : 13.8 GL/mo



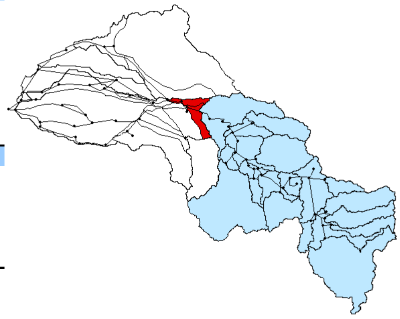
Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	0.6		0.6	1.2	1.5	0.6	1.2	1.5
Monthly streamflow	0.9		0.8	1.1	1.2	0.8	1.1	1.2





Downstream gauge	418037 Meehi D/S Combadello	Reach 21
Upstream gauge	418001 Gwydir River @ Pallamallawa	

Reach length (km)	22
Area (km^2)	2700
Outflow/inflow ratio	0.22
Net losing reach	



This is the same reach balance as reach 5, Yarraman Bridge, but here we examine the outflow at another of the three distributary outflow gauges.

This is a losing reach. Flows are dominated by infows and outflows in the main stem, and by diversions.

Most of the inflows are gauged. Estimated local runoff is small. There are large recorded diversions and ungauged losses.

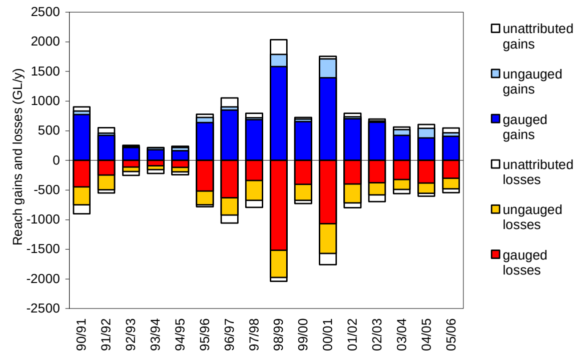
Baseline model performance is poor. Accounting explains flows very well. Predicted changes are generally similar to or greater than model uncertainty except for the P, Cwet and Dwet scenarios, and less than model uncertainty for the remaining scenarios.

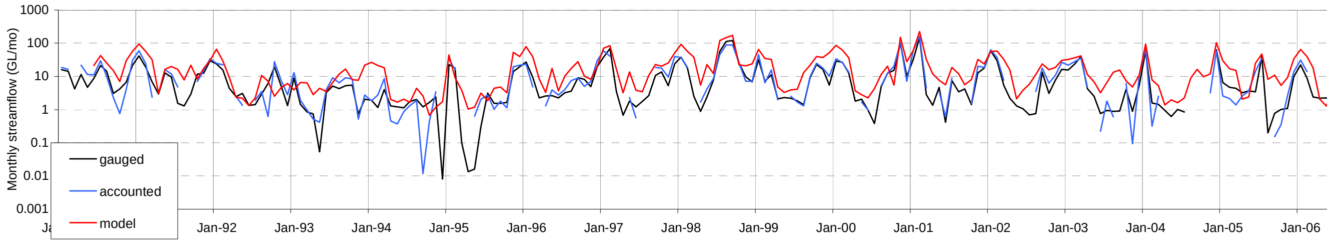
Land use	ha	%
Dryland	264,270	98
Irrigable area	-	-
Open water*	-	-
River and wetlands	5,720	2
Open water*	-	-

* averages for 1990–2006

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.81	0.58	0.69
Attributed	0.91	0.89	0.90
Fraction of variance			
Gauged	0.94	0.90	0.92
Attributed	0.98	0.98	0.98

Correlation with ungauged	Gains normal	Gains ranked	Losses normal	Losses ranked	Linear adjustment
Main gauge inflows	-0.46	-0.12	-0.56	-0.73	
Tributary inflows	-0.34	-0.21	-0.06	-0.09	
Main gauge outflows	-0.59	--	-0.35	--	
Distributary outflows	-0.60	-0.21	-0.18	-0.59	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.39	-0.23	-0.10	-0.29	

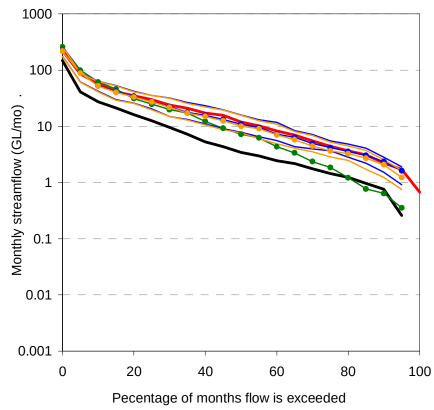




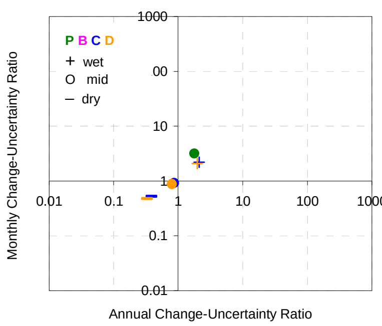
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	657	606	51
Tributary inflows	0	25	-25
Local inflows	98	83	15
Unattributed gains and noise	-	68	-68
Losses	GL/y	GL/y	GL/y
Main stem outflows	284	135	148
Distributary outflows	321	320	1
Net diversions	77	84	-7
River flux to groundwater	1	-	1
River and floodplain losses	0	159	-159
Unspecified losses	77	-	77
Unattributed losses and noise	-	84	-84

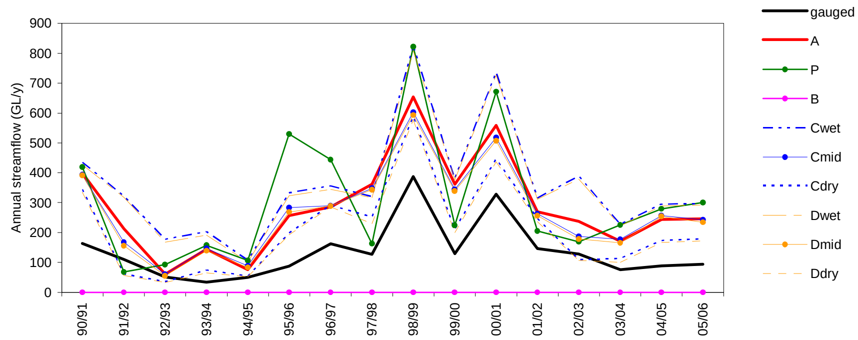
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.09	0.90
Log-normalised	-	-
Ranked	0.52	0.72
Low flows only	<0	<0
High flows only	<0	0.69
Annual		
Normal	<0	0.95
Log-normalised	<0	0.94
Ranked	0.79	0.95

Definitions:
- low flows (flows<10% percentile) : 0.8 GL/mo
- high flows (flows>90% percentile) : 27.2 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	1.8		2.1	0.9	0.4	2.0	0.8	0.3
Monthly streamflow	3.2		2.2	0.9	0.5	2.1	0.9	0.5



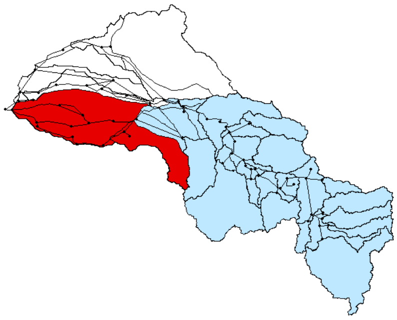


Downstream gauge	418055 Meehi D/S Collarenabri	Reach 22
Upstream gauge	418037 Meehi D/S Combadello	

Reach length (km)	167
Area (km^2)	3751
Outflow/inflow ratio	0.75
Net losing reach	

Land use	ha	%
Dryland	354,130	94
Irrigable area	-	-
Open water*	-	-
River and wetlands	21,010	6
Open water*	-	-

* averages for 1990–2006



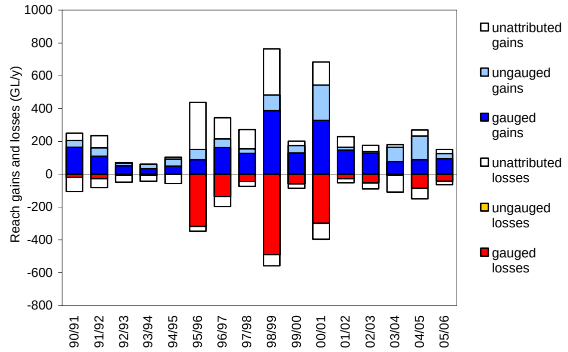
This is a losing reach. Flows are dominated by infows, outflows and diversions.

Some of the inflows are gauged, with occasional large ungauged inflows. Estimated local runoff is small. There are large recorded diversions and some ungauged losses.

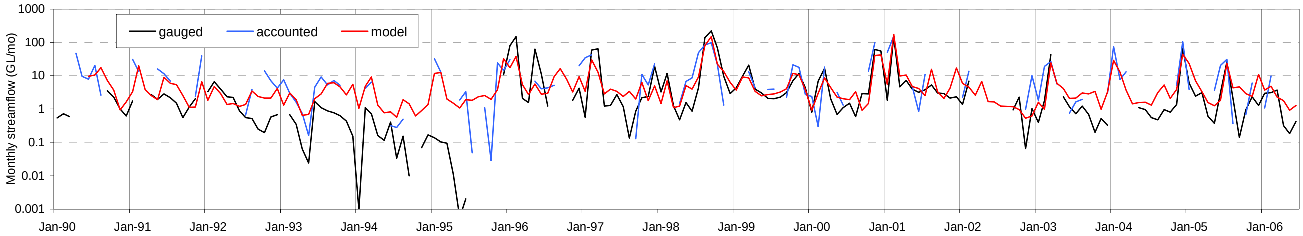
Baseline model performance is moderate. Accounting explains poorly.

The projected changes are generally similar to or less than model uncertainty.

Gauging data	Inflows and gains	Outflows and losses	Overall
Fraction of total			
Gauged	0.36	0.64	0.44
Attributed	0.57	0.64	0.59
Fraction of variance			
Gauged	0.57	0.85	0.66
Attributed	0.69	0.85	0.74



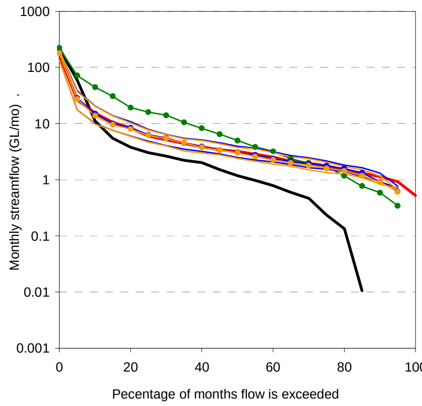
Correlation with ungauged	Gains		Losses		Linear adjustment
	normal	ranked	normal	ranked	
Main gauge inflows	-0.25	-	-0.48	-	
Tributary inflows	-	-	-	-	
Main gauge outflows	**-0.79**	**-0.53**	-0.08	-0.16	
Distributary outflows	-	-	-	-	
Recorded diversions	-	-	-	-	
Estimated local runoff	-0.10	-0.26	-0.26	-0.21	



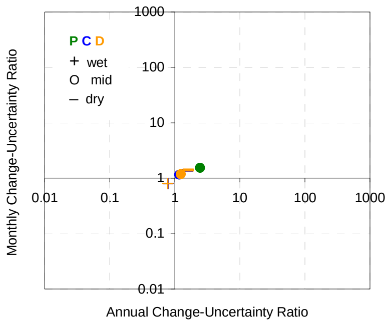
Water balance	Model (A)	Accounts	Difference
Jul 1990 – Jun 2006			
Gains	GL/y	GL/y	GL/y
Main stem inflows	284	135	148
Tributary inflows	0	0	0
Local inflows	56	79	-22
Unattributed gains and noise	-	161	-161
Losses	GL/y	GL/y	GL/y
Main stem outflows	93	101	-8
Distributary outflows	0	0	0
Net diversions	165	152	13
River flux to groundwater	1	-	1
River and floodplain losses	0	65	-65
Unspecified losses	81	-	81
Unattributed losses and noise	-	57	-57

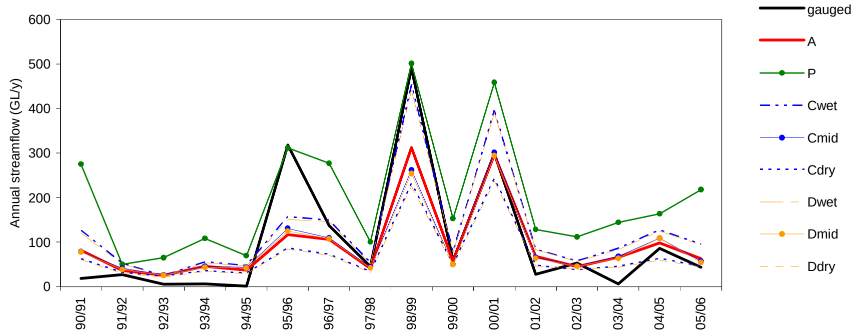
Model efficiency	Model (A)	Accounts
Monthly		
Normal	0.71	<0
Log-normalised	-	-
Ranked	<0	<0
Low flows only	-	-
High flows only	0.36	<0
Annual		
Normal	0.72	<0
Log-normalised	0.29	#NUM!
Ranked	0.49	<0

Definitions:
- low flows (flows<10% percentile) : 0.0 GL/mo
- high flows (flows>90% percentile) : 11.1 GL/mo



Change-uncertainty ratios	P	B	Cwet	Cmid	Cdry	Dwet	Dmid	Ddry
Annual streamflow	2.5		0.8	1.2	1.6	0.8	1.2	1.6
Monthly streamflow	1.5		0.8	1.2	1.4	0.8	1.2	1.4





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