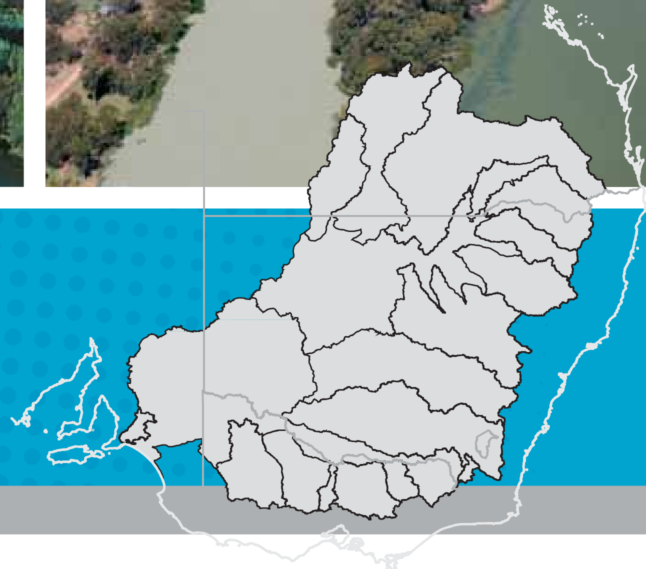


Water Availability in the Murray-Darling Basin

A report from CSIRO to the Australian Government

October 2008

www.csiro.au

Acknowledgments

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

Citation

CSIRO (2008). Water availability in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 67pp.

This report and associated project reports can be accessed at www.csiro.au/mdbsy.

Publication Details

ISSN 1835-095X

Photos courtesy of:

- CSIRO Land and Water (CSIRO)
- New South Wales Department of Water and Energy (DWE)
- Murray-Darling Basin Commission (MDBC)
- Australian Government Department of Environment, Water, Heritage and the Arts (DEWHA)
- Angela Gladman – North Central Catchment Management Authority, Victoria (North Central CMA)
- Water Information System for the Environment (WISE), NSW Department of Environment and Climate Change (NSW DECC)
- Queensland Department of Natural Resources and Water (QNRW)
- South Australia Department of Water, Land and Biodiversity Conservation (DWLBC)
- Victoria Environmental Protection Agency (Vic EPA)
- Victoria Department of Sustainability and Environment (DSE)
- Wimmera Catchment Management Authority (Wimmera CMA)

> The Murray River downstream from Morgan, SA (CSIRO)

> Cover: (left) Hume Dam near Albury, Vic/NSW (MDBC), (right) The confluence of the Darling and Murray rivers at Wentworth on the NSW/Victorian border (MDBC)

Contents

Executive Summary

> Weir on the Condamine River Cecil Plains, Qld (MDBC)

The Murray-Darling Basin Sustainable Yields Project

Following the November 2006 Summit on the southern Murray-Darling Basin (MDB), the then Prime Minister and MDB state Premiers commissioned CSIRO to report on sustainable yields of surface and groundwater systems within the MDB. This report from the CSIRO Murray-Darling Basin Sustainable Yields Project summarises the assessments for 18 regions that comprise the Basin. Separate reports for each of these 18 regions[2(a-r)] are available. Full technical documentation of project methods[3(a-r)] is also being provided. All these documents provide comprehensive citation details of materials used for the project.

The project is a world first for rigorous and detailed basin-scale assessment of the anticipated impacts of climate change, catchment development and increasing groundwater extraction on the availability and use of water resources. It represents the most comprehensive hydrologic modelling ever undertaken for the entire MDB including modelling of rainfall-runoff and groundwater recharge across the entire MDB, fully linked modelling of all major river systems and modelling of the major groundwater systems of the MDB and their connections to the surface water system. This work relied on existing river and groundwater models developed by state agencies and the Murray-Darling Basin Commission, and new models developed by the project. The river modelling results were compared against monthly surface water accounts for about 150 river reaches across the MDB. The accounts integrate all available data on streamflow and water use and estimates of evapotranspiration losses from satellite imagery.

The project was led by CSIRO and used the expertise of government agencies in Queensland, New South Wales, Victoria, the Australian Capital Territory and South Australia. The Murray-Darling Basin Commission and leading industry consultants were also involved. The project relied on the cooperative participation of nearly 200 people from over 15 organisations. It established comprehensive and efficient quality assurance processes including the external peer-review of project methods and modelling. All modelling results were captured, documented and translated into project reports.

Scenarios considered

Project results are framed around four scenarios of climate and development defined by 111 years of daily climate data.

The baseline scenario (for comparison with other scenarios) is the historical climate from mid-1895 to mid-2006 and the current level of water resource development.

The second scenario is based on the climate of 1997 to 2006. It is used to evaluate the consequences of a long-term continuation of the recent severe drought in south eastern Australia and provides a reference point for the climate change scenarios.

The third scenario considers climate change by 2030. A range of possible future climates is considered using three global warming levels and 15 of the global climate models included in the fourth assessment report of the Intergovernmental Panel on Climate Change[4(a)]. The reporting focuses on the median of the range and the uncertainty is reported as a 'wet extreme' and a 'dry extreme' in the range.

The fourth scenario considers likely future development and the 2030 climate. Development includes growth in farm dam capacity, expansion of commercial forestry plantations and increases in groundwater extraction. The projections of future farm dam and commercial forestry plantation development are 'best guesses' in the context of current policy and recent trends. The projections of future groundwater extraction represent maximum allowable use under existing water sharing arrangements.

Some results may be framed by a 'without-development' scenario. This scenario removes the effects of water management infrastructure and consumptive water use. Catchment characteristics such as vegetation cover are not adjusted and so this scenario does not represent 'pre-development' nor 'natural' conditions.

All these four scenarios assume the continuation of the existing surface and groundwater sharing plans implemented by states. In the future however, water sharing arrangements will need to comply with the Basin Plan to be developed under the *Commonwealth Water Act 2007*.

Key findings

- Water resource development has caused major changes in the flooding regimes that support nationally and internationally important floodplain wetland systems in the MDB. Integrating the flow impacts down through the connected rivers of the Basin shows that total flow at the Murray mouth has been reduced by 61 percent; the river now ceases to flow through the mouth 40 percent of the time compared to 1 percent of the time in the absence of water resource development.
- The south of the MDB was in severe drought from 1997 to 2006 and the catchment runoff in the southernmost parts of the MDB was the lowest on record. This event would occur once in more than 300 years without climate change. Such conditions will become increasingly common. The drought conditions in the south of the MDB have worsened in 2007 and 2008.
- The impacts of climate change by 2030 are uncertain; however, surface water availability across the entire MDB is more likely to decline than to increase. A decline in the south of the MDB is more likely than in the north. In the south of the MDB, a very substantial decline is possible. In the north of the MDB, significant increases are possible. The median decline for the entire MDB is 11 percent – 9 percent in the north of the MDB and 13 percent in the south of the MDB.
- The median water availability decline would reduce total surface water use by 4 percent under current water sharing arrangements but would further reduce flow at the Murray mouth by 24 percent to be 30 percent of the total without-development outflow. In volumetric terms, the majority of the impact of climate change would be borne by the environment rather than by consumptive water users.
- The relative impact of climate change on surface water use would be much greater in dry years. Under the median 2030 climate, diversions in driest years would fall by more than 10 percent in most New South Wales regions, around 20 percent in the Murrumbidgee and Murray regions and from around 35 to over 50 percent in the Victorian regions. Under the dry extreme 2030 climate, diversions in driest years would fall by over 20 percent in the Condamine-Balonne, around 40 to 50 percent in New South Wales regions (except the Lachlan), over 70 percent in the Murray and 80 to 90 percent in the major Victorian regions.
- Groundwater currently represents 16 percent of total water use in the MDB but under current water sharing arrangements groundwater use could increase by 2030 to be over one-quarter of total water use. One-quarter of current groundwater use will eventually be sourced directly from induced streamflow leakage which is equivalent to about 4 percent of current surface water diversions. Current groundwater use is unsustainable in seven of the twenty high-use groundwater areas in the MDB and will lead to major drawdowns in groundwater levels in the absence of management intervention.
- Expansion of commercial forestry plantations and increases in the total capacity of farm dams could occur by 2030. 'Best estimate' projections of these developments indicate only very minor impacts on the total runoff reaching rivers across the MDB. However, the volumes of surface water used by these developments, and the within-subcatchment streamflow impacts, may be significant.

> Castlereagh River at Coonamble, NSW (MDBC)

> Wetland near Narran Lakes, Condamine-Balonne region, NSW (MDBC)

> Claypan depression, Nocoleche Nature Reserve, Paroo region, NSW (WISE, NSW DECC)

Current climate and development

The MDB is naturally an inefficient hydrologic system. Surface water losses (via evapotranspiration and to groundwater) are naturally high and only 52 percent of the assessed total surface water resource of the MDB would reach the Murray mouth in the absence of flow regulation and consumptive water use. The surface water losses support floodplain and wetland ecosystems throughout the MDB (many are listed under the Ramsar Convention as wetlands of international importance) including the Coorong and the Lower Lakes on the Murray River. The losses are linked to the large but infrequent floods that characterise the highly variable natural flow regimes of the MDB – especially in the north-west rivers.

The relative level of current surface water use averaged over the historical climate sequence is high at 48 percent summed across the MDB, but varies widely between the 18 regions. Nearly two-thirds of the average annual consumptive surface water use across the MDB occurs in the Murray, Murrumbidgee and Goulburn-Broken regions. These regions collectively represent slightly over half the total MDB surface water resource. Consumptive water use across the MDB has reduced average annual streamflow at the Murray mouth by 61 percent. Water resource development has greatly reduced the frequency of flooding of many Ramsar sites and other key floodplains and wetlands across the MDB. Severe drought inflows to the Lower Lakes (annual inflow less than 1500 GL) – which would never occur in the absence of consumptive water use under the historical climate – prevail in 9 percent of years at the current level of water resource development. These hydrologic changes are linked to the significant levels of environmental degradation observed at numerous floodplains and wetlands across the MDB.

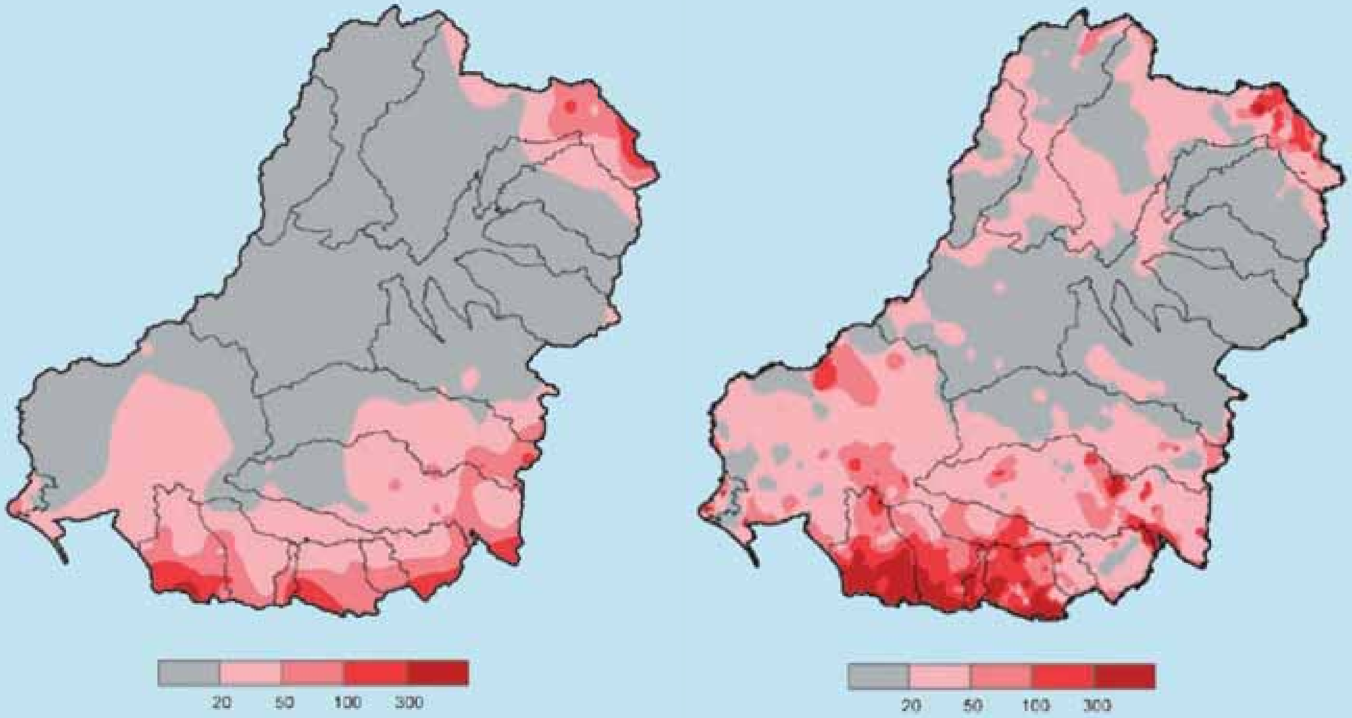
> Gwydir River, Bingara, NSW (DEWHA)

The recent drought

Annual rainfall in the southern MDB for the ten-year period 1997 to 2006 was significantly lower than the long-term average but similar low-rainfall periods occurred in the 1890s and around 1940. Modelled annual runoff in the southern MDB (1997 to 2006) was lower than for any other ten-year period in the last 112 years and is less than half the long-term average in some areas. The low runoff in the southernmost parts of the MDB has an average recurrence interval of over 300 years. Related work by CSIRO and the Bureau of Meteorology[4(b)] indicates that these extreme climate conditions may be partly attributed to global climate change and that such conditions are likely to become more common.

Rainfall and runoff averaged across the entire MDB (1997 to 2006) are not significantly different to the long-term historical averages.

These maps show the average recurrence interval (as number of years) of the 1997 to 2006 rainfall (left) and modelled 1997 to 2006 runoff (right) across the 18 regions of the MDB. The results indicate the average period between occurrences of 'ten-year events' similar to the 1997 to 2006 'event' and indicate that the drought was most severe in the southern Victorian regions



The impacts of climate change

> Riverbank, Warrego region, Qld (QNRW)

Surface water availability across the entire MDB is expected to decline due to climate change. The future will be significantly drier on average but these conditions would be less severe than a continuation of the recent climate in the south of the MDB. The median of likely climate changes by 2030 would be an 11 percent reduction in average surface water availability across the MDB – 9 percent in the north and 13 percent in the south. The reduction would be greatest in the south-east where the majority of the runoff is generated and where the impacts of climate change are expected to be greatest.

This reduction in surface water availability would reduce surface water use by 4 percent overall under current water sharing arrangements. The impact on surface water use ranges from a maximum reduction of 10 percent in the Wimmera region to a 2 percent increase in the Barwon-Darling (in this case due to increased irrigation demand under a warmer climate). Use in dry years would be affected far more. The minimum one-year diversion volumes would be reduced by as much as around 40 to 50 percent in the Victorian regions (Goulburn-Broken, Campaspe, Loddon-Avoca and Wimmera).

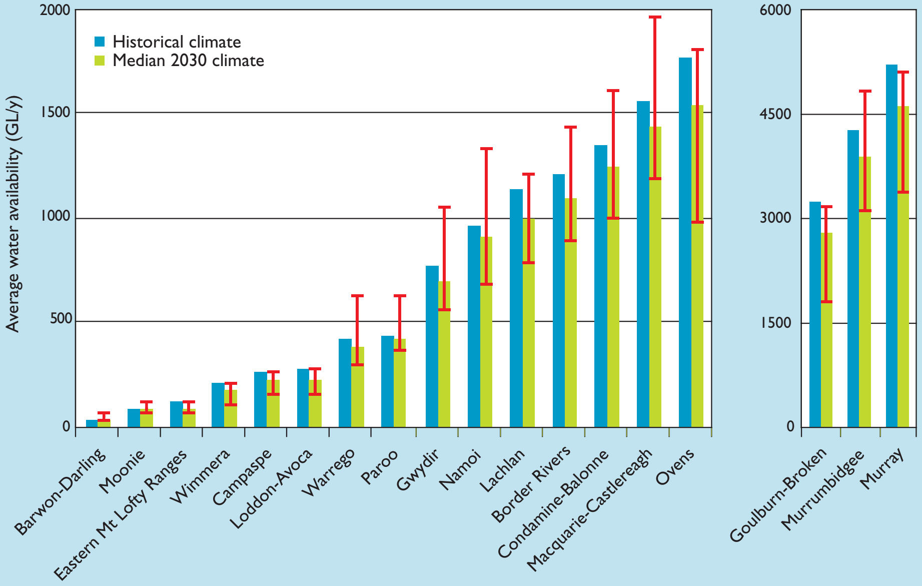
The impacts of climate change on the reliability of 'water products' vary greatly between the products, regions and states. High reliability water products (including town water supplies) would generally not be affected. 'General security' and 'low reliability' type water products would be affected in terms of the average seasonal allocation and the fraction of years of 100 percent allocations. The greatest reductions in reliability would occur in regions where the relative level of surface water use is already high and where the climate change is expected to have the largest impact on water availability, and for water products that are already less reliable. Some of the largest reductions in reliability would thus occur in the Murray, Goulburn-Broken, Campaspe, Loddon-Avoca and Wimmera regions, and under the dry extreme 2030 climate.

The reduction in surface water availability and the lesser reduction in surface water use would cause the overall relative level of use across the 18 regions (under the median 2030 climate) to rise to 54 percent. Outflows through the Murray mouth would fall from 39 to 30 percent of the without-development volume.

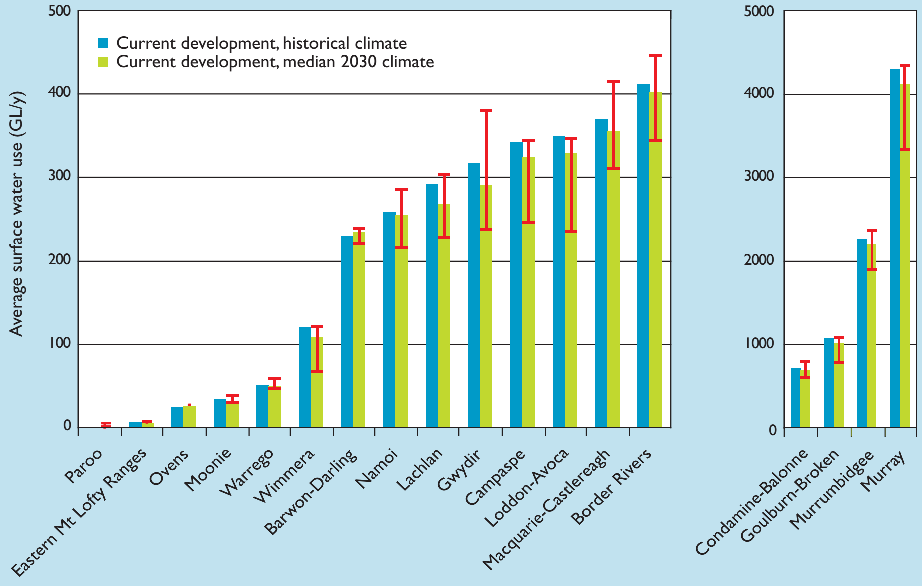
The reductions in surface water availability due to climate change would be focussed in the high water use Murray, Goulburn-Broken and Murrumbidgee regions. Under a continuation of current water sharing arrangements, much of the impact of reduced surface water availability would be transferred to the riverine environments along the Murray River including the Lower Lakes and the Coorong. Flow at the Murray mouth would cease 47 percent of the time and severe drought inflows to the Lower Lakes would occur in 13 percent of years. Current surface water sharing arrangements in the MDB would generally protect consumptive water users from much of the anticipated impact of climate change but offer little protection to riverine environments. This result should be considered in the development of future water sharing plans, as the National Water Initiative indicates that water plans should consider the risk of climate change on the size of the water resource and the implications for sharing. The Gwydir region is a notable exception as current arrangements would see the consumptive and non-consumptive water shares affected to a similar degree.

The hydrological impacts of climate change in the MDB remain very uncertain. For example, average surface water availability could reduce by as much as 34 percent by 2030 (more severe on average than the recent climate) or increase by up to 11 percent. Under the dry extreme 2030 climate (34 percent less surface water available on average), dry period use and allocation reliability are very greatly reduced. Uncertainty in the impacts of climate change is expected to reduce in the coming few years with improvements in climate change science. Projections further into the future become increasingly uncertain due to divergence in the range of possible greenhouse gas emissions trajectories. The median climate becomes increasingly drier further into the future and by 2070 the median climate under high global warming is expected to be broadly similar to the dry extreme 2030 climate. This highlights the need for far greater flexibility and adaptive capacity in water resources management in the MDB.

Current and likely future surface water availability across the 18 regions of the MDB is summarised in the chart below. Red bars indicate the uncertainty inherent in the climate change projections for 2030. The current total surface water resource across the 18 regions is 23,417 GL/year on average. The total average surface water resource summed across the 18 regions under the median 2030 climate is 20,936 GL/year with a range from 26,047 GL/year to 15,524 GL/year



Current and likely future surface water use across the 18 regions of the MDB are summarised in the chart below. Red bars indicate the uncertainty inherent in the climate change projections for 2030. Current total surface water use summed across the 18 regions are 11,327 GL/year on average. Total average surface water use under the median 2030 climate and current water sharing arrangements would be 10,876 GL/year with a range from 11,686 GL/year to 8962 GL/year



Groundwater resources

Groundwater resources and use in the MDB are concentrated in twenty out of nearly one hundred groundwater management units (GMUs) that cover the MDB. Current groundwater extraction is assessed as unsustainable in seven GMUs (Condamine, Border Rivers, Lower Namoi, parts of the Lower Macquarie, parts of the Lower Lachlan, the Upper Lachlan and the Mid-Murrumbidgee). There are also indications that extraction in the Upper Murray may not be able to be sustained. The absence of management intervention to manage these high rates of extraction would eventually lead to large reductions in groundwater levels. Current groundwater use represents 16 percent of the total water use in the MDB but a far greater fraction of total water use during dry periods.

One-quarter of total current groundwater use will eventually be sourced directly from induced streamflow leakage which is equivalent to about 4 percent of current surface water diversions. Around 40 percent of the eventual streamflow leakage will occur in the Namoi, Lachlan, Murrumbidgee and Murray regions.

Groundwater use across the MDB, given current groundwater management arrangements, could more than double by 2030 to exceed one-quarter of total average water use. This is despite existing planning controls that will reduce groundwater extraction to below current levels in some areas. It highlights the need to bring all groundwater use into the water entitlement system. The projected future levels of groundwater use could not be sustained in the Border Rivers, Lower Namoi, parts of the Lower Macquarie and the Lower and Upper Lachlan due to large reductions in groundwater levels. Future increases in groundwater use are expected to significantly affect baseflow in small tributaries and turn many into ephemeral streams. Increased use is expected in some of the major alluvial aquifers leading to significant increases in streamflow leakage induced by groundwater extraction.

Future development

Bureau of Rural Sciences projections indicate that (given current trends and current policy) MDB commercial forestry plantations could expand in area by 52,000 ha or 18 percent by 2030. The increases would be concentrated in the Eastern Mount Lofty Ranges (2000 ha), Murrumbidgee (17,000 ha) and Murray (33,000 ha) regions. These forestry developments would use a small volume of water in a MDB-wide context and the reduction in average annual runoff at the regional scale would be less than 1 percent (about 0.8 percent reduction in future average annual runoff over the Eastern Mount Lofty Ranges region and about 0.3 percent reduction in future average annual runoff over the Murrumbidgee and Murray regions). However, the expansion is likely to be concentrated in small areas and in these areas the local impact on runoff could be significant.

The current capacity of small farm dams across the MDB is estimated to be 2000 GL. Projections based on historical data for farm dam growth and current policy controls suggest a possible 10 percent increase in this total farm dam capacity by 2030. The increase in farm dam capacity would be less concentrated than commercial forestry plantation development and new farm dams would reduce average annual runoff by about 0.7 percent across the MDB. The biggest reduction would be in the Eastern Mount Lofty Ranges (3 percent). The projected farm dam development would reduce average annual runoff by 1.7, 0.8 and 0.4 percent in the Campaspe, Loddon-Avoca and Goulburn-Broken regions respectively. The projected farm dam development would reduce average annual runoff in eastern New South Wales by 1.0 to 1.5 percent. The small projected farm dam development in Queensland would have negligible impact on future runoff.

These developments may have more impact at the local or subcatchment scale including environmental consequences for tributary streams. Streamflow impacts by 2030 of commercial plantation forestry (28 GL/year), additional farm dams (170 GL/year) and the streamflow leakage induced by additional groundwater extraction (177 GL/year) would collectively represent a volume of surface water use of 375 GL/year. This potential increase in surface water use (375 GL/year), together with the 451 GL/year average reduction in surface water use that would occur due to the median 2030 climate, would mean only a small net reduction (76 GL/year) in total surface water use as a result of the combined effects of climate change and possible future development. This is in spite of the considerable reduction in water availability expected with climate change. These increases in surface water use due to development and the reductions in surface water diversions due to climate change, would occur in different relative proportions in each region.

Project legacy

The project results provide a strong base to determine a new sustainable diversion limit for surface and groundwater use across the MDB as required under the *Commonwealth Water Act 2007*. The results should also be valuable in future assessments which may contribute to the development of the Basin Plan including consideration of (i) the consumptive and other economic uses of MDB water resources; (ii) conservation and sustainable use of biodiversity; and (iii) social, cultural, Indigenous and public benefit issues. The project has developed for the first time an integrated modelling capability for the entire MDB linking multiple river systems models together with multiple groundwater models. This capability should be invaluable in coming years for additional investigations including for example, scenarios of: (i) altered water sharing to guide determination of sustainable diversion limits; (ii) river system management that explores opportunities for greater efficiency in water delivery and use; (iii) the implications of temporary and permanent water trade; and (iv) altered environmental watering. The major challenge for future water resource management in the MDB is to achieve sustainable water resource use while optimising economic, social and environmental outcomes in the context of a climate which is highly variable and non-stationary. The approaches of the past which assume an 'equilibrium' climate are no longer adequate.

Introduction

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 and is a most valuable resource. Climate change and other risks (including catchment development) make improved water resource data, understanding, planning and management a high priority for Australian communities, industries and governments.

On 7 November 2006, the then Prime Minister of Australia met with the premiers of Victoria, New South Wales, South Australia and Queensland at a Water Summit focused primarily on the future of the Murray-Darling Basin (MDB). Following the Summit they commissioned CSIRO to progressively report 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 required CSIRO to:

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

The project has now reported progressively to the Australian Government on all 18 regions of the MDB and these reports[2(a-r)] are all publicly available (see www.csiro.au/mdbsy). This report is for the whole of the MDB and is the project's culminating report. It summarises the results from the 18 regions and presents the findings of MDB-level analyses. This and the 18 regional reports are supported by a comprehensive series of technical reports detailing all aspects of the work undertaken[3(a-r)].

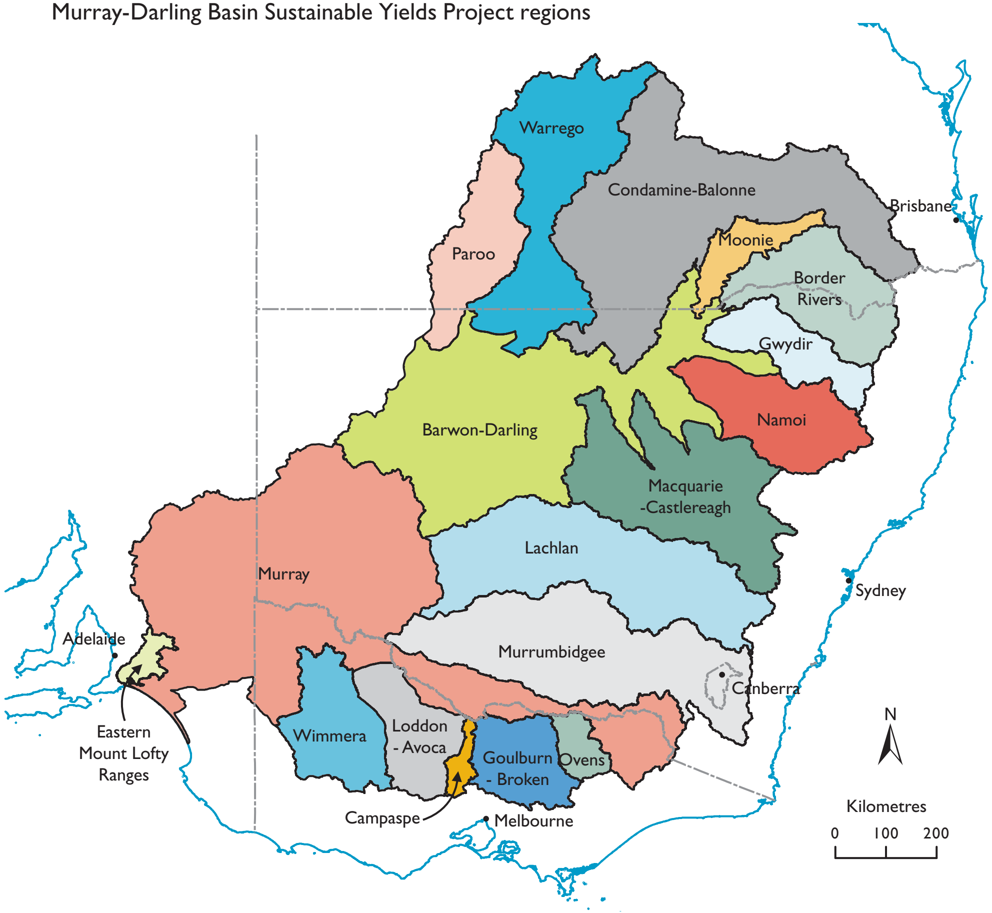
The project was funded under the Raising National Water Standards Program of the National Water Commission. This program is investing in high priority activities to improve Australia's national capacity to measure, monitor and manage its water resources. The Raising National Water Standards Program supports projects that will help to achieve the objectives, outcomes and actions of the National Water Initiative. The National Water Initiative, agreed in 2004 by the Council of Australian Governments, is the national blueprint for water reform. It represents the Australian Government's and state and territory governments' shared commitment to water reform in recognition of: (i) the continuing national imperative to increase the productivity and efficiency of Australia's water use; (ii) the need to service rural and urban communities; and (iii) ensuring the health of river and groundwater systems, including by establishing clear pathways to return all systems to environmentally sustainable levels of extraction. Importantly, the National Water Initiative signifies a commitment to identifying over-allocated water systems and restoring those systems to sustainable levels, and more sophisticated, transparent and comprehensive water planning.

Project findings are expected to inform the establishment of a new sustainable diversion limit for surface and groundwater in the MDB. This is one of the responsibilities of the Murray-Darling Basin Authority in formulating a new Murray-Darling Basin Plan as required under the Water Act 2007. These reforms are a component of the Australian Government's new national water plan 'Water for the Future'. Amongst other priorities, the plan will invest in projects that are able to secure a long-term sustainable future for irrigation communities, in the context of climate change and reduced water availability into the future. The projects must also deliver substantial and lasting returns of water to the environment to secure improvements in river health. The plan will also invest at least $3 billion over the next ten years to purchase water to put back into rivers in the Basin.

Project framework

The project framework and methods are summarised in a companion booklet[1(a)] and are fully described in a comprehensive set of peer-reviewed technical reports[3(a-r)]. Minimal details are provided here. The MDB was divided into 18 regions for the purposes of the project. The regions are the major tributaries of the MDB and reflect existing river system models and surface water sharing plan areas.

Murray-Darling Basin Sustainable Yields Project regions



The project considers water availability and use under the following hypothetical scenarios of climate and development:

Historical climate and current development: the baseline for comparison with other scenarios. The actual 1895 to 2006 climate and current development as represented in the river models used for developing current water sharing plans.

Recent climate and current development: a scaling of the 1895 to 2006 climate using statistics of the 1997 to 2006 climate.

Future climate and current development: scaling of the 1895 to 2006 climate using results from multiple global climate models for the climate around 2030. The median 2030 climate is presented together with an uncertainty range.

Future climate and future development: median 2030 climate and uncertainty range together with 2030 projected growth in farm dam capacity, commercial forestry plantations and groundwater extraction.

Without-development: some results are framed according to a without-development scenario which removes the effects of water infrastructure and consumptive use from the baseline scenario.

Rainfall-runoff modelling and rainfall-recharge modelling were undertaken for each scenario to input to river system modelling and groundwater modelling and other simpler groundwater assessments.

River models covering the entire MDB and groundwater models were linked to enable full propagation of scenario impacts including surface–groundwater exchanges, inter-basin transfers and the numerous feedbacks involved in water resource management. The uncertainty inherent in the river system models was assessed using monthly water accounting. The results of scenario outputs from the river system models were used to make limited eco-hydrological assessments of key environmental assets. The impacts of each scenario on water availability and water use under current water sharing arrangements were assessed and reported. Current water sharing arrangements are as represented in the existing river system models. Determining the full implications of any changes in water sharing arrangements that might occur when existing water sharing plans are reviewed (between 2012 and 2019) would require changes to these river system models.

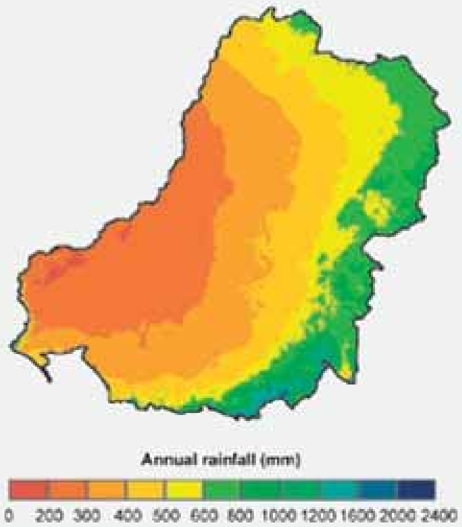
The Murray-Darling Basin

The MDB covers more than 1 million km^2 (one-seventh) of mainland Australia including parts of Queensland, New South Wales, Victoria and South Australia and all of the Australian Capital Territory. The landscape is dominated by vast plains and large areas of undulating hills. The Basin is bounded by the Great Dividing Range in the south and east. The Darling River (and its tributaries) drains southern Queensland and northern New South Wales, crosses the Darling Plain and joins the Murray River upstream of Wentworth. The Murray River and its tributaries harvest water from inland areas of southern New South Wales and northern Victoria. The Murray River dissects the Riverine Plain from east to west and flows to the Southern Ocean via the Lower Lakes system in South Australia. The Darling (2740 km), the Murray (2530 km) and the Murrumbidgee (1690 km) are Australia's three longest rivers.

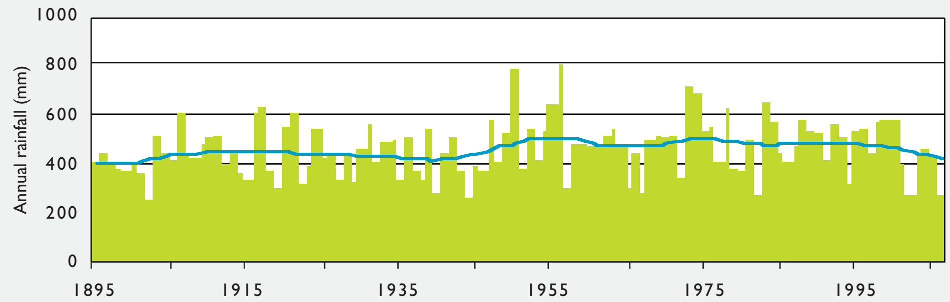
Climate and environments

There is a wide range of climatic conditions in the MDB including a strong east–west rainfall gradient and a strong north-west to south-east temperature gradient. Rainfall is summer dominated in the north and winter dominated in the south. Rainfall varies considerably between years in the north-west and less so towards the south-west. These climatic conditions variously support the rainforests of the cool and humid eastern uplands, the temperate Mallee country of the south-east, the sub-tropical areas of the north-east, and the hot, dry semi-arid and arid lands of the far western plains.

Spatial pattern of average annual rainfall across the MDB for the period 1895–2006



Temporal variability of annual rainfall averaged across the MDB for the period 1895–2006. Smoothed line indicates longer term variations



> Farm irrigation supply, near Moree, Gwydir region, NSW (DEWHA)

Population and land use

The MDB is home to around two million people including the national capital, Canberra, and the major centres of Toowoomba, Tamworth, Moree, Orange, Dubbo, Wagga Wagga, Griffith, Albury-Wodonga, Shepparton, Bendigo, Horsham, Mildura and Renmark.

Agriculture is the dominant economic activity in the MDB covering nearly 80 percent of the Basin and generating over 40 percent of the gross value of Australian agricultural production. The MDB uses 60 percent of all irrigation water in the country and is often referred to as Australia's 'food basket'. Agriculture also provides the raw materials for most of the manufacturing activity within the MDB and many processing companies located outside the Basin. Agricultural areas in the MDB are predominantly for livestock production, particularly dryland sheep and cattle production. Dairying is the main irrigated livestock industry. Important cropping activities include cereals (particularly wheat, barley and rice), oilseed, cotton, and horticulture (particularly citrus, stone and pome fruits, grapes and vegetables).

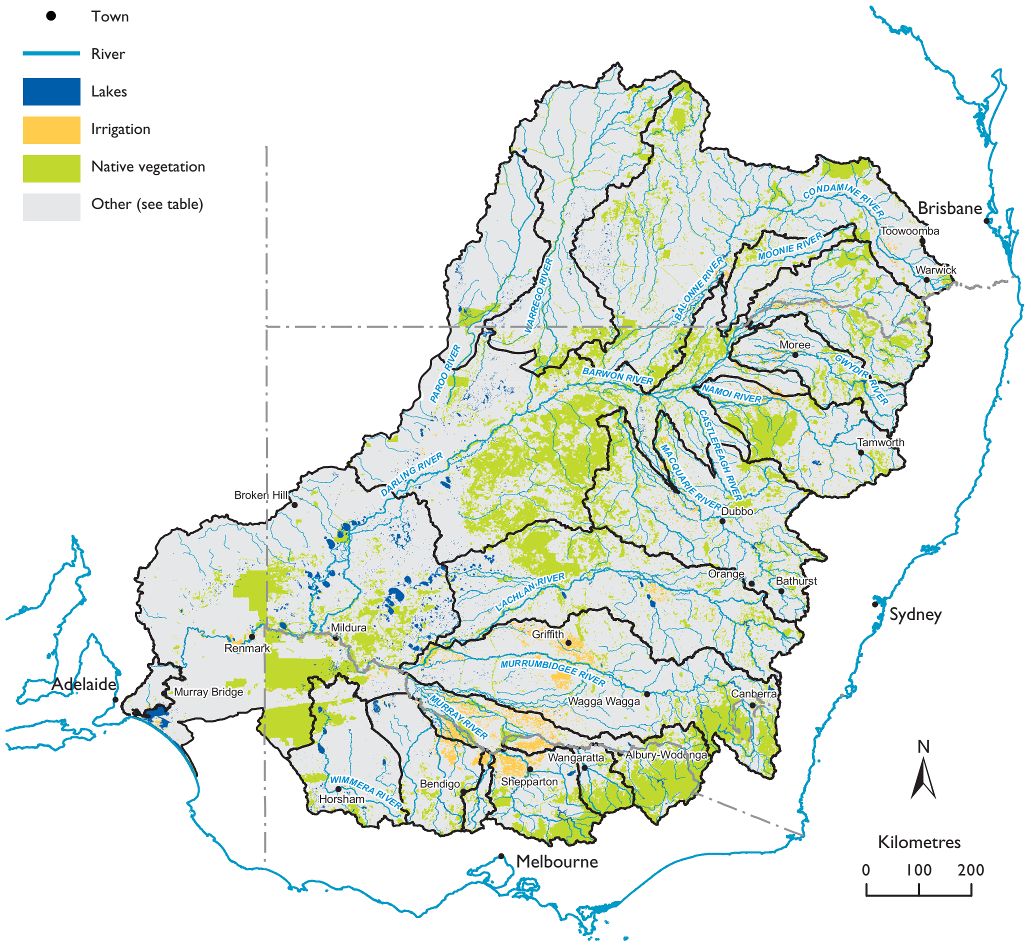
Remnant native vegetation covers around 20 percent of the Basin area. Agricultural and urban development has involved extensive clearing of native vegetation, disturbance of wetlands and other resource modification including construction of dams and the diversion of water for irrigation, stock and domestic uses.

Summary of MDB land use in the year 2000

Land use	Area	
	percent	ha
Dryland crops	10.5%	11,001,881
Dryland pasture	66.7%	69,970,726
Irrigated crops	1.8%	1,916,256
Cereals	*0.4%*	*467,178*
Cotton	*0.4%*	*426,519*
Horticulture	*0.0%*	*46,622*
Orchards	*0.1%*	*67,912*
Pasture and hay	*0.8%*	*820,890*
Vine fruits	*0.1%*	*87,135*
Native vegetation	20.3%	21,242,551
Plantation forests	0.4%	445,048
Urban	0.3%	276,104
Total	**100.0%**	**104,852,550**
Water		943,861

Source: Bureau of Rural Sciences(4c), 2005

Land use across the MDB



Overview of water resources

Patterns of water availability

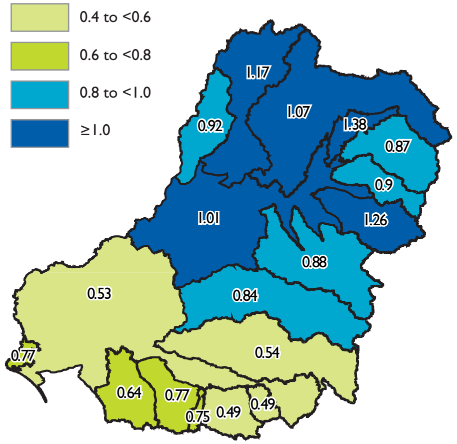
The MDB uses 60 percent of the water used in Australia yet it generates only 6 percent of the nation's surface water resource. Water availability varies greatly across the Basin; detailed assessments of this have been undertaken in the project and results are provided later in this report.

The net difference between rainfall and evapotranspiration provides a picture of the spatial pattern of the MDB water balance. Evapotranspiration is naturally high in floodplain wetlands and is also high in irrigated areas. The majority of the MDB water balance is negative (red shades on the map) – that is, evapotranspiration exceeds rainfall. On an annual basis, the balance is positive (blue) only in limited areas mainly in the south-east of the MDB. In winter when evapotranspiration is lower and rainfall in the south is higher, the balance is positive over much of the MDB. The balance is positive in the northern regions in the summer due to the summer dominance of rainfall in these areas.

Water availability also varies greatly between years. The coefficient of variation of annual streamflow within each region indicates the differences in streamflow variability between regions. Annual streamflow is most variable in the north of the MDB and is least variable in the south-east corner of the MDB.

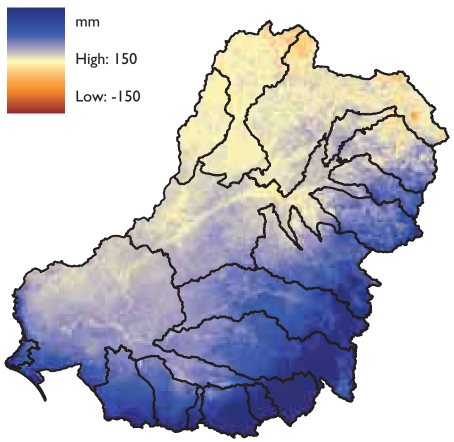
Natural (without-development) streamflow variability by region (assessed at point of maximum flow in each region). Scale: low, coefficient of variation (CV) 0.4 to <0.6; moderate, CV 0.6 to <0.8; high, CV 0.8 to <1.0; and very high, CV ≥ 1.0

Co-efficient of flow variation

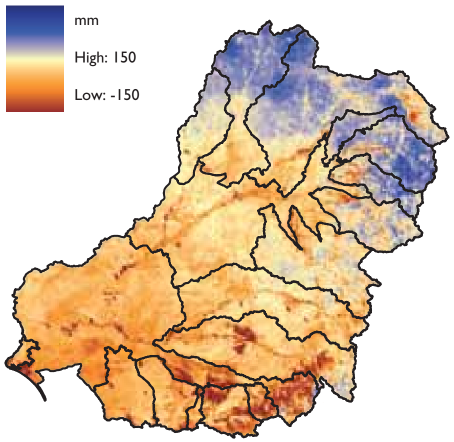


Spatial pattern of the annual, winter and summer water balance across the MDB. Red indicates a strongly negative water balance (evapotranspiration exceeds rainfall) and blue indicates a strongly positive water balance (rainfall exceeds evapotranspiration)

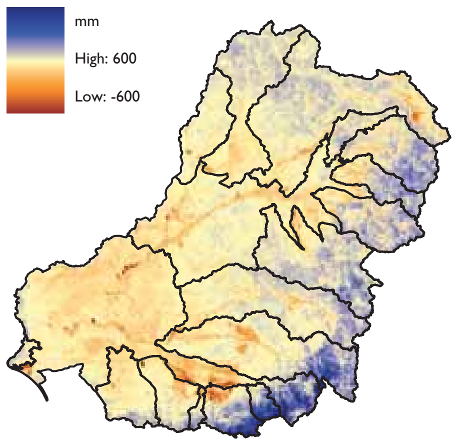
Winter water balance



Summer water balance



Annual water balance



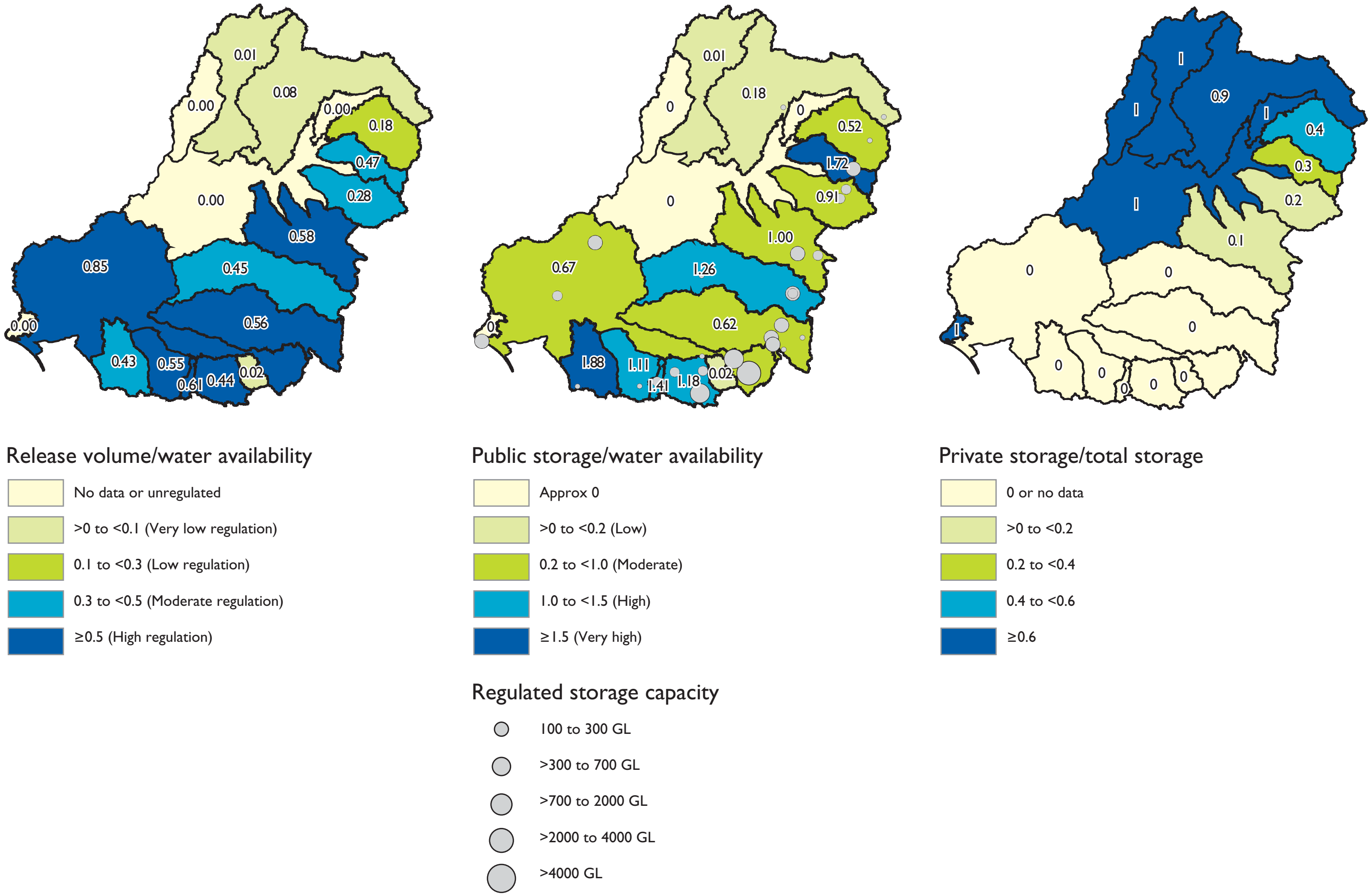
Water storage and regulation

Water storage and regulating structures have been built across the MDB to cope with the inter-annual variability of streamflow and enable longer term storage and re-release of water in drier years. Much of the public storage capacity in the MDB was constructed between the mid-1950s and 1990. The largest dams in the MDB (all with capacities exceeding 1000 GL) are Dartmouth, Eildon, Hume, Burrendong, Blowering, Copeton, Wyangala and Burrinjuck. The Menindee Lakes are also operated as a major storage in the system. The total storage capacity in the MDB is now close to three times the natural average annual flow through the Murray mouth.

The volume of public storage capacity varies across the 18 regions of the MDB from over 1.5 times the average annual available surface water in the Namoi and Wimmera regions to essentially no public storage capacity in the Moonie and Paroo, and very low relative storage in the Warrego, Barwon-Darling, Ovens and Eastern Mount Lofty Ranges.

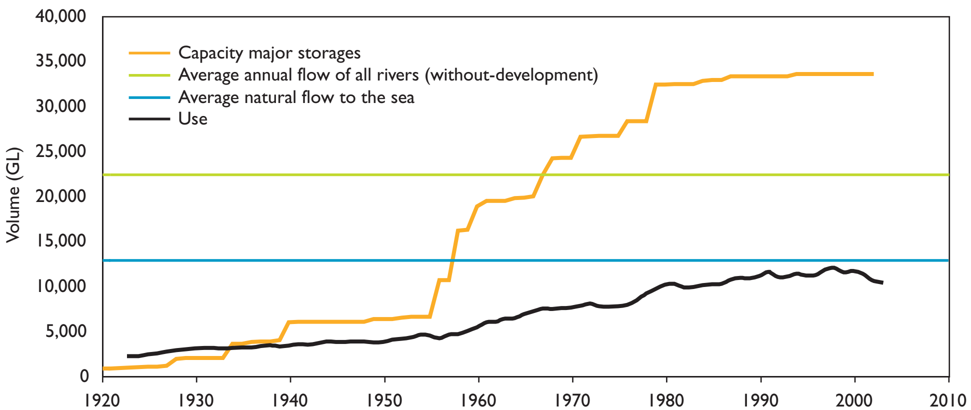
The degree of regulation provided by public storages also varies between regions. The degree of regulation is indicated by the ratio of regulated releases to total water availability. The degree of regulation is a function of relative storage capacity and inflow variability. Regions with larger dams and lower inflow variability – such as the Murray and the Murrumbidgee – show the greatest regulating effect.

Left: Combined degree of regulation for major public storages in each of the 18 regions of the MDB. This is defined as the ratio of regulated releases plus net storage evaporation to average surface water availability. Centre: Public water storage capacity relative to annual surface water availability in each of the 18 regions of the MDB. Right: Private storage capacity as a fraction of total capacity (as represented in existing river models) across the 18 regions of the MDB



There is also significant private on-farm storage capacity in parts of the MDB. On-farm storage is 90 percent or more of the total storage capacity in the Eastern Mount Lofty Ranges, Barwon-Darling, Paroo, Warrego, Condamine-Balonne and Moonie regions. The largest total on-farm storage capacity is in the Condamine-Balonne region. On-farm storages on lower river floodplains support large-scale irrigation enterprises in several northern regions. On-farm storage is via smaller hillside dams in the Eastern Mount Lofty Ranges and these are explicitly represented in the river models for this region. Hillside dams are also prevalent in the south-east and east of the MDB but are not explicitly represented in river models and so are not indicated on the map.

Growth in public storage capacity over the last 80 years compared to total water availability and total surface water use (five-year moving average)

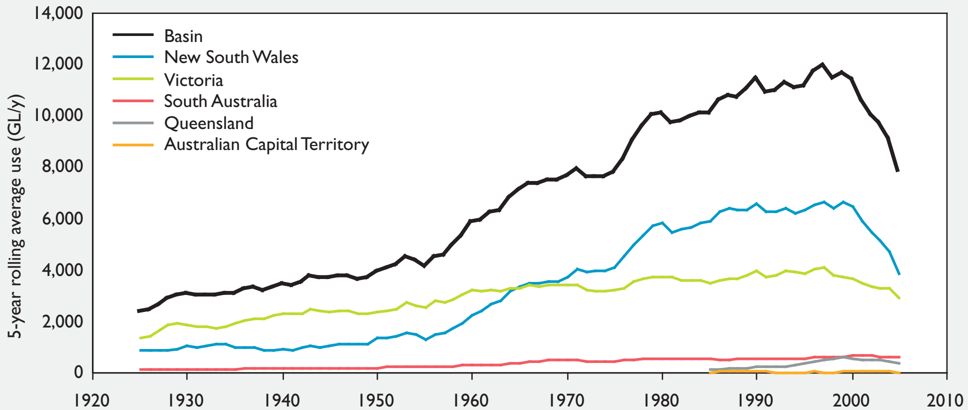


Source: Data from MDBC

Water use

Surface water use across the MDB grew with public storage capacity from the mid-1950s to the mid-1990s. In 1995 the Murray-Darling Basin Ministerial Council imposed a 'Cap' on surface water diversions. New South Wales and Victoria represent over 70 percent of total surface water use. The down-turn in diversions during the recent drought is very evident – especially for New South Wales. The recent drought is the first time that a limited supply has caused a major reduction in total use. Details of water use across the 18 regions under the historical and likely future climates are presented later in this report.

Growth in total and jurisdictional surface water use in the MDB (five-year moving averages)



Source: Data from MDBC

> Sprinkler irrigation, Moree, Gwydir region, NSW (DEWHA)

> Sunset over Tragowel Swamp near Echuca, Loddon-Avoca region, Vic (CSIRO)

> Bremer River catchment, Eastern Mount Lofty Ranges region, SA (DWLBC)

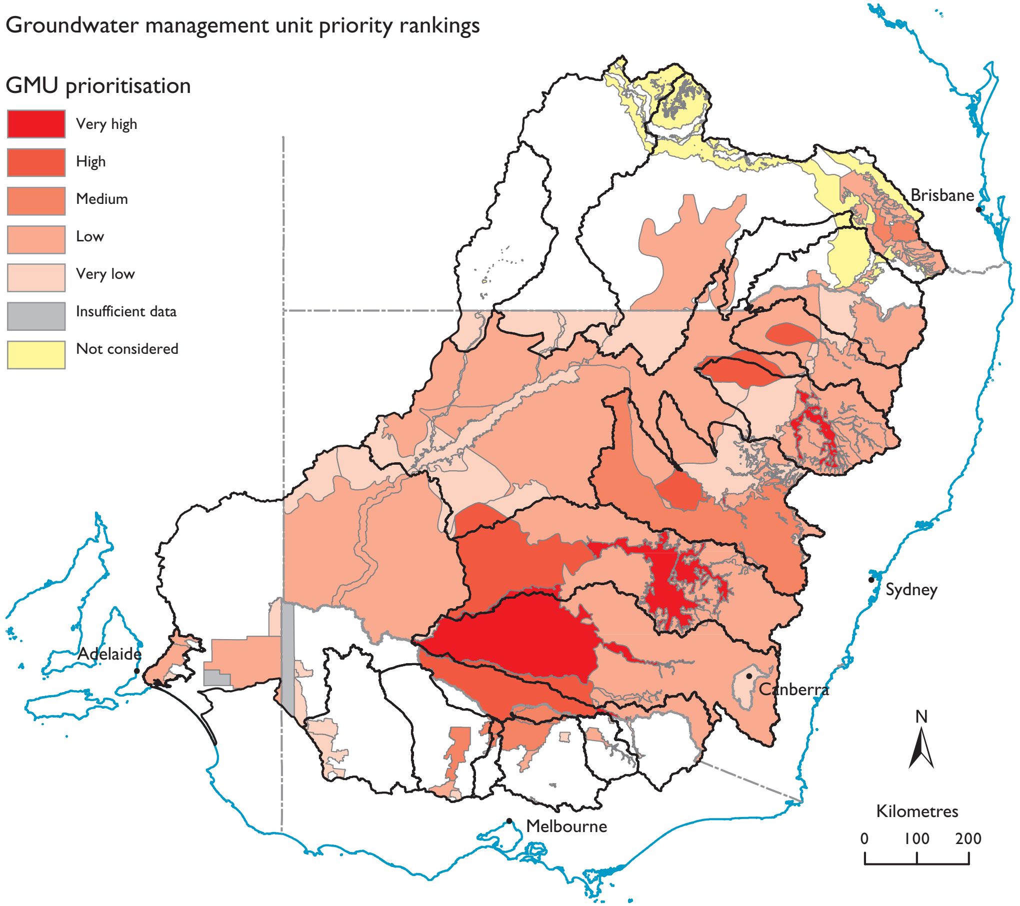
> Wimmera River, Horsham, Vic (Wimmera CMA)

Groundwater resources and use

The aquifers of the MDB include the sedimentary aquifers of the Murray Geological Basin and the Darling Drainage Basin, the porous sandstone of the Great Artesian Basin (GAB) and fractured hard rocks. The sedimentary aquifers are large porous systems extending across surface water region boundaries. They contain most of the groundwater resources of the MDB. Fractured rock aquifers occur within smaller flow systems although their total area is large. The GAB sandstones are extensive and supply large volumes of groundwater. However, they are not considered in this project as they are separated from surface aquifers by thick confining layers which prevent interaction with the overlying surface water or near-surface aquifers.

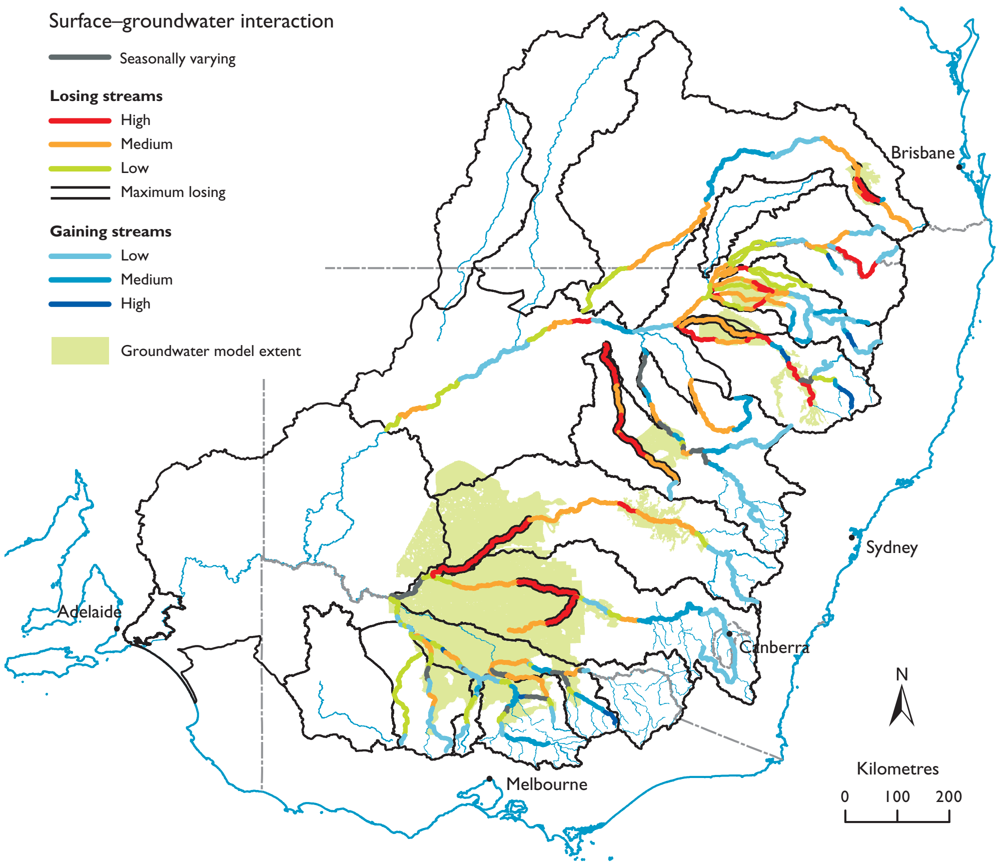
Groundwater in the MDB is managed according to 'groundwater management units' (GMUs) that are administrative areas declared under government legislation and are three-dimensional in nature and definition. There are 96 GMUs across the MDB. These were ranked in the project as very high, high, medium, low or very low priority in terms of the size of the resource, level of use and degree of connection with surface water systems. Twenty GMUs are ranked as medium, high or very high priority. These are in the mid-valley and riverine plains systems that are highly developed and connected to surface water, including the alluvial systems of the Campaspe, Lachlan, Loddon, Goulburn, Gwydir, Macquarie, Murray, Murrumbidgee and Namoi valleys.

Groundwater management unit priority rankings



The degree of connection between groundwater systems and surface drainage systems varies across the MDB. Connectivity is affected by bedrock 'chokes' under the alluvial plains that create gaining conditions (net movement to surface water) in the Condamine-Balonne, Namoi and Lachlan regions. Connectivity changes from gaining to losing at the points where rivers leave the narrow palaeo-valleys and enter broad alluvial valleys in the southern MDB. Groundwater extraction leads to falls in water tables that increase the losses from the stream. In areas of intensive extraction, a stage is reached where losses reach a maximum level, for example, downstream of Wagga Wagga on the Murrumbidgee River and downstream of Warwick on the Condamine River.

Surface–groundwater connectivity across the MDB showing gaining and losing river reaches

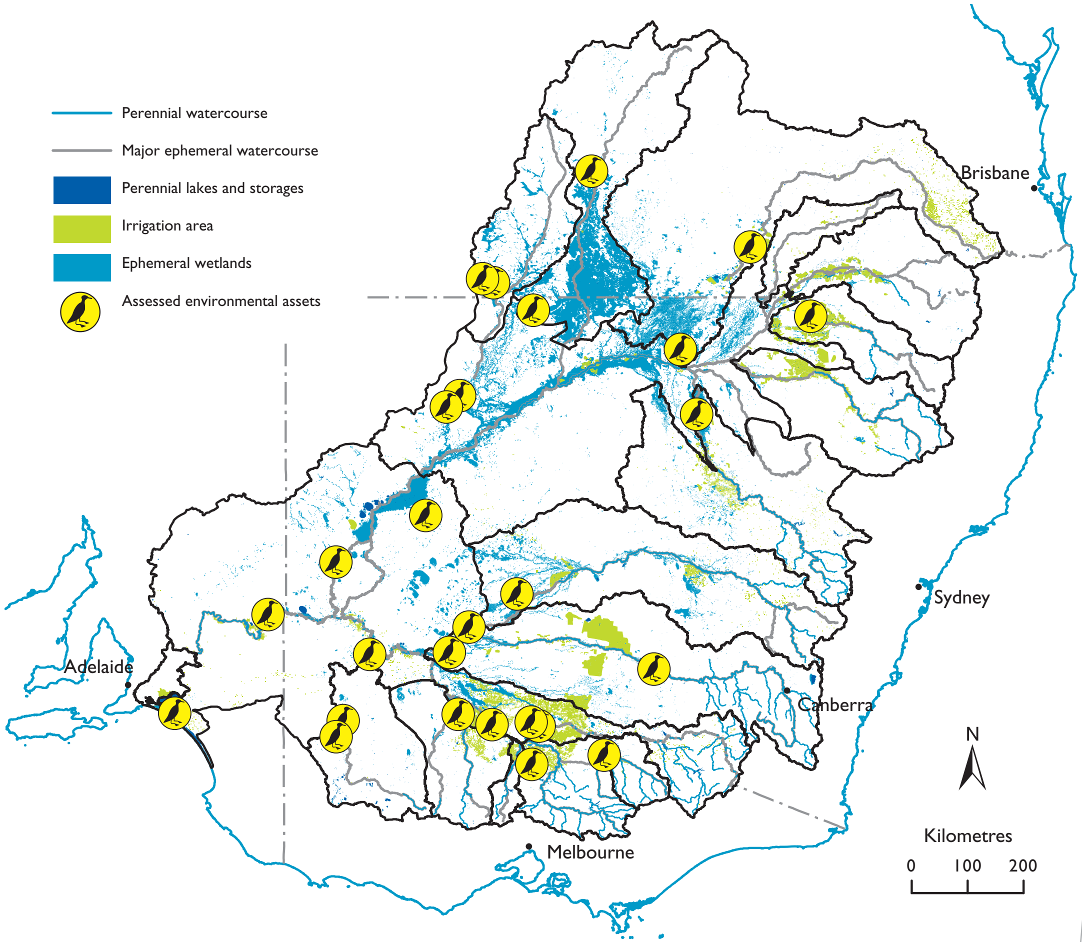


Development of MDB groundwater resources began in the 1960s with the advent of rotary drilling technology. However, very few GMUs have metered use records that go back to the 1970s so it is difficult to trace the increases in groundwater use in any detail. MDB groundwater extraction was 800 to 900 GL/year in the 1980s and early 1990s – about half the current rate. Drier conditions and the implementation of the Murray-Darling Basin Ministerial Council Cap on surface water diversions in the mid-1990s meant that extraction grew to between 1300 and 1500 GL/year. Detailed assessments of current and likely future groundwater use and the impacts of this use on groundwater levels and streamflow are provided later in this report. Groundwater levels and streamflow impacts have not reached equilibrium with current extraction, especially in the larger GMUs.

Floodplain wetlands

There are some 30,000 wetlands in the MDB – most are on private land. Sixteen MDB wetlands are listed as internationally important under the Ramsar Convention on Wetlands and around 220 are listed in the Directory of Important Wetlands in Australia. Large wetland systems occur along the Darling River and its tributaries, including the Paroo Overflow Lakes, Narran Lakes, the Gwydir Wetlands, Macquarie Marshes and the Great Cumbung Swamp. There are also major floodplain forests along the Murray River including Barmah-Millewa, Gunbower, Koondrook-Perricoota, Chowilla Floodplain and Lindsay-Wallpolla Islands. Many of the floodplain wetlands and forests have been degraded and some have suffered significant loss of area over recent decades due to changes in flooding and land use. The Lower Lakes, Coorong and Murray mouth are at the terminus of the Murray River in South Australia. These wetlands are listed as internationally important under the Ramsar Convention and are important for breeding and feeding of many species of waterbirds and native fish. The Lower Lakes are isolated from the Murray mouth and the Coorong by barrages constructed in the 1920s. The Coorong is a 140 km long wetland that runs parallel with the coast and covers 660 km^2. The hydrological impacts of water resource development and potential climate change on these major floodplain wetlands and forests, as well as the Lower Lakes and the Coorong, are considered in the project and summarised later in this report.

Distribution of perennial lakes, ephemeral wetlands and irrigation areas across the MDB. The location of the major floodplain wetlands assessed in this project are indicated



Climate and runoff

Key findings

- There is a clear east–west rainfall and runoff gradient across the MDB and most of the runoff is generated in upland catchments in the south-east, particularly the headwaters of the Murray, Murrumbidgee, Ovens and Goulburn rivers.
- Rainfall in the southern MDB over the ten-year period 1997 to 2006 was significantly lower than the long-term average but there were similar low-rainfall periods in the 1890s and around 1940. The low runoff in the southernmost parts of the MDB (up to 50 percent lower than the long term average) is unprecedented in the historical record.
- There is considerable uncertainty in rainfall change by 2030 and hence considerable uncertainty in the resultant runoff. Averaged over the entire MDB, average annual runoff could decrease by as much as 33 percent but could increase by as much as 16 percent. Under the median 2030 climate average annual rainfall would be reduced by about 2 percent in the northern MDB and by about 5 percent in the southern MDB. Average annual runoff would be reduced by 5 to 10 percent in the north-east and southern parts of the MDB and by about 15 percent in the southernmost areas of the MDB. Averaged across the entire MDB average annual runoff would reduce by 9 percent.
- The impact of projected growth in commercial forestry plantations and farm dams on runoff at the regional or MDB scale is small relative to the expected impacts of climate change. However, at the local (subcatchment) scale these developments are likely to have significant impact on runoff and hence streamflow.

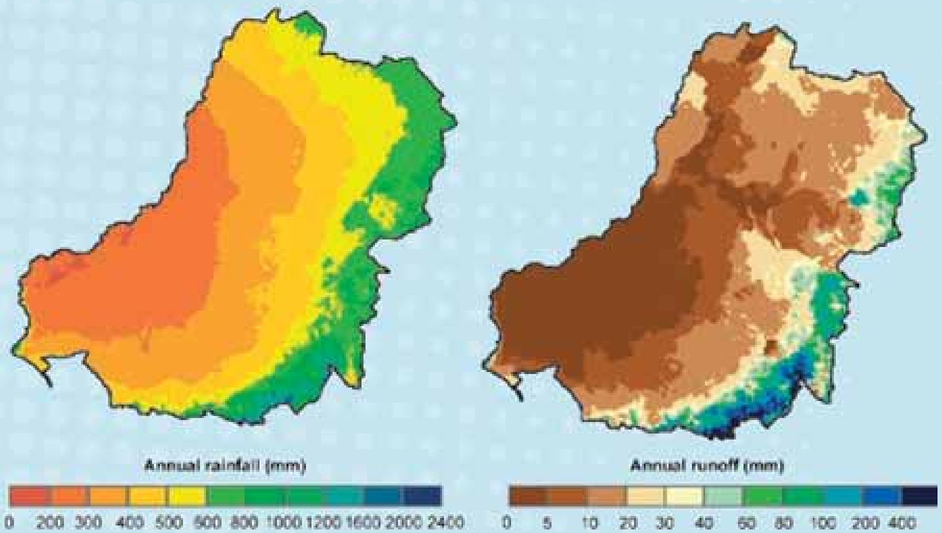
Average annual rainfall and runoff averaged across the MDB

	Rainfall (mm)	Rainfall (% change from Historical)	Runoff (mm)	Runoff (% change from Historical)
Historical (1985–2006) climate	457		27.3	
Recent (1997–2006) climate	440	-4%	21.7	-21%
Future (~2030) climate – median	444	-3%	24.7	-9%
Future (~2030) climate – dry extreme	396	-13%	18.3	-33%
Future (~2030) climate – wet extreme	495	+8%	31.7	+16%

Historical climate and runoff (1895 to 2006)

Average annual rainfall for 1895 to 2006 (averaged across the entire MDB) is 457 mm. There is a clear east–west rainfall gradient in the average rainfall, with rainfall highest in the south-east (more than 1500 mm) and along the eastern perimeter, and lowest in the west (less than 300 mm). Average annual areal potential evapotranspiration for 1895 to 2006 (averaged across the entire MDB) is 1440 mm (more than three times the average annual rainfall) – from 1700 mm in the north to 1000 mm in the south. Average annual runoff for 1895 to 2006 (averaged across the entire MDB) is 27.3 mm. The east–west runoff gradient is much more pronounced than the rainfall gradient. Runoff in the south-east (more than 200 mm) and eastern perimeter (20 to 80 mm) are far higher than elsewhere in the MDB. Rainfall and runoff in the northern MDB occur mainly in the summer half of the year. In the southernmost areas of MDB rainfall and runoff occur predominantly in the winter half of the year.

Average annual rainfall (left) and modelled average annual runoff (right) for 1895 to 2006



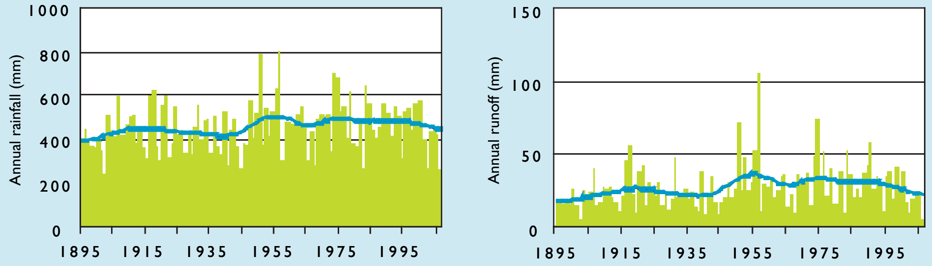
Recent climate and runoff (1997 to 2006)

Rainfall and runoff in the MDB show high inter-annual and inter-decadal variability as there are long periods that are considerably wetter or drier than others. The inter-annual variability of runoff in the MDB is almost twice that of large river basins elsewhere in the world. There is a marked increase in rainfall and runoff after the mid-1940s. Several dry periods are evident in the 1890s, around 1940, the mid-1960s, the early 1980s and the last five to ten years.

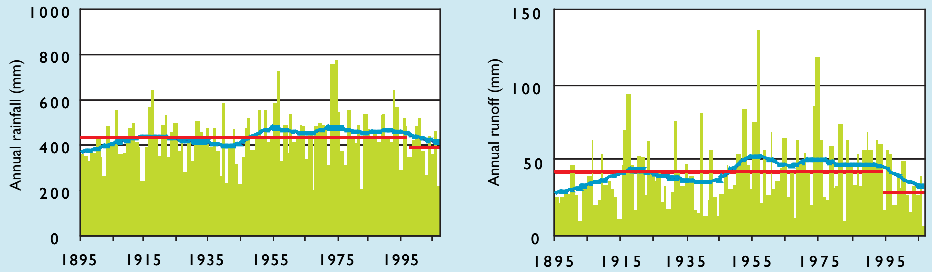
The average annual rainfall for 1997 to 2006 (averaged over the entire MDB) was 440 mm – 4 percent lower than the 1895 to 2006 average. The average annual runoff for 1997 to 2006 (averaged over the entire MDB) was 21.7 mm – about 21 percent lower than the 1895 to 2006 average.

Rainfall in the southern MDB for 1997 to 2006 was significantly lower than the long-term average – up to 15 percent lower in the southernmost parts. Runoff in the southern MDB for 1997 to 2006 was around 30 percent lower than the long-term average, and around 50 percent lower in the southernmost parts. There were similar dry periods in the 1890s and around 1940, and the average recurrence intervals for recent rainfall in the southern MDB vary from 20 to 100 years. The low runoff in the southernmost MDB is unprecedented in the historical record and has average recurrence intervals of more than 300 years.

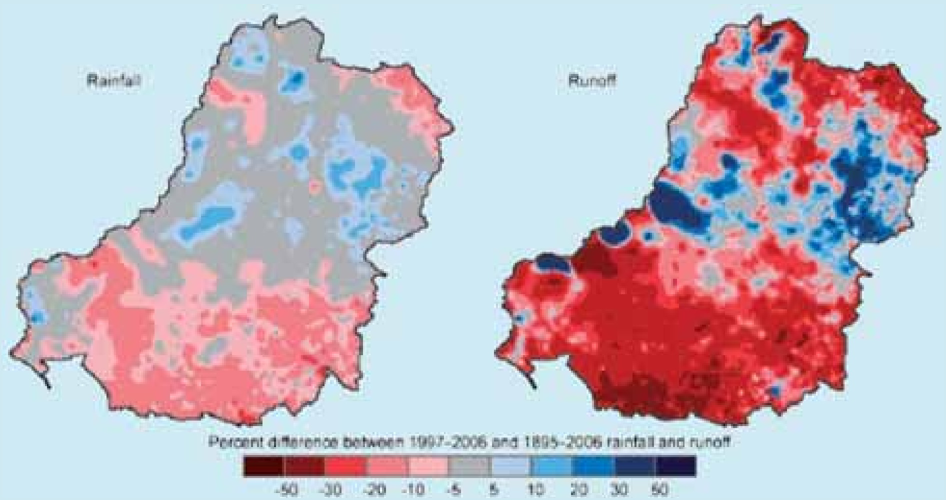
Annual rainfall (left) and modelled annual runoff (right) averaged over the MDB. Smoothed lines indicate longer term variability



Annual rainfall (left) and modelled annual runoff (right) averaged over the southern MDB (Murrumbidgee, Murray, Ovens, Goulburn-Broken, Campaspe, Loddon-Avoca, Wimmera and Eastern Mount Lofty Ranges regions). Smoothed lines indicate longer term variability. Red lines indicate the 1895–1996 and 1997–2006 average values



Percent difference between average annual rainfall and runoff in 1997–2006 and in 1895–2006

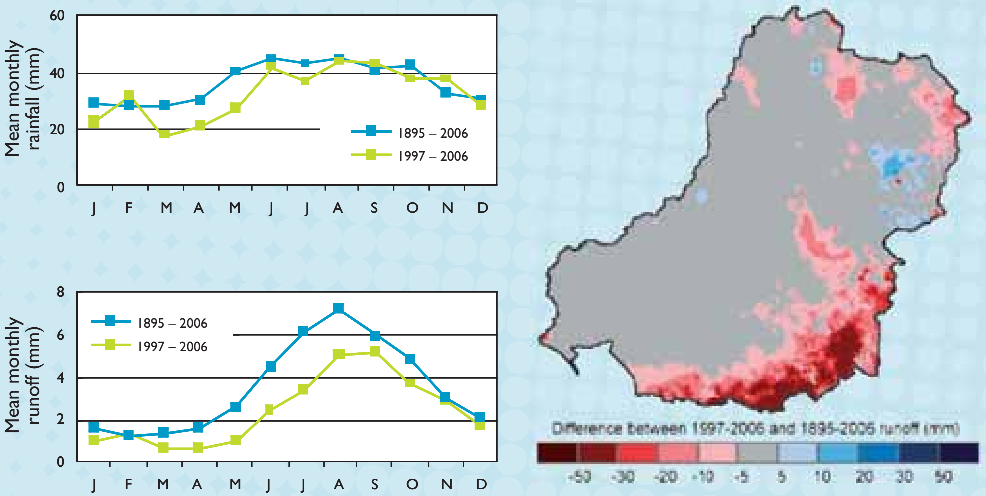


The main reason for the unprecedented low runoff in the southern MDB is the disproportionately large decline in autumn and early winter rainfall. Most of the runoff in the southern MDB occurs in winter and early spring. As a result of the low autumn rainfall, the soils are less saturated in winter, and this together with the lower winter rainfall results in low winter runoff. It is also likely that after a prolonged dry period, there is less connectivity between the subsurface storage and the river system, and significant amounts of rainfall and diffuse recharge are required to fill the storage before runoff can occur.

The recent low rainfall and runoff in the southern MDB cannot be entirely attributed to global warming because of the relatively short instrumental record and high natural inter-annual and inter-decadal variability in the hydroclimate system. However, related work by CSIRO and the Bureau of Meteorology[4(b)] indicates that this recent climate may be partly attributed to climate change and that such conditions are likely to become more common.

> Bondanza Dam, Moonie region, Qld (DEWHA)

Difference (in mm) between average annual runoff in 1997–2006 and 1895–2006 (right); and average monthly rainfall and runoff averaged over southern MDB in 1997–2006 and 1895–2006



> Border Rivers region, north-west of Inverell, NSW (CSIRO)

> Gwydir River, NSW (DWE)

> Natural reserve, Moonie region, Qld (DEWHA)

Future climate and runoff

The project used 45 climate scenarios for 2030 based on results from 15 global climate models (GCMs) and three global warming scenarios from the Intergovernmental Panel on Climate Change Fourth Assessment Report[4(a)]. This approach incorporates two sources of uncertainty. Firstly, the approach incorporates the uncertainty in global warming projections arising from a range of greenhouse gas emissions scenarios and the uncertainty in the sensitivity of the global climate system to greenhouse gas concentrations. Secondly, the approach incorporates the uncertainty amongst the current GCMs of the regional rainfall response to global warming. The GCM results indicate changes in rainfall by 2030 relative to average climate conditions around 1990.

In the northern MDB, current GCMs disagree on the direction of change in future rainfall, with slightly over half the GCMs indicating that rainfall will decrease in the future. In the southern MDB, and particularly in the southernmost parts, practically all the GCMs indicate that rainfall will decrease in the future. Most of the GCMs indicate that winter rainfall is likely to be lower across the entire MDB in the future. Most of the rainfall and runoff in the southern MDB occurs in the winter half of the year and hence decreases in winter rainfall in these areas translate to significant decreases in winter runoff and in total annual runoff.

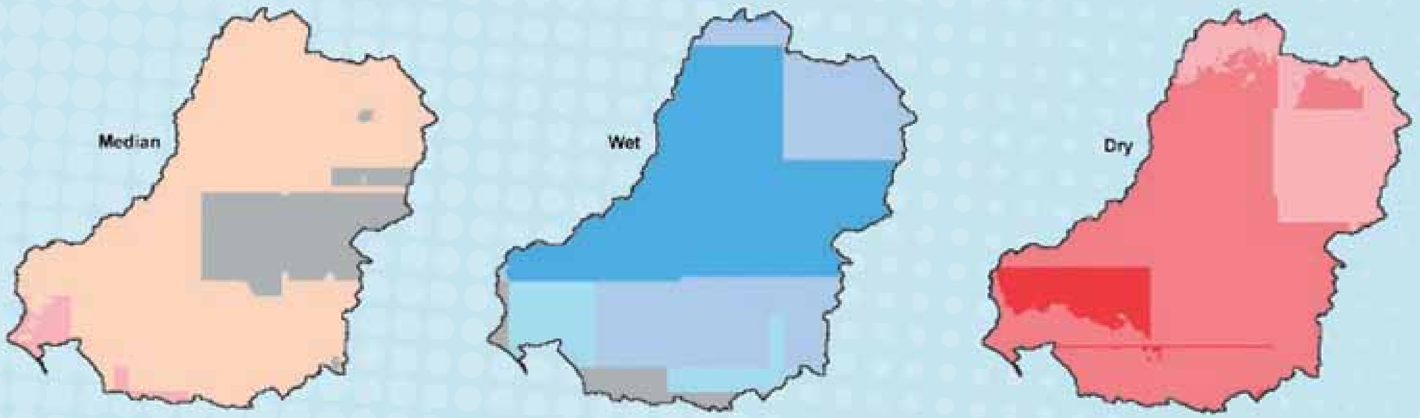
The median 2030 climate from the 45 scenarios indicates reductions in average annual rainfall of about 2 percent in the north of the MDB and about 5 percent in the south of the MDB. Averaged across the entire MDB the median 2030 climate indicates a 3 percent reduction in average annual rainfall. These changes in rainfall translate to reductions in average annual runoff of 5 to 10 percent in the north-east and southern MDB and 15 percent in the southernmost areas. Averaged across the entire MDB, there would be a 9 percent reduction in average annual runoff.

The possible range (from the second wettest to the second driest of the 45 climate scenarios) in average annual runoff outcomes for the northern half of the MDB is from a reduction of up to 30 percent to an increase of up to 30 percent. For the southern half of the MDB, the possible range in average annual runoff outcomes is from a reduction of up to 40 percent to an increase of up to 20 percent. In the southernmost areas of the MDB, the possible range in average annual runoff outcomes for the southernmost areas of the MDB is from a reduction of up to 50 percent to very little change in average annual runoff.
The possible range in average annual runoff outcomes averaged over the entire MDB is from a reduction of up to 33 percent to an increase of up to 16 percent.

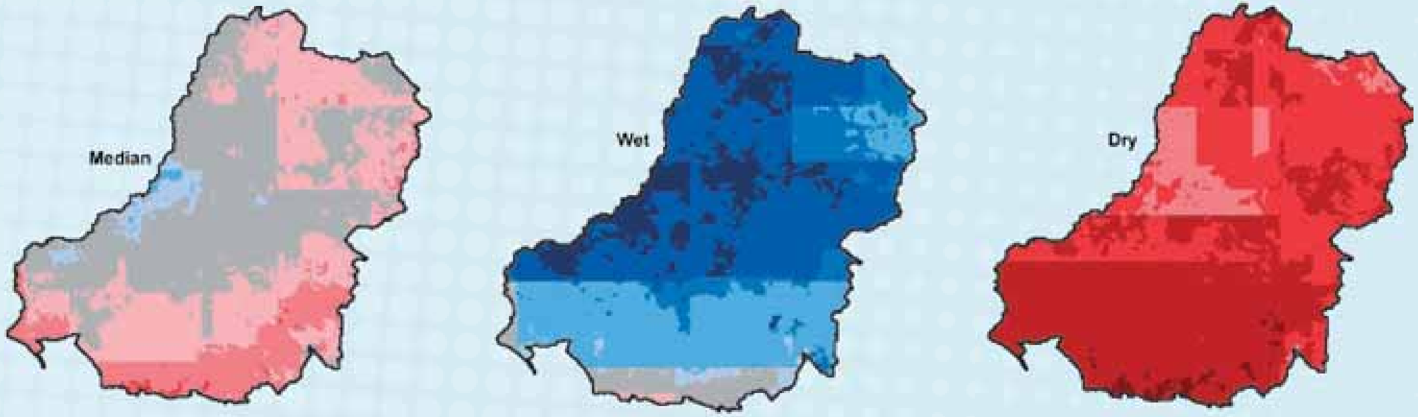
The adjacent maps show the full spatial pattern of the percent change in the median rainfall and runoff and the extremes of the possible range. The patterns on the rainfall and runoff change maps are largely due to ranking of the rainfall and runoff results from the 45 climate scenarios for every 5 km by 5 km grid cell. The patterns also reflect the large and differing grid cells of GCMs. The patterns on the runoff change maps differ from those on the rainfall change maps because of the non-linear nature of the transformation of rainfall into runoff.

The full spatial pattern of the absolute changes (in mm) in the median average annual runoff and the extreme of the possible range are also shown on the maps. These maps clearly indicate the runoff changes that will largely determine changes in streamflow will occur in the high runoff areas of the south and east of the MDB.

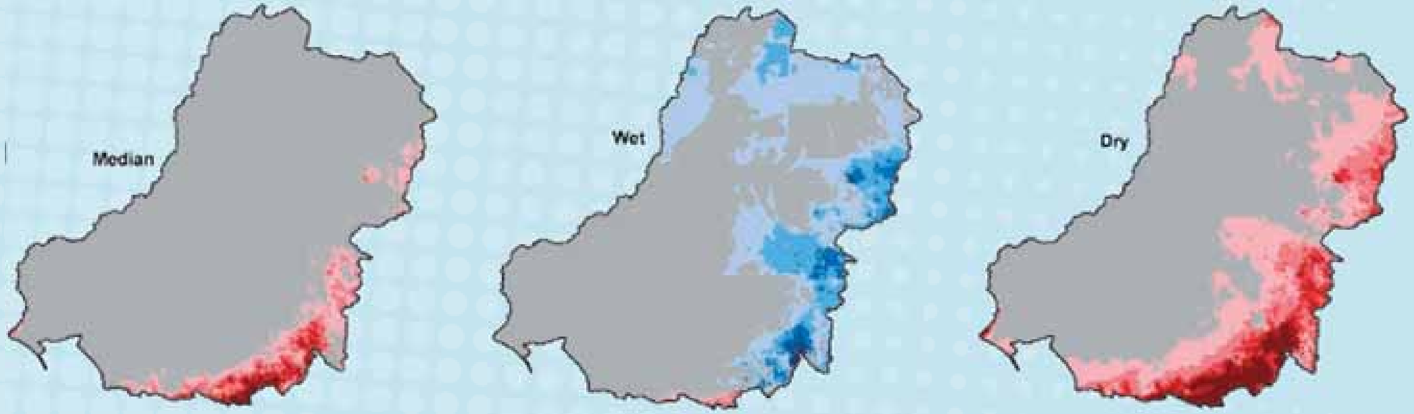
Percent change in average annual rainfall by 2030 across the MDB showing the median result and the wet and dry ends of the possible range



Percent change in average annual runoff by 2030 across the MDB showing the median result and the wet and dry ends of the possible range



Change (in mm) in average annual runoff by 2030 across the MDB showing the median result and the wet and dry ends of the possible range



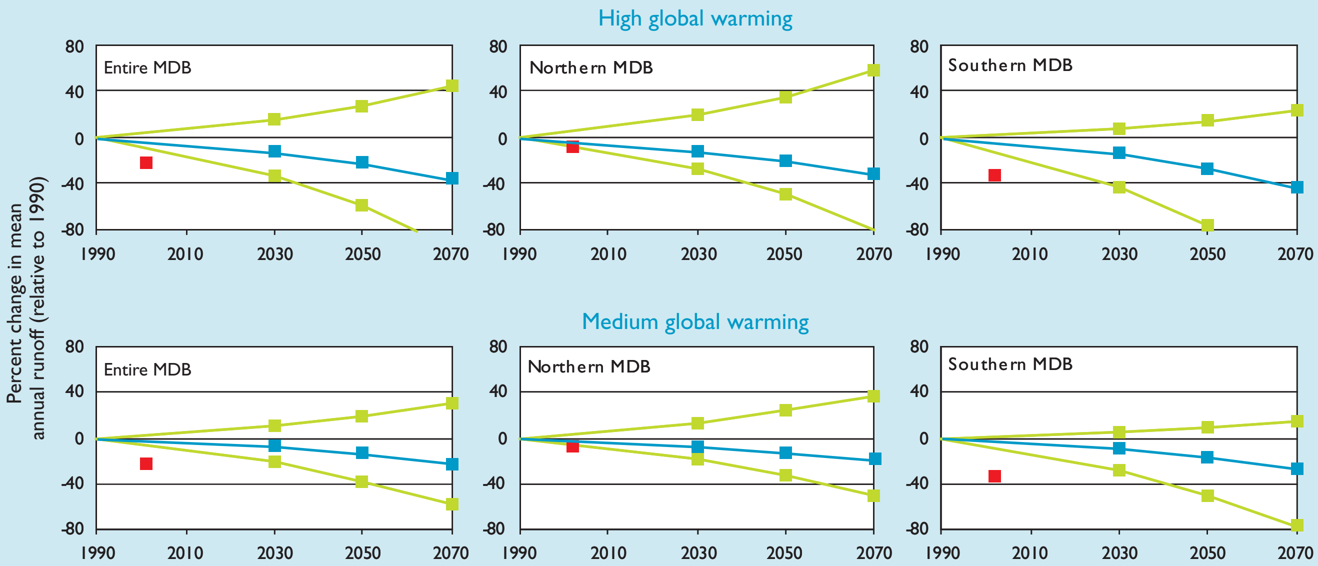
Climate projections beyond 2030

The project has not considered climate projections beyond 2030 and the runoff implications. However, the adjacent graphs provide a longer term context. The results for 2050 and 2070 are derived by extrapolation using the 'climate elasticities of runoff concept', global temperature projections for 2050 and 2070 (from www.climatechangeinaustralia.gov.au) and the runoff results for 2030. The assumptions involved in these simple extrapolations may well not hold for larger changes in rainfall and for longer term projections.

The plots highlight the large uncertainty in future runoff projections. The range of uncertainty is greater in the high global warming scenario than in the medium global warming scenario. Averaged over the entire MDB, the median estimate for the medium global warming scenario is a reduction in average annual runoff of 9 percent by 2030, 15 percent by 2050 and 23 percent by 2070.

In the future runoff in the southern MDB is likely to decrease with almost all the GCMs indicating lower rainfall and higher temperatures. The median estimates averaged over the southern MDB for the medium global warming scenario are 11 percent, 17 percent and 27 percent reductions in average annual runoff by 2030, 2050 and 2070 respectively (with higher reductions in the southernmost parts). The corresponding extreme dry estimate for the high global warming scenario for southern MDB is a 43 percent reduction in average annual runoff by 2030 and 77 percent by 2050. Runoff in the past ten years (1997 to 2006) in the southern MDB is similar to the extreme dry estimate for 2030 (from the high global warming scenario) and lower than the median estimate for 2070 (from the medium global warming scenario).

Runoff projections for 2030, 2050 and 2070 relative to 1990 for the entire MDB, the northern MDB and the southern MDB under the high and medium global warming scenarios. The blue lines show the trajectory of the median runoff change and the green lines indicate the breadth of the possible range of runoff changes. The red squares indicate the percentage change in runoff associated with the recent (1997–2006) climate



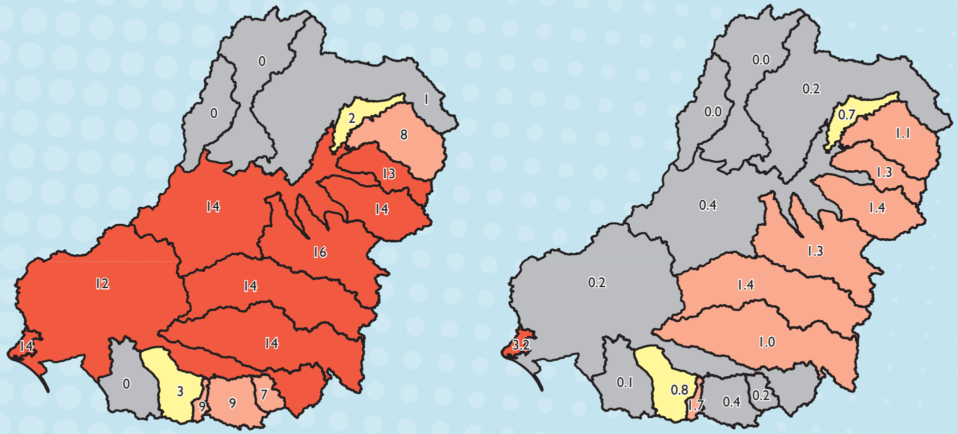
Development impact on future runoff

Existing commercial forestry plantations in the MDB cover about 290,000 ha or less than 0.3 percent of the area of the MDB. Bureau of Rural Sciences projections indicate that MDB commercial forest plantations could expand in area by 52,000 ha or 18 percent by 2030. Significant increases are only expected in three regions: the Eastern Mount Lofty Ranges (2000 ha), the Murrumbidgee (17,000 ha) and the Murray (33,000 ha) regions. Commercial forestry plantations significantly reduce runoff where they are located. However, for these projected forestry developments the impacts on runoff averaged over entire regions of the MDB is small. The reductions in average annual runoff due to the above forestry projections would be 0.8 percent for the Eastern Mount Lofty Ranges region and 0.3 percent for each of the Murrumbidgee and Murray regions.

The current capacity of small farm dams across the MDB is estimated to be 2000 GL. Projections based on historical farm dam expansion and current policy controls suggest that farm dam capacity across the MDB could increase by about 10 percent by 2030. The increase in farm dam capacity would be less concentrated than commercial forestry plantation development and new farm dams would reduce average annual runoff by about 0.7 percent across the MDB. The biggest reduction would be in the Eastern Mount Lofty Ranges region where average annual runoff reaching rivers is expected to fall by 3 percent. In Victoria, the projected farm dam development would reduce average annual runoff reaching rivers by 1.7, 0.8 and 0.4 percent in the Campaspe, Loddon-Avoca and Goulburn-Broken regions respectively, with negligible reductions in the remaining Victorian regions. In eastern New South Wales, the projected farm dam development would reduce average annual runoff reaching rivers by 1.0 to 1.5 percent. The small projected farm dam development in Queensland has negligible impact on future runoff reaching rivers.

Overall, the estimated impact of expected additional commercial forestry plantations and farm dam development by 2030 on the total volumes of runoff reaching rivers is expected to be small compared to the modelled impact of climate change on runoff. However, there is considerable uncertainty in the estimation of growth in commercial forestry plantations and farm dams. The projections of this project are based on historical trends and current policy controls and there is considerable uncertainty both as to how landholders will respond to the development policies and how governments may set policies in the future. The water use associated with these developments, although comparatively small, represents water use outside the current surface water entitlement regime which can be managed by regional-scale policy.

Projected percentage increase in small farm dam storage capacity by 2030 across the 18 regions of the MDB (left) and modelled impact of this on the average annual runoff reaching rivers (right)



> The Murray River and the Snowy Mountains (MDBC)

Surface water

Key findings

- The current average surface water resource of the MDB totalled across the 18 regions is 23,417 GL/year. Streamflow losses are naturally high across the MDB. In the absence of flow regulation and consumptive water use, only 14,493 GL/year (62 percent of the total surface water resource) would reach Wentworth on the Murray River and only 12,233 GL/year (52 percent of the total surface water resource) would reach the Murray mouth on average.
- Current surface water use totalled across the 18 regions of the MDB is 11,327 GL/year. This is 48 percent of the available surface water resource and is a very high relative level of use. Because of the high natural losses in the MDB this level of use has reduced outflows through the Murray mouth by 61 percent.
- Under the median 2030 climate, average total surface water availability for the MDB would fall by 12 percent or 2481 GL/year. Around 67 percent of this reduction would occur in the Goulburn-Broken, Ovens, Murray and Murrumbidgee regions (including the reductions in the contribution from the Snowy Mountains Hydro-electric Scheme). These four regions generate most of the runoff in the MDB and are also where the impact of climate change is expected to be greatest.
- There is considerable uncertainty in the hydrologic implications of climate change by 2030 for the MDB. Average surface water availability across the MDB could increase by as much as 11 percent or decrease by up to 34 percent by 2030. In spite of this wide range of possibilities, there is a clear and accelerating trend in the median hydrologic impact of climate change in the decades ahead. For example, surface water availability under the median climate for high global warming by 2070 would be broadly similar to the dry extreme climate at 2030. Surface water availability in the southern MDB under these conditions would be slightly lower on average than during the 1997 to 2006 period.
- The median 2030 climate would reduce total average surface water use across the MDB (under current water sharing arrangements) by 4 percent or 451 GL/year. Nearly two-thirds of this reduction would occur in the high water use regions of the Murray, Goulburn-Broken and Murrumbidgee. The relative level of surface water use totalled across the 18 regions would increase from 48 to 52 percent.
- The wet extreme 2030 climate would increase total average surface water use across the MDB by 3 percent. This increase would occur mainly in the northern MDB; water use in the southern MDB would be largely unaffected. The dry extreme 2030 climate would reduce total average surface water use by 21 percent or 2365 GL/year. Seventy percent of this reduction would occur in the high water use regions of the Murray, Goulburn-Broken and Murrumbidgee.
- In dry years, the relative impact of climate change on surface water use would be far greater, and the greatest impacts would be in the south of the MDB. Under the median 2030 climate, diversions in driest years would fall by more than 10 percent in most New South Wales regions (except the Namoi and Barwon-Darling), around 20 percent in the Murrumbidgee and Murray regions and from around 40 to over 50 percent in the Victorian regions. Under the dry extreme 2030 climate, diversions in driest years would fall by over 20 percent in the Condamine-Balonne, around 35 to 50 percent in New South Wales regions (except the Lachlan), over 70 percent in the Murray and 80 to 90 percent in the major Victorian regions.
- Reductions in water availability reduce the reliability of surface water supply. The greatest reductions in reliability would occur in regions where the relative level of surface water use is already high and where climate change is expected to have the largest impact on water availability, and for water products that are already comparatively less reliable. Some of the largest reductions in reliability would thus occur in the Murray, Goulburn-Broken, Campaspe, Loddon-Avoca and Wimmera regions, and under the dry extreme 2030 climate.
- Anticipated future development of farm dams and expansion of commercial plantation forestry, together with the maximum currently allowable levels of groundwater extraction by 2030, would increase surface water use across the MDB by 170 GL/year, 28 GL/year and 177 GL/year respectively. This total potential additional use of 375 GL/year would, if realised, largely offset the reduction in surface water use that would occur due to the median 2030 climate (a 451 GL/year reduction). The net effect of median climate change by 2030 combined with possible future development would thus be a small decrease in total surface water use across the MDB in spite of a considerable reduction in water availability. At the regional level, there is significant variation in the degree of offsetting between the increase in surface water use caused by development and the reduction in diversions caused by climate change.

Surface water availability

The total current surface water resource of the MDB can be considered in several ways:

- the sum of the surface runoff generated across the MDB land surface (28,900 GL/year)
- the sum of water availability across all 18 regions, including the internally generated portion of surface water availability for the Barwon-Darling and Murray regions (23,417 GL/year)
- the water availability for the MDB, assessed at Wentworth (14,493 GL/year)
- streamflow at the mouth of the Murray River (12,233 GL/year).

These different assessments of water availability include different proportions of the natural water losses in the MDB and are based on modelling without consumptive water use. The last three of the above assessment options also include the inter-basin transfer contributions to streamflow in the MDB from the Snowy Mountain Hydro-electric Scheme. The net 1010 GL/year transfer is equivalent to about 3 percent of the 28,900 GL/year of runoff generated across the MDB.

The 23,417 GL/year sum of water availability is suggested to be the most useful assessment of the total current surface water availability for the MDB as it:

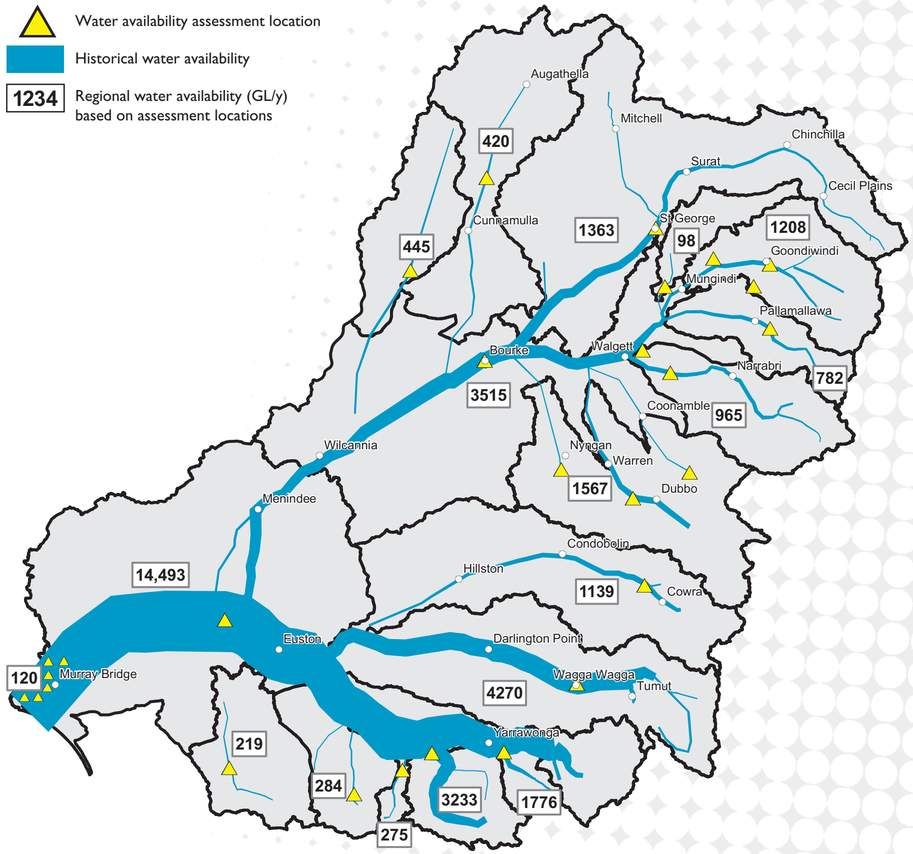
- is assessed at the points of maximum available flow in each of the regions – points where the surface water models are well calibrated
- includes some but not all of the natural losses which occur as water moves through the MDB, thus providing a reliable integrative measure of the total accessible surface water resource.

The pattern of water availability can also be portrayed in terms of mean annual flow under without-development conditions across the major rivers of the MDB (right) and clearly illustrates the dominance of the south eastern portion of the MDB in terms of water availability. Over 60 percent of the total surface water resource of the MDB is in the Murray, Murrumbidgee, Ovens and Goulburn-Broken regions.

The point of maximum available flow in a region is the point where the river changes from a net gaining to a net losing river under 'without-development' conditions. In several regions an adjustment is made to these average annual flow values to account for the reduction in streamflow due to groundwater extraction that is inherent in the streamflow observations to which the river models are calibrated. For the Barwon-Darling and Murray regions, surface water availability is determined based on current development inflows from upstream regions and without-development inflows and development within the region. For the entire MDB surface water availability is the sum of the individual region values – but considering only the internally-generated streamflow for the Barwon-Darling and Murray regions.

A tabulation of surface water availability and use data for each region under different scenarios is provided in Appendix A.

Current average surface water availability across the MDB



> Pump station on the Condamine River, Qld (MDBC)

> Gogeldrie Weir on the Murrumbidgee River east of Darlington Point, NSW (CSIRO)

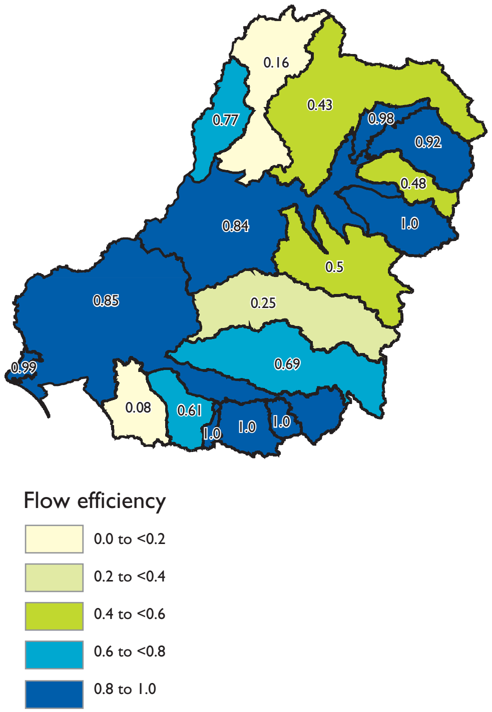
Water availability can also be considered in the context of a simple surface water balance for the entire MDB: inflows, use, losses and outflows. The water balance shows that the MDB is naturally an inefficient system in terms of water delivery – that is, losses are naturally high, with 61 percent of the inflows never reaching the Murray River mouth under the historical climate and without-development conditions. Importantly, the natural water 'losses' include recharge to groundwater – an important and connected resource – and large volumes of water use by floodplain and wetland ecosystems. Thus the losses have both an important environmental function and an important function in recharging groundwater and thus supporting groundwater use.

Average annual surface water balance for the MDB

	Without-development, historical climate	Current development, historical climate	Current development, median 2030 climate	Future development, median 2030 climate
	GL/y			
Inflows				
Inflows	28,630	28,711	25,846	25,602
Transfers into basin	1,010	1,068	1,041	1,041
Irrigation and urban returns	0	163	155	154
Sub-total	**29,640**	**29,942**	**27,041**	**26,797**
Surface water use				
Surface water diversions	0	10,075	9,673	9,575
Channel and pipe loss	0	1,233	1,183	1,181
Net streamflow loss induced by groundwater use	0	181	229	352
Evaporation from reservoirs and lakes	4,448	3,851	3,473	3,428
Losses	12,959	9,868	8,908	8,779
Sub-total	**17,407**	**25,209**	**23,467**	**23,315**
Outflows				
Outflows	12,233	4,733	3,575	3,482
Efficiency				
Efficiency (outflow/net inflow)	41%	16%	13%	13%

The natural water delivery efficiency varies between the regions of the MDB. The delivery efficiency for a region is the fraction of the assessed available surface water that under without-development conditions would flow out to downstream regions or the sea.

Average water delivery efficiency by regions for without-development conditions under the historical climate. Numbers indicate the fraction of surface water available in the region which reaches the end of system gauge



Delivery efficiencies can also be considered between different locations across the MDB. For example, on average, 1 ML of water in the Condamine-Balonne region (at the point of maximum flow) represents only 0.18 ML of water at the Murray River mouth. These efficiencies apply to average annual flow volumes and are based on flows for without-development conditions and the historical climate. Efficiencies are given firstly to the end-of system for a region – indicating how well the river is linked into the downstream network. Efficiencies to end-of-system locations range from a low of 0.08 for the Wimmera region (just 8 percent of the generated flow naturally leaves the region) to values of 100 percent for the Ovens, Goulburn-Broken, Campaspe and Namoi regions. The values of 0.77, 0.25 and 0.08 for the respective Paroo, Lachlan and Wimmera regions reflect the location of the end-of-system gauge in the river models. The Paroo, Lachlan and Wimmera rivers actually terminate in floodplain wetlands and only in very large floods contribute any flow to the Darling River in the case of the Paroo River, the Murrumbidgee River in the case of the Lachlan River and the Murray River in the case of the Wimmera. The table indicates that the Paroo region does not contribute to flow at Menindee. Similarly, the northern rivers of the Eastern Mount Lofty Ranges region lose a considerable fraction of their flow downstream of the end-of-system gauge locations before entering the Murray River or Lake Alexandrina.

The efficiencies will differ between wet and dry years, and how efficiency varies between years will differ between regions according to the nature of the 'connectedness' of the river network. The largest losses in the systems are associated with flooding and evapotranspiration from floodplain forests, lakes and wetlands. Hence during very wet years, while delivery is high, the efficiency of delivery is lower than average. During very dry years, losses are also high in a relative sense – as direct evaporation and seepage can represent a considerable fraction of the flow – and so efficiency is lower than average. The highest efficiencies occur when rivers are running full but are not flooding.

Average surface water delivery efficiencies between key locations across the MDB for without-development conditions under the historical climate

	Maximum flow (GL/y)	End-of-system*	Bourke	Menindee (upstream of lakes)	Burtundy	Yarrawonga	Wentworth	Murray mouth
Paroo	445	0.77	-	-	-	-	-	-
Warrego	423	0.16	-	0.07	0.04	-	0.04	0.03
Condamine-Balonne	1,298	0.43	0.41	0.33	0.21	-	0.21	0.18
Moonie	98	0.98	0.84	0.74	0.40	-	0.40	0.34
Border Rivers	905	0.92	0.77	0.62	0.38	-	0.38	0.32
Gwydir	782	0.48	0.41	0.33	0.20	-	0.20	0.17
Namoi	888	1.00	0.92	0.76	0.43	-	0.43	0.36
Macquarie-Castlereagh								
Macquarie	1,460	0.48	0.43	0.35	0.21	-	0.21	0.17
Castlereagh	107	0.68	0.61	0.50	0.29	-	0.29	0.25
Barwon-Darling								
Bourke	3,484	0.84	1.00	0.84	0.54	-	0.54	0.46
Menindee	2,944	1.00		1.00	0.64	-	0.64	0.54
Lachlan	1,139	0.25	-	-	-	-	-	-
Murrumbidgee	3,842	0.69	-	-	-	-	0.68	0.61
Ovens	1,776	1.00	-	-	-	0.99	0.81	0.70
Goulburn-Broken	3,233	1.00	-	-	-	-	0.86	0.75
Campaspe	275	1.00	-	-	-	-	0.86	0.75
Loddon-Avoca								
Loddon	201	0.61	-	-	-	-	0.52	0.45
Avoca	84	0.30	-	-	-	-	-	-
Wimmera	219	0.08	-	-	-	-	-	-
Eastern Mount Lofty Ranges	122	0.99	-	-	-	-	-	-
Murray	14,493	0.84	-	-	-	-	1.00	0.84

* as represented in river model

Surface water use

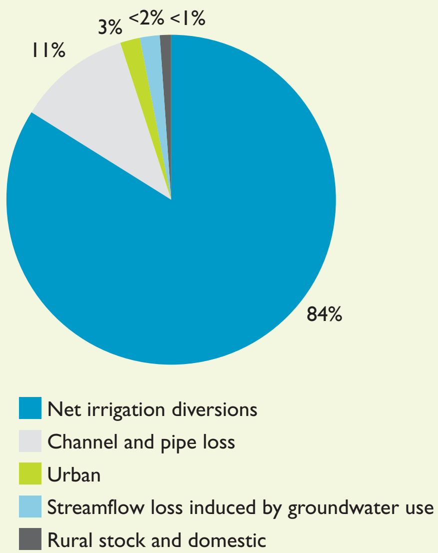
Average annual surface water use includes diversions for irrigation, rural stock and domestic use and urban town supply, the pipe and channel losses associated with this supply, and the eventual streamflow impacts of groundwater extraction. The water use associated with additional (future) farm dams and additional (future) commercial plantation forestry is also included in the assessment of surface water use. The water use associated with existing farm dams and commercial plantation forests has not been assessed, except in the Eastern Mount Lofty Ranges region where farm dam use is explicitly modelled.

Under current water sharing arrangements, current water entitlements and the current irrigated agriculture portfolio, the average consumptive surface water use across the MDB is 11,327 GL/year. Over two-thirds (68 percent) of this use occurs in the Murray, Murrumbidgee and Goulburn-Broken regions. The eventual (yet to be fully realised) groundwater use impacts of current development on subcatchment inflow and streamflow leakage will represent 2 percent of the total surface water use.

Current average surface water use for the MDB

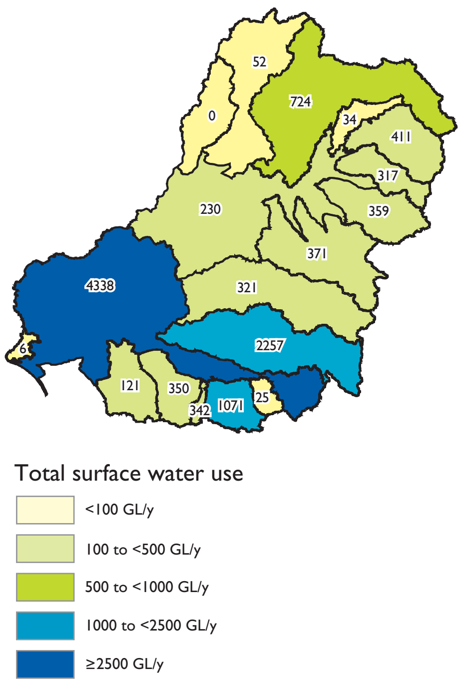
	GL/y	Percent
Net irrigation diversions	9,511	84%
Rural stock and domestic	80	<1%
Urban	318	3%
Channel and pipe loss	1,238	11%
Sub-total	**11,146**	**98%**
Streamflow loss induced by groundwater use	181	<2%
Total	**11,327**	**100%**

Current average surface water use for the MDB



The pattern of surface water use across the MDB illustrates the large volumes used in the southern MDB, particularly in the Murray (4338 GL/year), Murrumbidgee (2257 GL/year) and Goulburn-Broken (1071 GL/year) regions.

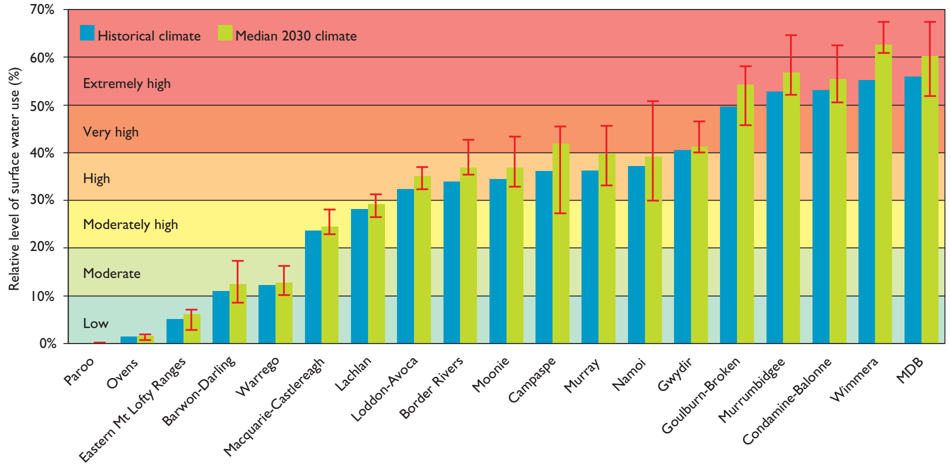
Total surface water use across MDB regions for current development and historical climate (GL/year)



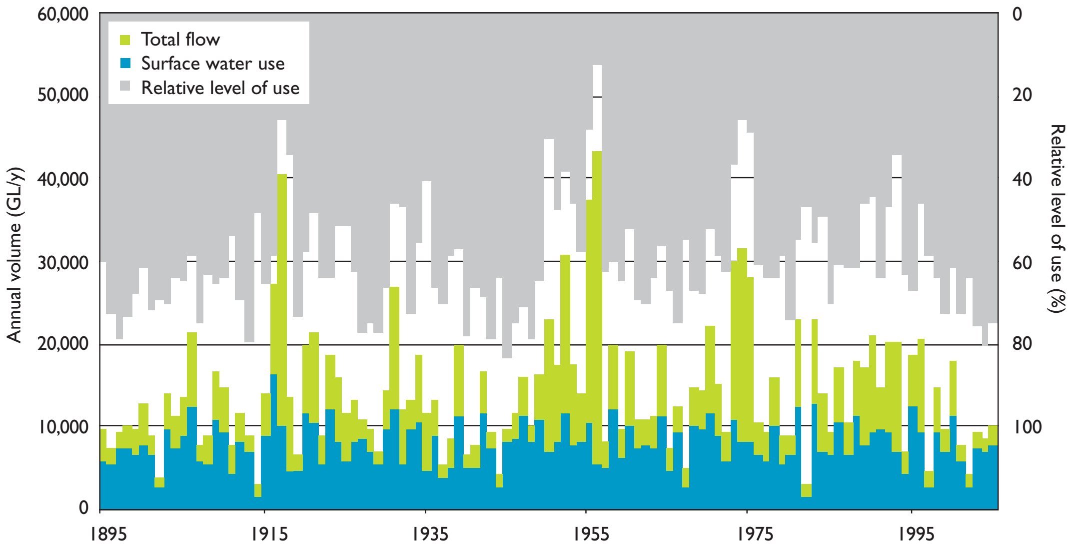
The relative level of surface water use for a region (or the MDB) is the ratio of surface water use to water availability – usually expressed as a percentage. For the MDB, current average surface water use summed across the 18 regions is 11,327 GL/year, which relative to the 23,417 GL/year surface water resource, gives a relative level of surface water use of 48 percent. Across the 18 regions, the relative level of surface use varies from close to zero (Paroo and Ovens) to 50 percent and over (Goulburn-Broken, Murrumbidgee, Condamine-Balonne, Wimmera). Integrated down the MDB system to Wentworth on the lower Murray River, the relative level of surface water use (including downstream use) is 56 percent of the available water assessed at this location. In this project, qualitative categories of the relative level of surface water use have been used to facilitate comparison between regions; these categories are shown on the graph (top right opposite).

The relative level of surface water use also varies considerably from year to year. The level of use is lowest in wet years, when although water use is typically high, water availability is very high and so the relative level of use is comparatively low. Conversely, in dry years when availability is low, a greater fraction of the available water is diverted for use. For example, average relative level of use over the last eight years in this historical record is greater than 70 percent. Because of the skewed nature of the annual flow distribution, the relative level of use is 64 percent or greater in half of the years, even though the overall average relative level of use integrated down through the connected river system to Wentworth is 56 percent.

Relative level of use for each of the 18 regions individually, and for the entire MDB integrated to Wentworth, under the historical and 2030 (median with uncertainty range) climate



Time series at Wentworth (integrating the MDB) of total effective surface water use (including downstream use), total without-development flow and relative level of surface water use under the historical climate



> Wimmera River, Horsham, Vic (Wimmera CMA)

> Serpentine Weir on the Loddon River, Vic (North Central CMA)

> Irrigator at Cowl Cowl Station near Hillston, Lachlan region, NSW (CSIRO)

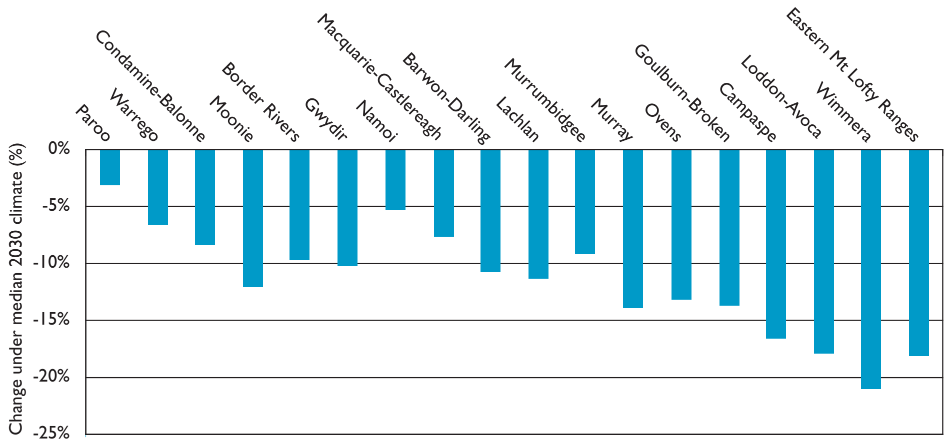
> Bridge over Barwon River near Brewarrina, NSW (MDBC)

Impacts of climate change on surface water availability

The impact of the median 2030 climate on average surface water availability across the MDB would be 11 percent reduction, or 2481 GL/year less surface water on average. Integrating down through the connected river system of the MDB, and thus incorporating the natural water losses, the reduction at Wentworth on the Murray River would be 1682 GL/year less surface water on average (or a 12 percent reduction).

This proportional reduction in water availability due to climate change varies considerably between regions from a 3 percent reduction in the Paroo to a 21 percent reduction in the Wimmera. Much of the reduction in surface water availability would occur in the south-east of the MDB, where firstly, most of the runoff in the MDB is generated, and secondly, the impact of climate change is likely to be greatest. Thus, 67 percent of the water availability reduction across the 18 regions is a result of the reductions in the Goulburn-Broken, Ovens, Murray and Murrumbidgee regions (including the reductions in the contribution from the Snowy Mountains Hydro-electric Scheme).

Percentage changes in average surface water availability by region under the median 2030 climate



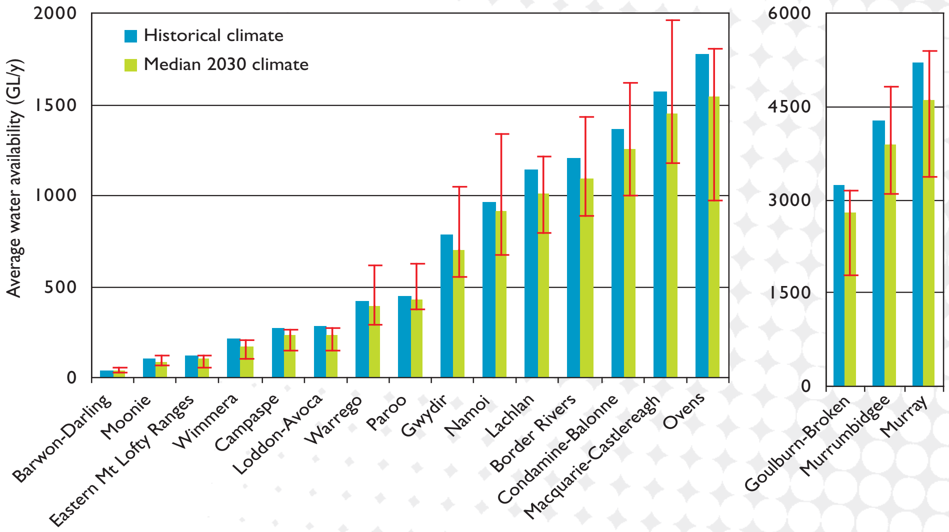
There is a large uncertainty associated with climate change impacts by 2030. Summed across regions the change in surface water availability ranges from an 11 percent increase (2631 GL/year) under the wet extreme 2030 climate to a 34 percent reduction (7893 GL/year) under the dry extreme 2030 climate. In terms of the streamflow changes integrated down through the connected river system of the MDB to Wentworth, the climate change impacts range from a 7 percent increase under the wet extreme 2030 climate to a 37 percent reduction under the dry extreme 2030 climate with a median reduction of 12 percent.

Effect of climate change by 2030 on water availability (GL/year) for each region and the MDB

	Historical climate	2030 climate		
		Wet extreme	Median	Dry extreme
	GL/y			
Paroo	445	626	432	372
Warrego	420	619	393	292
Condamine-Balonne	1,363	1,616	1,249	1,004
Moonie	98	122	87	70
Border Rivers	1,208	1,427	1,092	891
Gwydir	782	1,049	703	554
Namoi	965	1,336	915	677
Macquarie-Castlereagh	1,567	1,967	1,450	1,180
Barwon-Darling*	41	61	40	32
Lachlan	1,139	1,212	1,012	792
Murrumbidgee	4,270	4,816	3,881	3,087
Murray*	5,211	5,391	4,614	3,358
Ovens	1,776	1,802	1,542	974
Goulburn-Broken	3,233	3,146	2,792	1,788
Campaspe	275	263	230	148
Loddon-Avoca	285	270	234	146
Wimmera	219	207	173	102
Eastern Mount Lofty Ranges	120	117	99	58
Total	**23,417**	**26,047**	**20,936**	**15,524**
MDB integrated to Wentworth	14,493	15,450	12,811	9,155

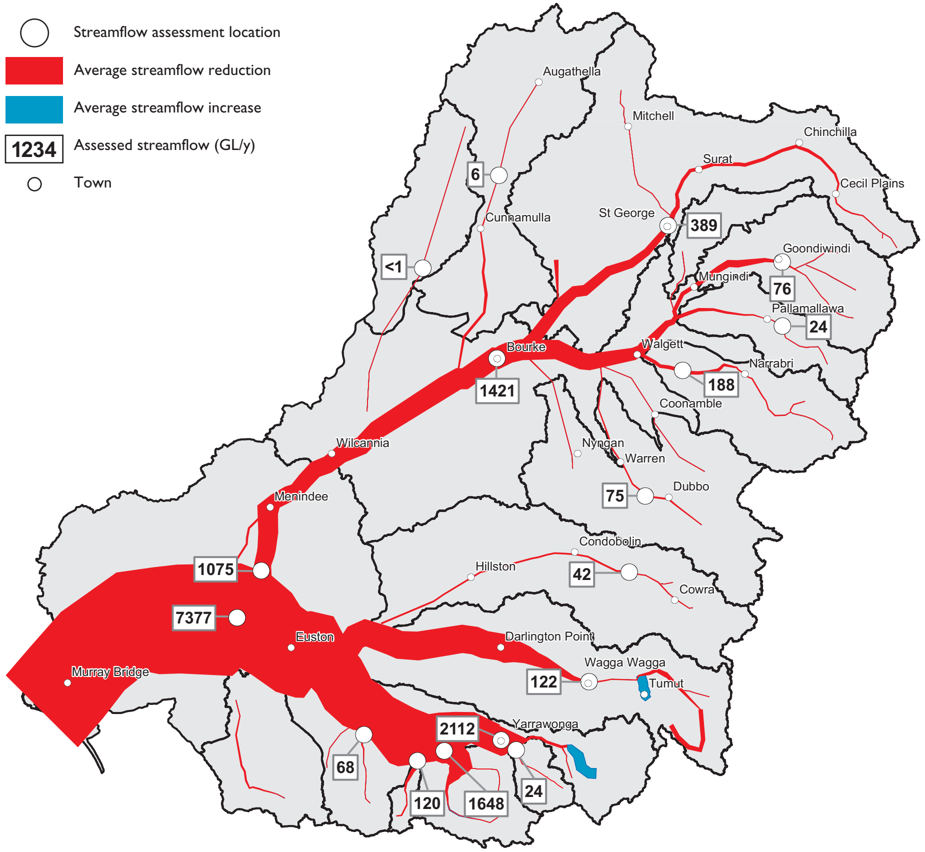
*For the Barwon-Darling and Murray regions only the fraction of the water availability generated within the region is shown

Average surface water availability (GL/year) for each region in the MDB under the historical and median 2030 climates; the uncertainty range for future climate is indicated. For the Barwon-Darling and Murray regions only the fraction of the water availability generated within the region is included

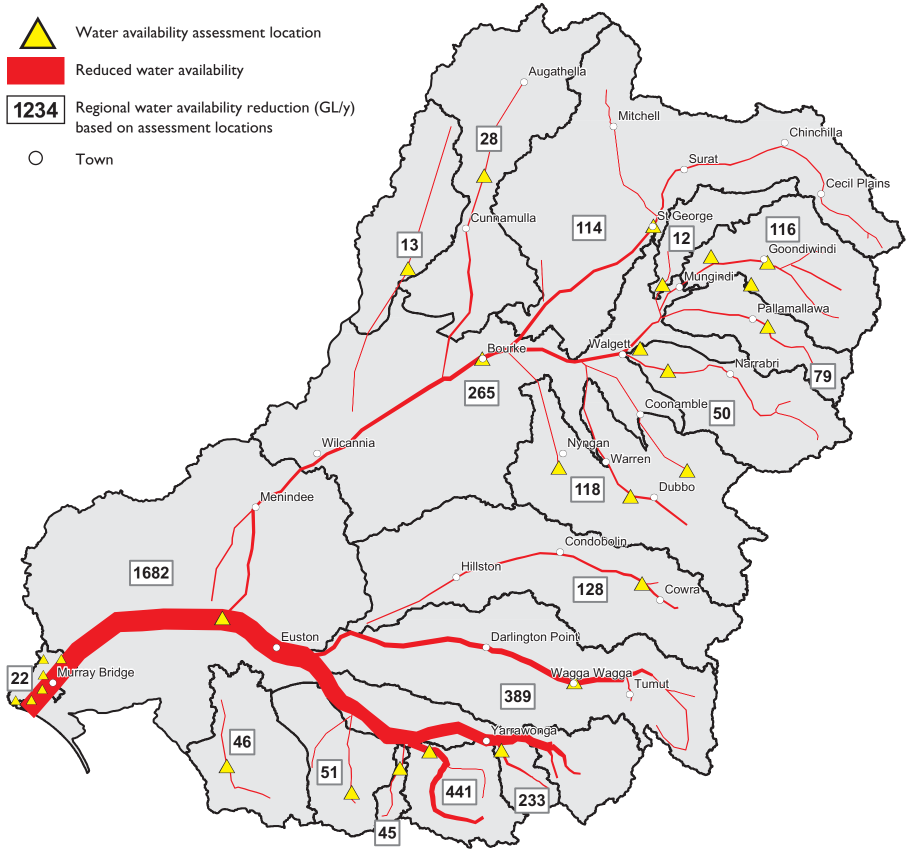


Although the impact of climate change by 2030 on streamflow could be very considerable, the impact will be less than the impact that current development has already had on streamflow, even under the dry extreme 2030 climate. Importantly, surface water availability and surface water use are both highest in the south-eastern regions of the MDB; it is here also that the impacts of climate change on water availability are anticipated to be greatest.

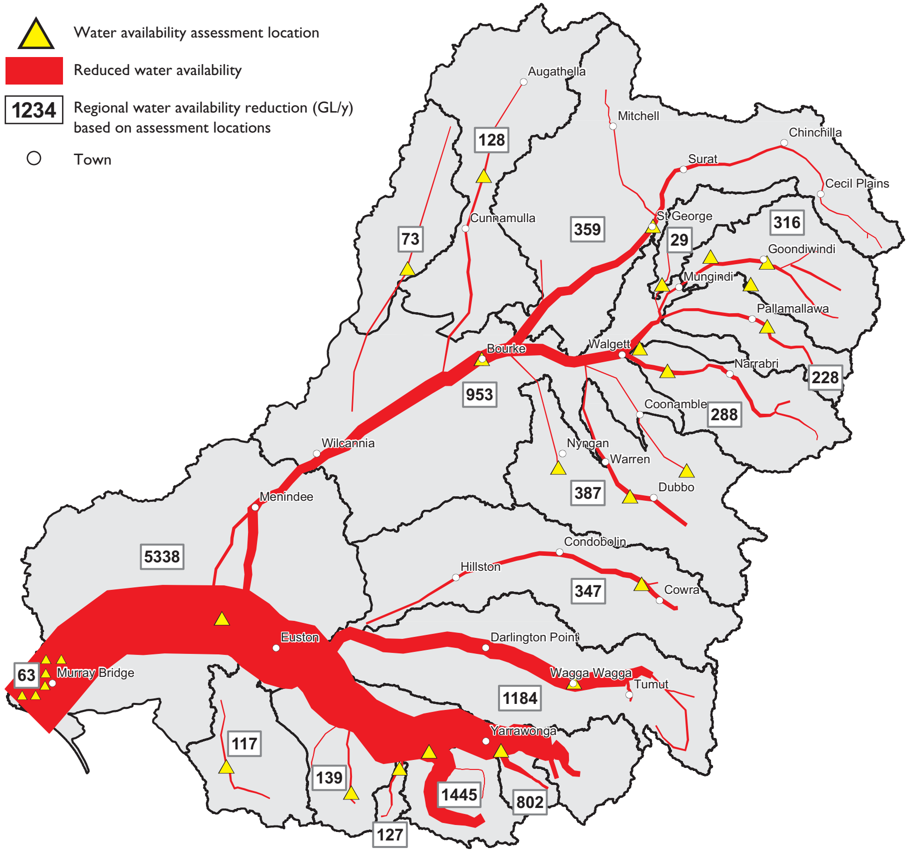
Changes in average annual streamflow as a result of water resource development



Reductions in average annual water availability (without-development flows) that would occur under the median 2030 climate



Reductions in average annual water availability (without-development flows) that would occur under the dry extreme 2030 climate

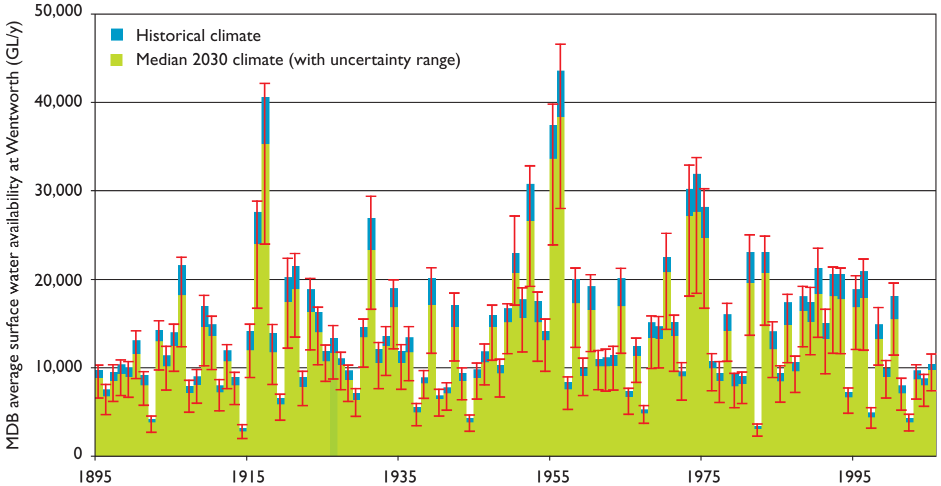


> King Charlie's Waterhole, Paroo River, NSW (WISE, NSW DECC)

> Gwydir River at Copeton Dam, NSW (DWE)

There will of course continue to be considerable year to year variation in water availability as indicated on the time series graph below. The time series graph shows however, that in every year – wet and dry years alike – the proportional change in surface water availability is reasonably similar.

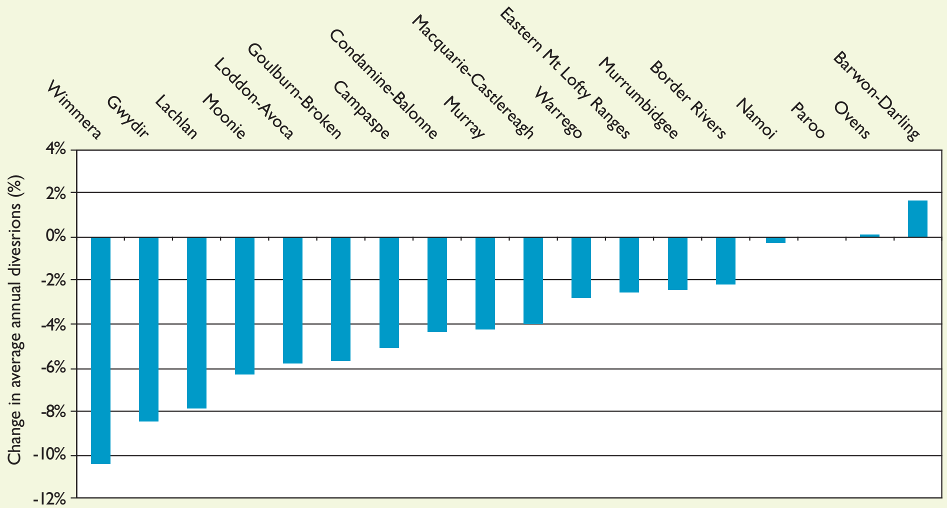
Annual surface water availability for the MDB integrated to Wentworth under historical and 2030 (median with uncertainty range) climates



Impacts of climate change on surface water use

Under current water sharing arrangements, the impact of climate change on surface water use would be much less than the impact on surface water availability. Under the median 2030 climate, and summed across the 18 regions of the MDB, surface water diversions would be expected to fall by 4 percent. Thus the relative impact on consumptive water users would be around one-third of the relative impact on surface water availability. The impact on surface diversions varies considerably across the 18 regions from small increases or no reduction in diversions in three regions (including the regions where diversions are very low) up to a more than 10 percent reduction in diversions in the Wimmera. Volumetrically, the reduction in surface water diversions would be a little over 450 GL/year on average under the median 2030 climate. Nearly two-thirds (65 percent) of this reduction would occur in the high water use regions of the Murray, Goulburn-Broken and Murrumbidgee. The smaller reduction in surface water diversions compared to the reduction in surface water availability means that under current water sharing arrangements the relative level of surface water use would increase from 48 percent to 52 percent under the median 2030 climate.

Percentage change in average annual surface water diversions under the median 2030 climate



The current suite of global climate models indicates a wide range of possible outcomes for the MDB by 2030. Under the wet extreme 2030 climate, surface water diversions would increase by 3 percent and the relative level of surface water use would fall to 45 percent. Under the dry extreme 2030 climate, surface water diversions would decrease by 21 percent and the relative level of surface water use would increase to 58 percent. Volumetrically, the changes in surface water diversions would again occur largely in high water use regions of the Murray, Goulburn-Broken and Murrumbidgee. Nonetheless, the smaller volumetric impacts in other regions would clearly be very significant at the regional scale.

While there is a wide range of possible outcomes, for the southern MDB there is greater agreement amongst global climate models in the direction of change, with nearly all models predicting a reduction in water availability. Looking further into the future, the uncertainty in the impact of climate change on water availability increases in a non-linear manner as shown in the Climate and Runoff section. Importantly however, the trend in the median is very clearly for an increasing reduction in water availability. For all parts of the MDB, the median 2070 climate is, in runoff terms (and hence water availability), equivalent to the dry extreme 2030 climate.

Total surface water use (GL/year) by region under different climates

		2030 climate		
	Historical climate	Wet extreme	Median	Dry extreme
Paroo	0	0	0	0
Warrego	52	58	50	45
Condamine-Balonne	724	783	693	606
Moonie	34	37	32	29
Border Rivers	411	443	403	343
Gwydir	317	378	290	236
Namoi	359	368	358	327
Macquarie-Castlereagh	371	414	356	310
Barwon-Darling	230	237	234	219
Lachlan	321	331	296	254
Murrumbidgee	2,257	2,363	2,202	1,902
Murray	4,338	4,371	4,157	3,349
Ovens	25	25	25	26
Goulburn-Broken	1,071	1,062	1,011	765
Campaspe	342	343	325	245
Loddon-Acoca	350	346	330	234
Wimmera	121	120	108	66
Eastern Mount Lofty Ranges	6	6	6	6
Total	**11,327**	**11,686**	**10,876**	**8,962**
Murray at Wentworth	8,095	8,223	7,726	6,296

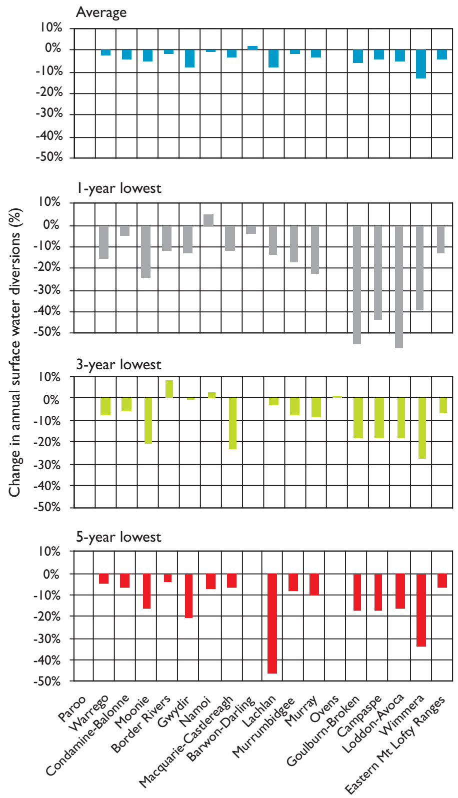
> Chaffey Dam, Namoi region, NSW (CSIRO)

> The Molonglo River near Canberra, Murrumbidgee region, ACT (CSIRO)

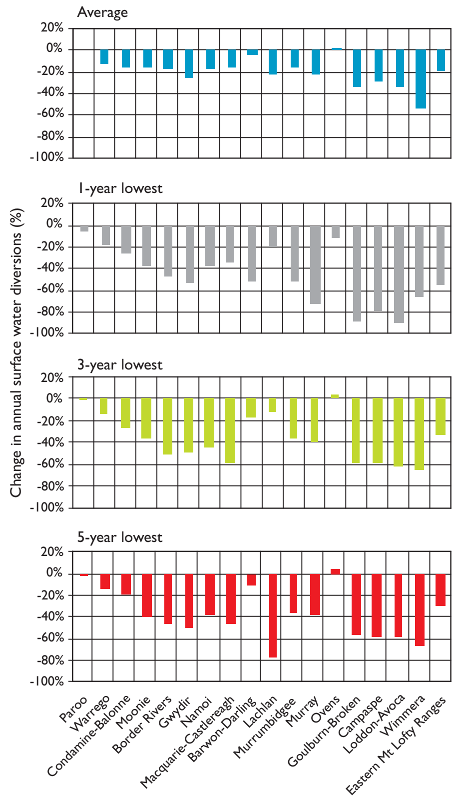
The impact of a reduction in surface water availability on surface water diversions is considerably greater in dry years. Under the median 2030 climate, diversions in driest years would fall by 4 percent in the Condamine-Balonne, 12 percent in most New South Wales regions north of the Murrumbidgee (except the Namoi and Barwon-Darling) and in the Eastern Mount Lofty Ranges, around 20 percent in the Murrumbidgee and Murray regions and from around 40 to over 50 percent in the Victorian regions. A similar pattern is apparent for the three-year low diversion period (with higher impacts also occurring in the Moonie and Macquarie-Castlereagh regions) and for the five-year low diversion period (with higher impact also occurring in the Moonie, Gwydir and Lachlan regions). The greatest three-year impact is a 28 percent reduction in the Wimmera region and the greatest five-year impact is a 45 percent reduction in the Lachlan.

Under the dry extreme 2030 climate, the percentage reductions in surface water diversions in the year of lowest diversion are far greater than for the median 2030 climate. Surface water diversions in driest years would fall by over 20 percent in the Condamine-Balonne, around 35 to 50 percent in New South Wales regions (except the Lachlan), over 70 percent in the Murray and 80 to 90 percent in the major Victorian regions.

Percentage change in surface water diversions under the median 2030 climate on average; in the lowest water use year; in the lowest three-year water use period and in the lowest five-year water use period



Percentage change in surface water diversions under the dry extreme 2030 climate on average; in the lowest water use year; in the lowest three-year water use period and in the lowest five-year water use period



As well as the proportional changes in use during low water use years, the impact of changed water availability for water users can be expressed in terms of changes in the reliability of water supply. These are difficult to summarise across the MDB, as there are different 'water products' in each State that have different reliability profiles. In most regions, the highest reliability water products (for example, town supply) would be largely unaffected by climate change by 2030. The greatest reductions in reliability would occur in regions where the relative level of surface water use is already high and where the climate change is expected to have the largest impact on water availability, and for water products that already are comparatively less reliable.

Some of the largest reductions in reliability would thus occur in the Murray, Goulburn-Broken, Campaspe, Loddon-Avoca and Wimmera regions. For example, in the Goulburn and Loddon rivers, holders of Victorian 'low reliability water shares' receive no allocation in 24 percent of years under the historical climate. This would increase to 36 percent of years under the median 2030 climate and to 93 percent of years under the dry extreme 2030 climate. For the Victorian Murray system, holders of low reliability water shares receive no allocation in 9 percent of years under the historical climate. This would increase to 15 percent of years under the median 2030 climate and to 82 percent of years under the dry extreme 2030 climate. Changes in reliability by region and by water product are tabulated in Appendix B.

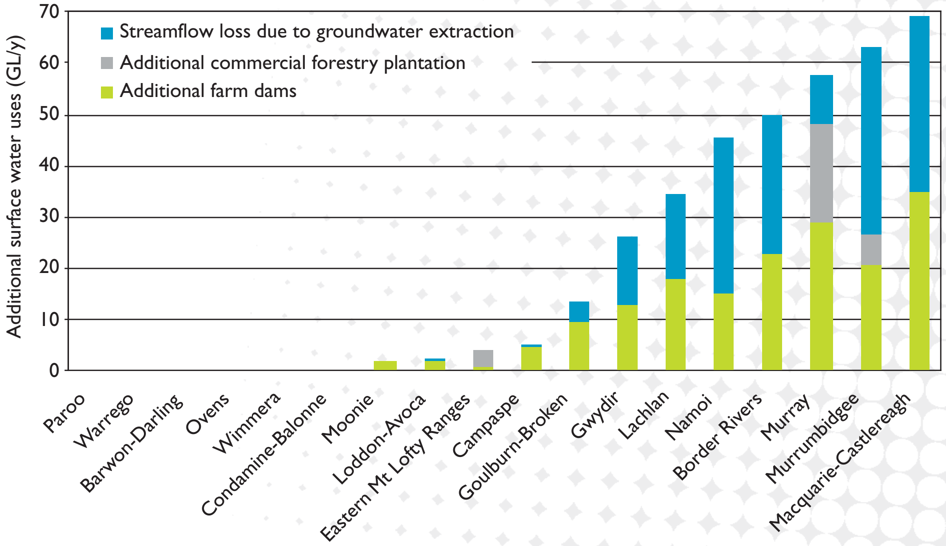
The impacts of future development

Increases in farm dam capacity, increases in commercial plantation forestry extent and increases in groundwater extraction, all have the potential to use additional surface water in the future. While all of these so-called 'other risks' ('other' than climate change) may affect water availability to water users downstream, herein they are all considered as water uses in their own right. That is, these activities do not intrinsically affect overall water availability. Rather, they represent activities which use surface water and may incidentally affect water access for downstream water users. Overall by 2030, best estimate projections for farm dams and commercial plantation forestry, and groundwater use at the maximum currently allowed level, would lead to a total additional surface water use of 375 GL/year. This is comprised of 28 GL/year by additional commercial forestry plantations, 170 GL/year by additional farm dams and 177 GL/year of additional streamflow loss induced by increases in groundwater extraction. Some of the groundwater use was not considered in the surface water models because they had a small impact (<2 GL/year) on inflows or were in areas not covered by the surface water models. Consequently, groundwater losses are larger than that reported in surface water models. In all cases, the assessed streamflow impact of groundwater extraction is the net impact considering any groundwater recharge that has resulted from surface water irrigation.

Because of the natural water losses which occur across the MDB, the volumetric impact of these additional water uses reduces with distance downstream. Considered at the points of water availability assessment across the 18 regions, these additional water uses would represent about 3 percent of the total future surface water use. In some cases the water use associated with these developments would significantly affect water access for downstream water users – particularly irrigators. For example in the Namoi region, these developments (largely increases in groundwater extraction) would lead to a 4 percent reduction in surface water diversions. Across the MDB the total impact would be 100 GL/year (or 1 percent) reduction in net surface water diversions.

The total net increase in surface water use by 2030 (under the median 2030 climate) is thus estimated to be 275 GL/year (375 GL/year less the 100 GL/year reduction in surface water diversions).

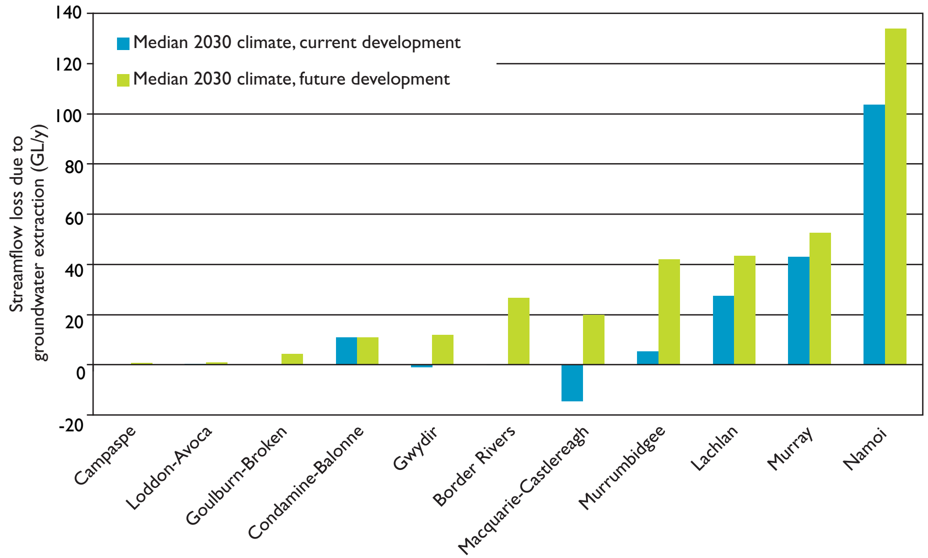
Additional future surface water use due to possible development



> Castlereagh River near Coonabarabran, NSW (MDBC)

The surface water impact due to groundwater extraction includes loss of baseflow in tributary streams and induced streamflow leakage to groundwater in alluvial river reaches. Only a fraction of this impact is typically captured in the calibrations of river models as, in most cases, much of this impact is yet to occur because of the lag times inherent in groundwater responses. Much of this impact has therefore not been explicitly considered in the development of the existing surface water sharing plans. The surface water impact of groundwater extraction presented here is the total eventual impact, and as shown in the graph below, this impact is largest in the Namoi. While these volumes of streamflow use are significant, they are small compared to the volumes of surface water diverted for irrigation.

Total eventual streamflow loss (GL/year) induced by groundwater extraction, by region



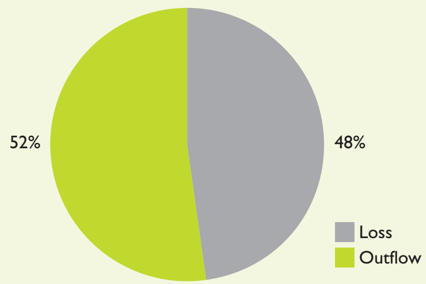
Combined, the median 2030 climate and the impacts of likely future development would increase the relative level of surface water use across the entire MDB to 53 percent. The relative level of surface water use also increases in 17 of the 18 regions. These increases are largely a result of reduced water availability rather than increased use.

Although the impacts of future development (especially the increase in groundwater extraction) are significant, they are not generally expected to lead to discernible additional environmental consequences above and beyond the consequences of climate change. Important exceptions are for the Barmah-Millewa Forest and the Gunbower and Koondrook-Perricoota forests where regional groundwater levels are expected to fall further with future increases in groundwater extraction, reducing groundwater accessibility for deep-rooted River Red Gums.

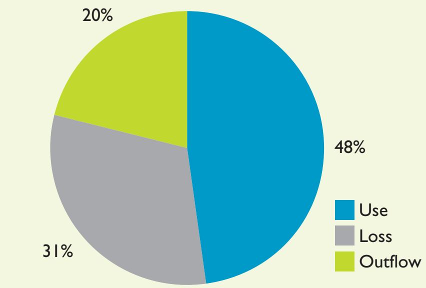
Impact sharing

The surface water availability assessments represent the resource which can be considered to be shared between consumptive use, losses and outflows. At the MDB scale, the losses and outflows represent the water which helps maintain river and floodplain ecosystems. The relative proportions of these components vary considerably between without-development conditions and current development conditions. As a result of water resource development, outflows have been reduced from 52 to 20 percent of the average available surface water. As the size of the available resource changes, so too does the relative sharing between use, losses and outflow. Under the median 2030 climate, average available surface water would fall by 11 percent. This reduction would reduce use by 4 percent, losses by 12 percent and outflows by 24 percent. At the MDB scale therefore, the largest share of the hydrological impact of climate change under current water sharing arrangements would occur at the end of the Murray River – that is, inflows to the Lower Lakes and the Coorong.

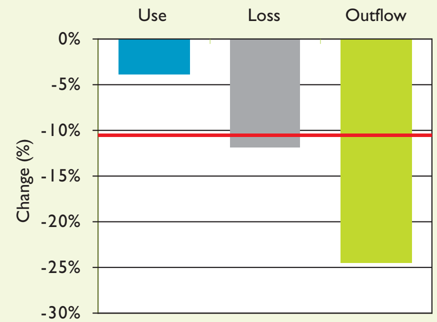
Sharing of MDB surface water availability between losses and outflows under without-development conditions



Sharing of MDB surface water availability between use, losses and outflows under current development conditions



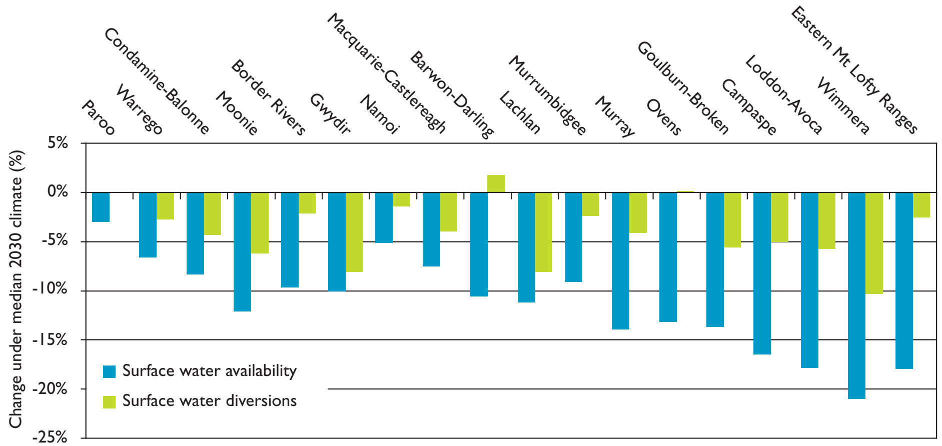
Percentage reduction in use, losses and outflows for the MDB under the median 2030 climate. The red horizontal line indicates the percentage reduction in MDB surface water availability



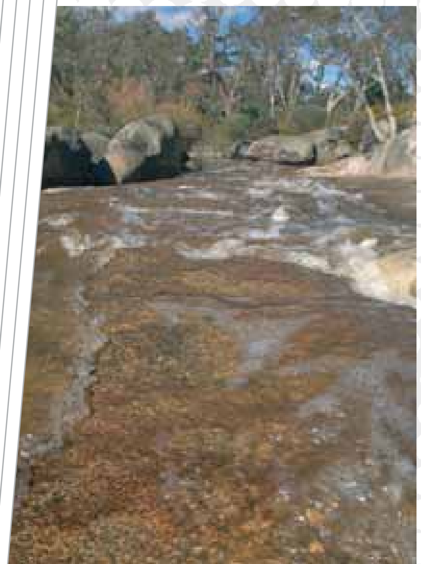
Importantly, there is no clear pattern across the 18 regions in terms of how the reduction in surface water availability translates into a change in surface water diversions. This is a result of differences between regions in the surface water sharing arrangements. That is, current water sharing arrangements protect surface water users from the impacts of climate change to differing degrees. In the Paroo, Barwon-Darling and Ovens regions an increase or no change in diversions would result from the predicted reduction in water availability (median 2030 climate) because use is not limited by water access. In the Barwon-Darling region, there is an increase in surface water use as most use is opportunistic harvesting of high flows, and this use is not reduced by the reduction in water availability; however, water demand is higher under a hotter, drier climate.

In the Gwydir region, various measures, including an 'environmental contingency allowance' in Copeton Dam and minimum flows to the Gwydir Wetlands, mean that the relative impact on surface water diversions is similar to the impact on surface water availability. In all other regions, surface water users would be insulated to greater or lesser extents from the impacts of climate change by existing water sharing arrangements. In the three highest water use regions (Murray, Murrumbidgee and Goulburn-Broken) and in the Border Rivers, Namoi and Campaspe regions, there is a high degree of protection for surface water users from the impacts of climate change under current sharing arrangements. Conversely, as discussed later, in these regions there is a low level of protection offered to the environment.

Impact of median 2030 climate on water availability and surface water diversions by region



> Evening light and reflections on the main irrigation canal at Griffith, Murrumbidgee region, NSW (CSIRO)



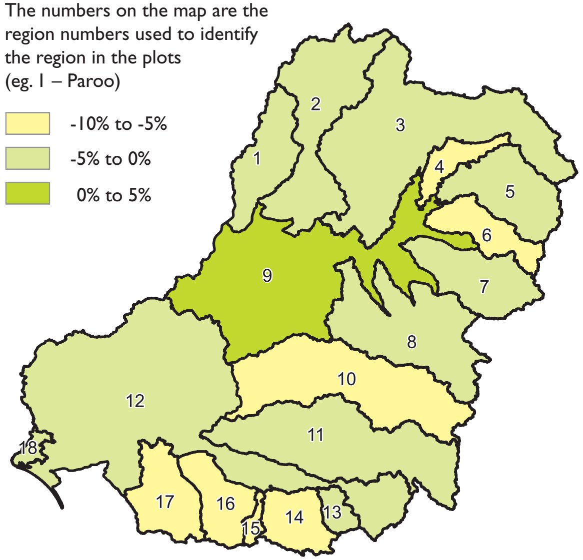
> Campaspe River near Redesdale, Vic (North Central CMA)

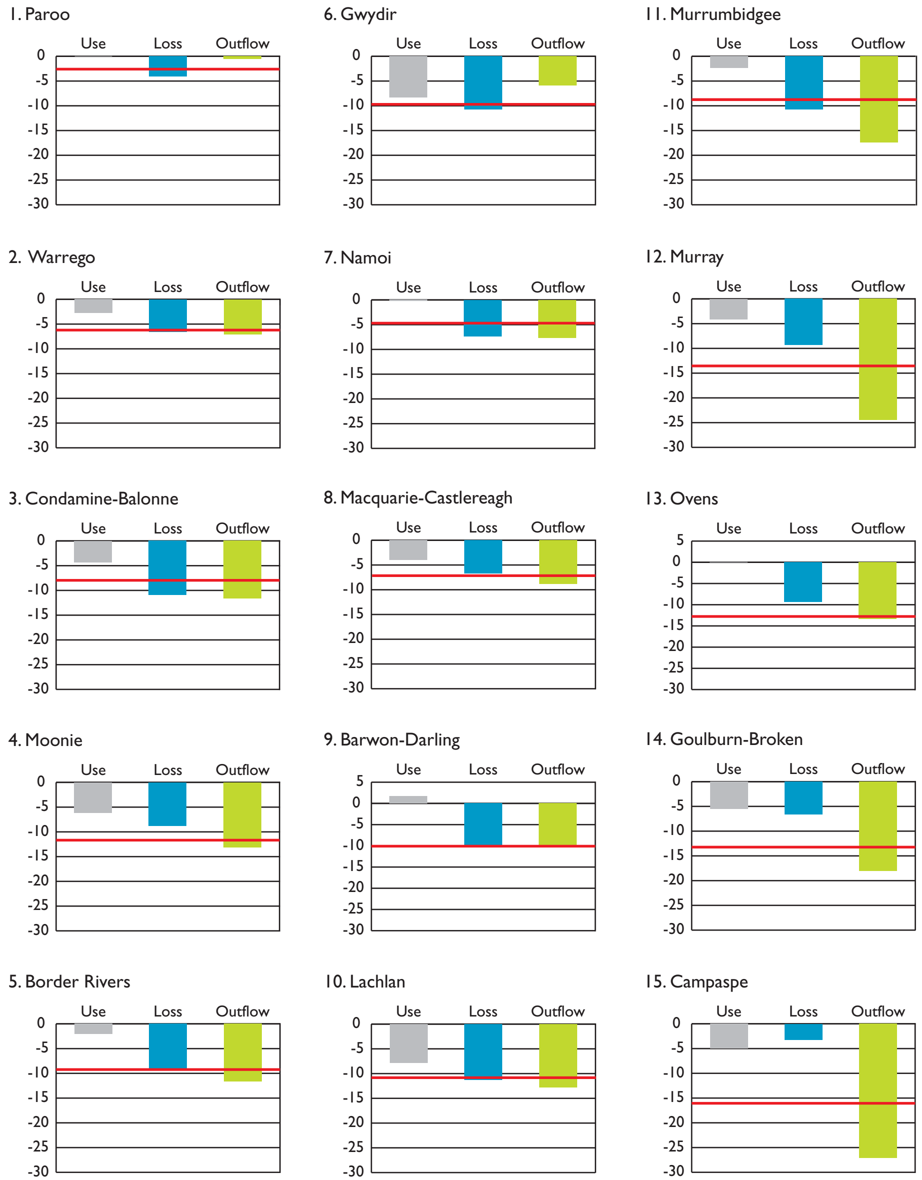
> Horsham Weir, Wimmera region, Vic (Wimmera CMA)

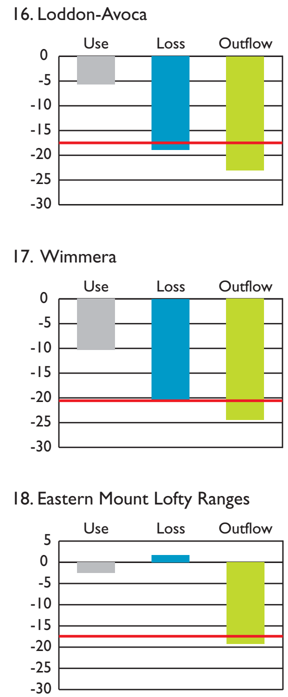
As described earlier, the impact of climate change on water availability is shared amongst the water balance components of use, losses and outflows. Where a lower share of the impact is borne by water users, a greater share of the impact must be borne by the loss and outflow components. It is these components of the water balance that essentially support the environment. The adjacent graphs show the impact sharing across the 18 regions. The red horizontal line on each bar graph indicates the reduction in water availability for the region under the median 2030 climate. The depth of the bars indicates the percentage change in water use, losses and outflows respectively.

Change in water use

The numbers on the map are the region numbers used to identify the region in the plots (eg. 1 – Paroo)







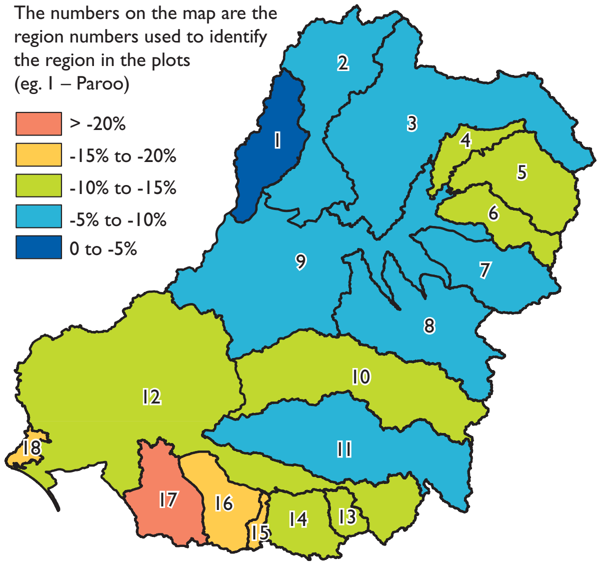
Relative impacts (percent) of surface water availability reduction on surface water use, losses and outflows for each region under the median 2030 climate

The Murray, Goulburn-Broken and Murrumbidgee regions represent not only the majority of the surface water resource, but are also where the greatest volume reduction is expected under the median 2030 climate. Some of the smallest relative impacts on surface water diversions would occur in these regions. This indicates that it is in these regions that the largest impacts on the local and downstream environmental water share would occur under current water sharing arrangements.

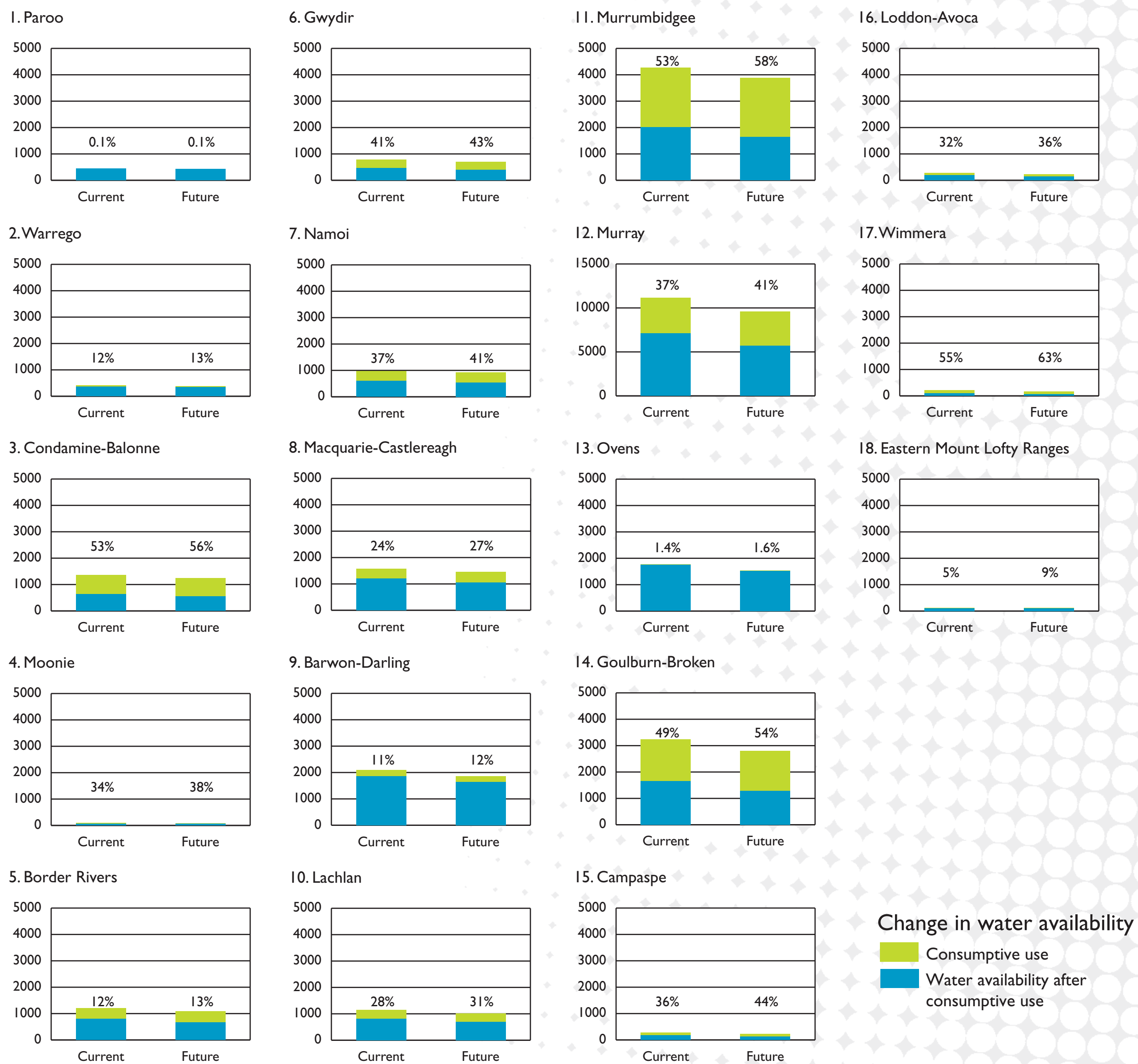
The map and graphs show the change in water availability across regions. The map indicates that the greatest relative impact under the median 2030 climate would occur in the Wimmera, with large reductions in all southern regions of the MDB. The bar charts indicate surface water availability volumes for each region and the fraction that is allocated to consumptive use under current sharing arrangements, firstly under the current (historical) climate, and secondly, under future (median 2030) climate. These charts reinforce that the majority of the MDB resource occurs in the Murray, Goulburn-Broken and Murrumbidgee regions and that it is in these regions that the greatest volume reductions would occur under the median 2030 climate. Note the different vertical scale for the Murray chart.

Change in water availability

The numbers on the map are the region numbers used to identify the region in the plots (eg. 1 – Paroo)



Average surface water availability (GL/year) for each region under current and future climates indicating the fraction of the available water allocated to consumptive use under current sharing arrangement and the remaining fraction of available water. The number above each bar indicates the relative level of surface water use for the region – under current (historical) and future (median 2030) climates



> Jilliby crossing, Moonie region, Qld (DEWHA)

> Catherine River, Ovens region, Vic (DSE)

> Broken Creek at Carlands Bridge, Goulburn-Broken region, Vic (Vic EPA)

Groundwater

> Windmills on the Silver City Highway and the turnoff to Pooncarie, Barwon-Darling region, NSW (MDBC)

Key findings

- There are twenty major groundwater management units (GMUs) that represent 75 percent of the groundwater extraction in the MDB. The current level of extraction cannot be maintained indefinitely in seven of these GMUs and large reductions in groundwater levels will result.
- Current (2004/05) estimated groundwater extraction (for the MDB GMUs) is 1832 GL/year. However, this estimate excludes extraction from confined aquifers of the Great Artesian Basin and some areas outside management units and hence extraction may be up to 25 percent higher. This extraction volume represents 16 percent of the total water use in the MDB. Groundwater use represents a greater fraction of total water use during dry periods. For example, 80 percent of the total water use is from groundwater in the Lachlan region during the three-year period of lowest surface water diversion, compared to an average of 45 percent.
- Current groundwater extraction will eventually reduce streamflow across the MDB by 447 GL/year. Thus one-quarter of total groundwater extraction will eventually be sourced directly from induced river recharge which represents 4 percent of current total surface water use. Around 91 percent of the streamflow impact will have occurred by 2014 and 40 percent of the impact will occur in the Namoi, Lachlan, Murrumbidgee and Murray regions.
- An estimated 91 GL/year out of the total eventual streamflow impact from current groundwater extraction is not captured in existing surface water model calibrations. This volume is additional to the groundwater extraction impacts determined in the surface water assessments that underpin existing surface water sharing plans and highlights an overestimation of the future surface water resource.
- The impact of 2030 climate conditions on rainfall recharge and groundwater levels would be minor compared to the impacts resulting from current and additional future extraction. Climate change would have only very small impacts on the rate of water exchange between rivers and aquifers and there would be no net impact across the MDB.
- Future groundwater extraction could (according to current groundwater management plans) reach 3956 GL/year by 2030. This is an approximate doubling of groundwater use. The greatest increases could occur in the New South Wales macro groundwater sharing plan areas – mainly in fractured rock aquifers. Groundwater use would then represent 24 percent of the total water use in the MDB and a far higher fraction in dry periods, particularly at a regional scale. There are however, some areas of the MDB where existing planning controls will reduce groundwater extraction to below current levels.
- Future increases in groundwater use are expected to significantly affect baseflow in small tributaries, turning some into ephemeral streams. Significant increases are also expected in some of the major alluvial aquifers. These changes would increase the streamflow leakage induced by groundwater extraction. The total additional streamflow impact of future groundwater extraction is estimated to be 393 GL/year meaning total impact could reach 840 GL/year. Importantly, the projected future level of groundwater extraction could not be sustained in some areas (Border Rivers, Lower Namoi, parts of the Lower Macquarie and the Lower and Upper Lachlan) due to large reductions in groundwater levels. There are also indications that future extraction in the Upper Murray may not be able to be sustained.

Current groundwater use

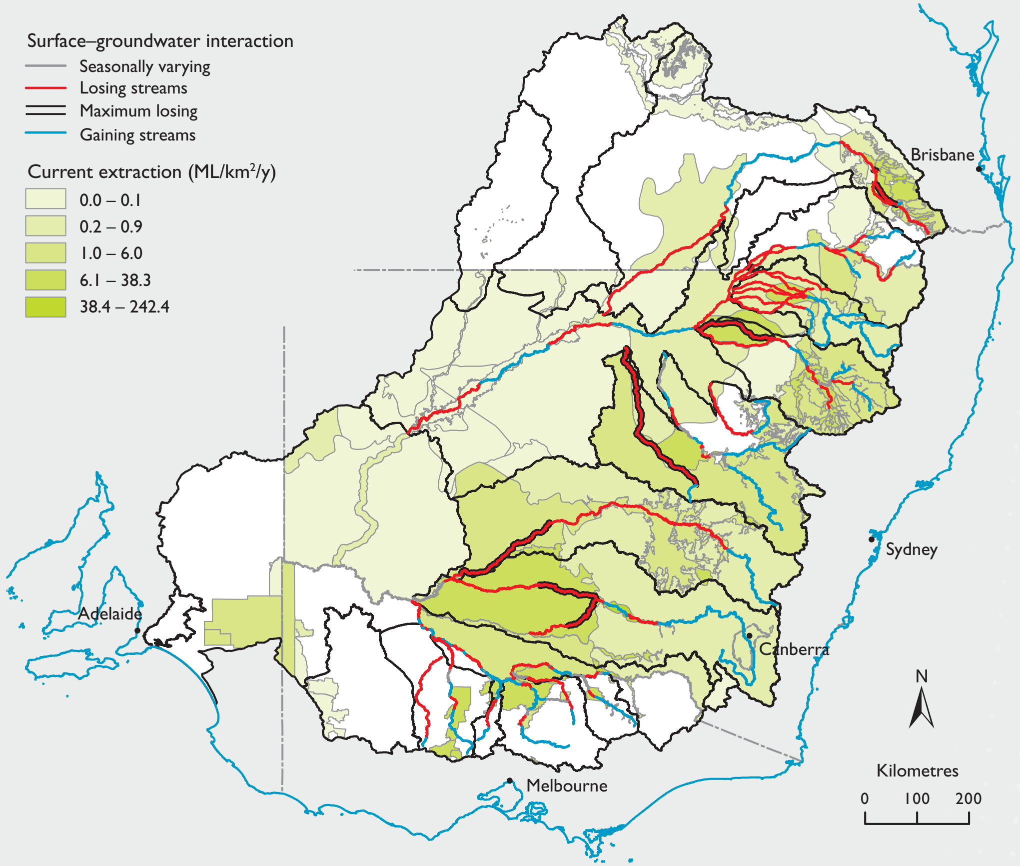
> Bore water irrigation near Moree, Gwydir region, NSW (DEWHA)

> Waterhole outside Narrabri, Namoi region, NSW (DEWHA)

The total groundwater extraction across the MDB in 2004/05 is estimated to have been 1832 GL/year or 16 percent of current total water use for the MDB. This volume excludes extraction from the deeper confined aquifers of the Great Artesian Basin and also excludes about 23 GL/year extracted by salt interception schemes along the lower reaches of the Murray River. Most groundwater extraction in the MDB is from the large riverine plain GMUs such as the Lower Murrumbidgee (324 GL/year) and the Lower Lachlan (126 GL/year). Current extraction from the medium to very high priority GMUs (see Appendix C) accounts for more than 75 percent of the total groundwater extraction in the MDB even though these GMUs represent only 15 percent of the total area of the MDB.

There is a wide range in the intensity of groundwater extraction both between and within GMUs. Production bores are often clustered in areas where there is good quality water, higher yields and good soils for irrigation. This clustering has implications for any evaluation of the sustainability of groundwater extraction. The GMUs with more intense groundwater extraction (annual extraction divided by GMU area) tend to be located through the riverine plain GMUs in New South Wales, the Katunga Water Supply Protection Area and Campaspe GMUs in Victoria and those in the Upper Condamine in Queensland. Areas of less intense extraction could indicate development potential.

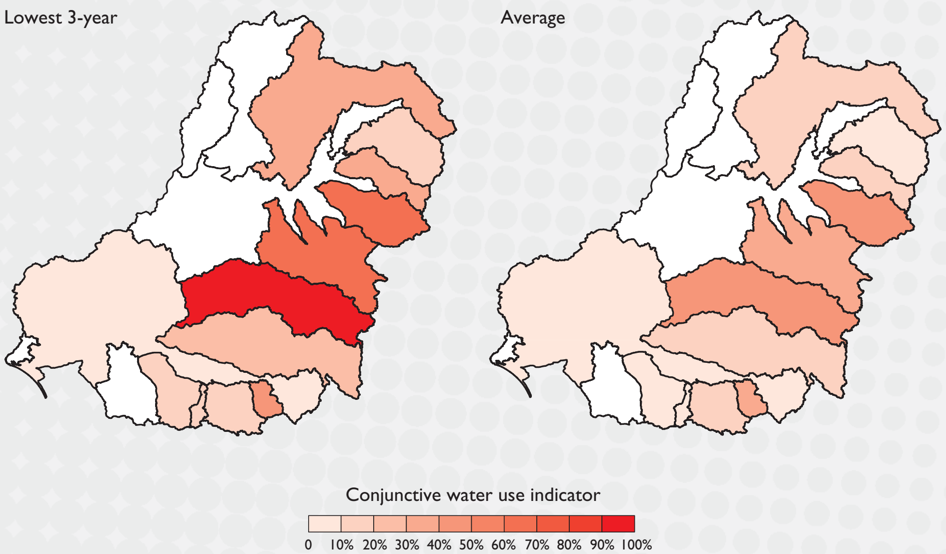
Ratio of current extraction within each GMU to the GMU area. The darker shades of green indicate areas of more intense extraction



The 'Achieving Sustainable Groundwater Entitlements' structural adjustment program announced in June 2005 reduced entitlements by over 900 GL in the Upper and Lower Namoi, Lower Macquarie, Lower Lachlan, Lower Murray, Lower Gwydir and Lower Murrumbidgee groundwater sources. The entitlements in the groundwater systems of these areas were reduced to equal the long-term average extraction limit within the groundwater source water sharing plans. Groundwater modelling for these systems assumed use at the long-term average extraction limit.

Groundwater use ranges from less than 10 percent of total water use (for example, in the Border Rivers region) to nearly 50 percent of total water use (for example, in the Lachlan and Namoi regions) under the historical climate and current development conditions. However, in periods when surface water use is lowest, groundwater use becomes relatively more important, ranging for example from around 15 percent of total water use in the Border Rivers to more than 80 percent of total water use in the Lachlan in the lowest three-year surface water use period. See also Appendix D.

Variation in the percent of groundwater use to total water use in the 18 regions of the MDB for the three-year period of lowest surface water use (left) and for the average surface water use (right)



Impacts of climate change

Climate change has the potential to alter the rates of rainfall recharge to groundwater. However, in areas where rainfall recharge is predicted to be lower under a drier climate, other sources of recharge (such as streamflow leakage from rivers) would support continued groundwater extraction. The rate of streamflow leakage could offset some of the fall in groundwater levels in areas where there is a strong connection between the aquifer and the river. However, in areas where there is a poor connection between the aquifer and the river, streamflow leakage is not induced by extraction to the same extent and a decline in groundwater levels would occur.

Under the median 2030 climate only small changes in rainfall recharge would be expected across the MDB: small decreases in the south and small increases in the north. At the wet extreme of the possible range of climate by 2030, rainfall recharge would increase across the MDB: by up to 50 percent in the north but by only 5 percent in the south. At the dry extreme of the possible range of climate by 2030, recharge would decrease across the MDB: by up to 15 percent in the north and by over 30 percent in the south.

Overall, the impacts of climate change by 2030 on rainfall recharge and groundwater levels would be minor compared to either the impacts already caused by groundwater extraction or the additional impacts associated with expected additional future extraction. Climate change by 2030 will have only very small impacts on water exchange between aquifers and rivers and would have no net impact on these exchanges across the MDB.

> Lachlan River near Jemalong Ridge, NSW (MDBC)

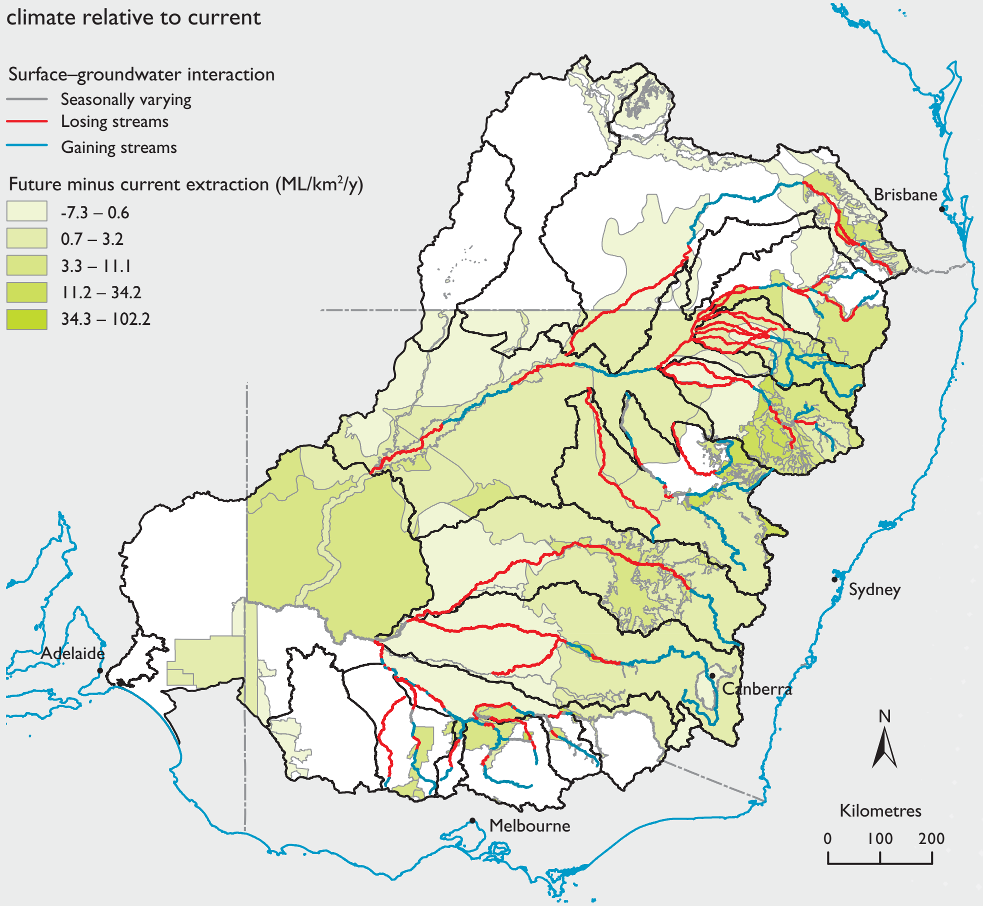
> Bore water irrigation near Narrabri, Namoi region, NSW (DEWHA)

> Sprinkler irrigation, Moree, Gwydir region, NSW (DEWHA)

Future groundwater use

According to current groundwater management plans, groundwater extraction by 2030 could increase to 3956 GL/year in the absence of management intervention. This represents an approximate doubling of groundwater use across the MDB. By 2030, groundwater extraction is expected to exceed 2004/05 levels in the majority of GMUs. The greatest increases could occur in the New South Wales macro groundwater sharing plan areas, which mainly cover fractured rock aquifers. At this level of extraction groundwater use represents 24 percent of the total water use in the MDB on average, and a far higher fraction in dry periods, particularly at the regional scale.

Ratio of the change in groundwater extraction within each GMU to the GMU area under future climate relative to current



In some GMUs (for example, the Lower Namoi Alluvium, Lower Gwydir Alluvium, Lower Murrumbidgee Alluvium and some of the Upper Condamine Groundwater Management Area), current planning controls will force future extraction to fall below 2004/05 levels. Many of these are adjacent to maximum losing (or 'disconnected') reaches of river. However, future growth in extraction will occur mainly in the aquifers that are connected to rivers (such as the Upper Lachlan and the Mid-Murrumbidgee) further reducing streamflow.

Impacts of groundwater use on streamflow

The total eventual impact of current groundwater extraction on streamflow is estimated to be a loss to groundwater of 447 GL/year. About 60 percent of this total streamflow impact is expected to occur in the higher priority GMUs which have been modelled and which cover about 13 percent of the MDB. Across these modelled areas, about three-quarters of the impact is expected to occur in the Namoi, Lachlan, Murrumbidgee and Murray regions. Because of time lags in the response of groundwater systems to pumping, not all of this eventual streamflow impact has yet occurred. Modelling of the higher priority GMUs shows that in these areas nearly two-thirds of the eventual impact has already occurred and over 90 percent of the impact will have occurred by 2014. Of the streamflow loss that has already occurred, only slightly less than half is accounted for in existing river models. Hence over 90 GL/year of expected streamflow loss has not been considered in the modelling and assessments that underpin current surface water sharing plans – this therefore represents an overestimation of the longer-term surface water available for sharing.

Given that groundwater use is projected to double by 2030, the total eventual impact of future groundwater extraction could increase to be a 840 GL/year streamflow loss to groundwater. This 840 GL/year of streamflow loss is considered as a surface water use and represents about 8 percent of the expected total surface water use by 2030. The additional streamflow loss by 2030 (associated with the projected growth in groundwater extraction) would largely occur in the Namoi and Macquarie-Castlereagh regions.

The estimated impacts of groundwater extraction on streamflow reported here are higher than those represented in the river modelling: (p41). This is because firstly, impacts of less than 2 GL/year for surface water catchments have been ignored in the river modelling as this is less than a measurable impact at an individual gauging station. However the total impact across the MDB could be almost 100 GL/year under the future development scenario. Secondly, not all of the surface water features (some streams and drains) are explicitly represented in the river modelling (for example, Broken Creek in Victoria). Finally, the river modelling does not separate the impacts of groundwater extraction from the groundwater returns from surface water irrigation. This will have the effect of decreasing the assessed impact.

Changes in groundwater levels

When groundwater is pumped from a bore the area of the aquifer which contributes water expands as extraction continues, and the area influenced by extraction depends upon the capacity of the aquifer to store and transmit water.

The capacity of aquifers to maintain current and future extraction was inferred for modelled GMUs according to whether pumped groundwater levels stabilise to a new equilibrium level by the end of each model run.

Modelling indicates that current extraction rates can be maintained in the Lower Gwydir, Upper Namoi, Lower Murrumbidgee, Lower Murray and across the Riverine Plain in Victoria. Current extraction rates cannot be maintained in the Condamine, Border Rivers, Lower Namoi, parts of the Lower Macquarie, parts of the Lower Lachlan, the Upper Lachlan and the Mid-Murrumbidgee GMUs. Management intervention (leading to a reduction in extraction) is expected that will reduce the potential for falling groundwater levels. For the GMUs in these areas, the entire GMU is not affected by falling groundwater levels – rather, levels fall around the production bores and the greatest decline is associated with the greatest intensity of use.

Projected groundwater extraction by 2030 (under a future climate) cannot be sustained by the existing distribution of bores in the Border Rivers, Lower Namoi, parts of the Lower Macquarie, and Lower and Upper Lachlan as large reductions in groundwater levels are expected to occur. There are also indications that future extraction in Upper Murray may not be able to be sustained.

The assessed future patterns of extraction can be maintained in the Lower Gwydir, Lower Murray, Lower Murrumbidgee and across the Riverine Plains in Victoria. In some areas (including the western part of Lower Gwydir, parts of the Lower Macquarie and the western parts of Lower Murrumbidgee and Lower Murray) watertables are expected to rise due to additional recharge in irrigated areas and/or due to increased flood frequency.

> Black Charlie Creek at James Reserve, Goulburn-Broken region, Vic (Vic EPA)

> Middle Creek crossing, Moonie region, Qld (DEWHA)

> Paroo River, near Currawinya National Park, Hungerford, Qld (DEWHA)

> Flooded wetland near Swan Reach, Murray region, SA (CSIRO)

Flow regimes and floodplain wetlands

Key findings

- Water resource development has altered the seasonal character of flow regimes in the MDB. In particular, in the major southern rivers high winter flows are captured for irrigation release in the summer leading to seasonal inversion of flow downstream of major dams. Further downstream, past the major diversion points, flow seasonality is largely restored but the amplitude of the seasonal variation is greatly reduced due to consumptive use.
- Climate change by 2030 could have major additional effects on the seasonal patterns of flow. The greatest changes are likely at the high-flow times of year. In the north, wet season flows may either increase due to increasingly extreme events or decrease due to an overall drying. In the south, flows are generally expected to be lower, particularly during the wet season.
- Overall, consumptive water use in the MDB has reduced average annual streamflow at the Murray mouth by 61 percent and has increased the incidence of cease-to-flow conditions from 1 percent of the time to 40 percent of the time. Severe drought inflows to the Lower Lakes (which would never occur in the absence of consumptive water use under the historical climate) prevail in 9 percent of years at the current level of water resource development.
- The median 2030 climate would worsen conditions for the Lower Lakes. Flow at the Murray mouth would cease 47 percent of the time and severe drought inflows to the Lower Lakes would occur in 13 percent of years. The situation would be considerably worse under the dry extreme 2030 climate: flow at the Murray mouth would cease 70 percent of the time and severe drought inflows to the Lower Lakes would prevail in 33 percent of years.
- Water resource development has had major impacts for the flooding regimes of many important floodplain forests and wetlands, including for several Ramsar-listed wetlands. For example, the proportion of years in which lakes in the Narran Lake Nature Reserve receive sufficient flooding to provide optimal waterbird breeding habitat has been more than halved; the average period between environmentally beneficial flooding of the Macquarie Marshes has more than doubled; and the average period between environmentally beneficial flooding of the major floodplains and wetland systems along the Murray River has approximately doubled. Prior to regulation, water levels in the Ramsar-listed terminal Lake Albacutya in the Wimmera region never fell low enough to be deemed 'shallow' for more than 8 years. As a result of water resource development, Lake Albacutya is now shallow for periods of up to 33 years, which has fundamentally altered the natural character and habitat value of the lake.
- The impacts of climate change by 2030 on environmentally beneficial flooding would, in nearly all regions and especially the highly developed regions, be smaller than those already brought about by water resource development. This would even be the case under the dry extreme climate of the possible 2030 climate range. In spite of this, when the incremental impacts of climate change are superimposed on the existing impacts from water resource development, the ecological consequences could be major. This is because important ecological thresholds may be crossed and resulting changes may well be largely irreversible. The population and wider ecosystem consequences of such changes could be catastrophic.
- In the three highest water use regions (the Murray, Murrumbidgee and Goulburn-Broken) current water sharing arrangements would protect water users from much of the climate change impact and thus transfer a disproportionate share of the climate change impact to the environment. For the Murrumbidgee and Goulburn-Broken regions this means that much of the impact of climate change would effectively be transferred downstream to

the Murray region. In the south of the MDB, current water sharing arrangements offer floodplain wetlands little protection from the expected impacts of climate change. Without changes to water sharing arrangements in these regions, climate change would be likely to lead to irreversible ecological degradation.

- The median 2030 climate would increase the duration of the dry periods between important flood events for all the Living Murray 'Icon Sites'[4(e)]. There would only be relatively small increases in the average period between flooding for most Icon Sites, but the average period would double for Chowilla Floodplain and Lindsay-Wallpolla Islands to be about every 18 years – almost eight times the without-development period. The average annual volumes of environmentally beneficial floods would be close to halved for all the Icon Sites along the Murray River. On average they would only receive about one-tenth of the flooding volume they received under without-development conditions.

Environmental assessments

Assessment of the environmental consequences of water resource development and future climate change form a minor component of this project. Environmental assessments are largely restricted to consideration of specific rules for applying environmental water and the assessment of a small number of hydrological indicators (defined by prior studies) for key environmental assets across the MDB. Furthermore, while for some regions consideration is given to flow regime indicators relevant to instream habitats, limitations of existing data and models largely restrict the assessments to consideration of flood regimes for floodplain forests and floodplain wetlands. Floodplain 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 reported herein are based on limited investigation with no direct quantitative relationships for environmental responses. Determination of environmentally sustainable flow regimes for the MDB requires a range of other environmental assessments.

Flow regime change

Water resource development and river regulation has altered many aspects of river flow regimes including the seasonality and amplitude of seasonal flow variations, the nature of the low flows, flooding regimes and the total volumes of flow. The Sustainable Rivers Audit (SRA)[4(f)] recently released by the Murray-Darling Basin Commission provides assessments for each of these aspects of flow regimes change using five different indicators combined into a single 'Hydrology Condition Index'; assessments are provided for 23 SRA valleys. Future climate change is also expected to significantly alter river flow regimes including flooding.

Herein, the focus is on changes in flooding regimes that affect major floodplain wetland systems – both as a result of water resource development and future climate change. Firstly however, a graphical presentation is provided of the seasonal patterns of flow across the MDB with the development and climate change impacts on these; together with a synthesis of the changes in inflows to the Lower Lakes on the Murray River and flows through the Murray mouth.

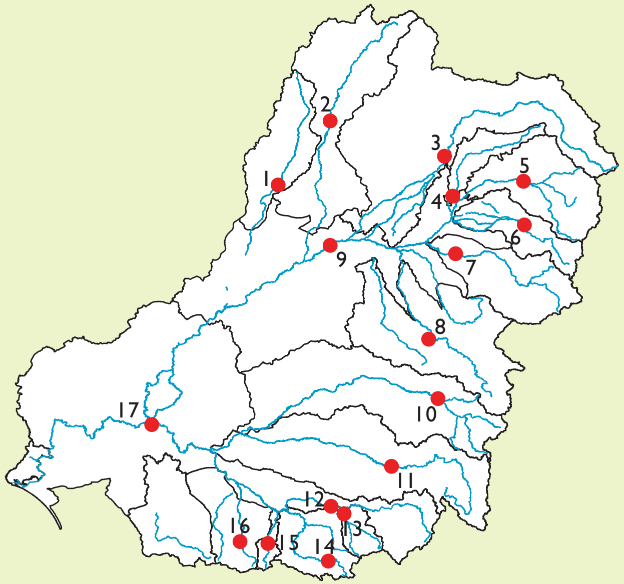
Seasonal flow patterns

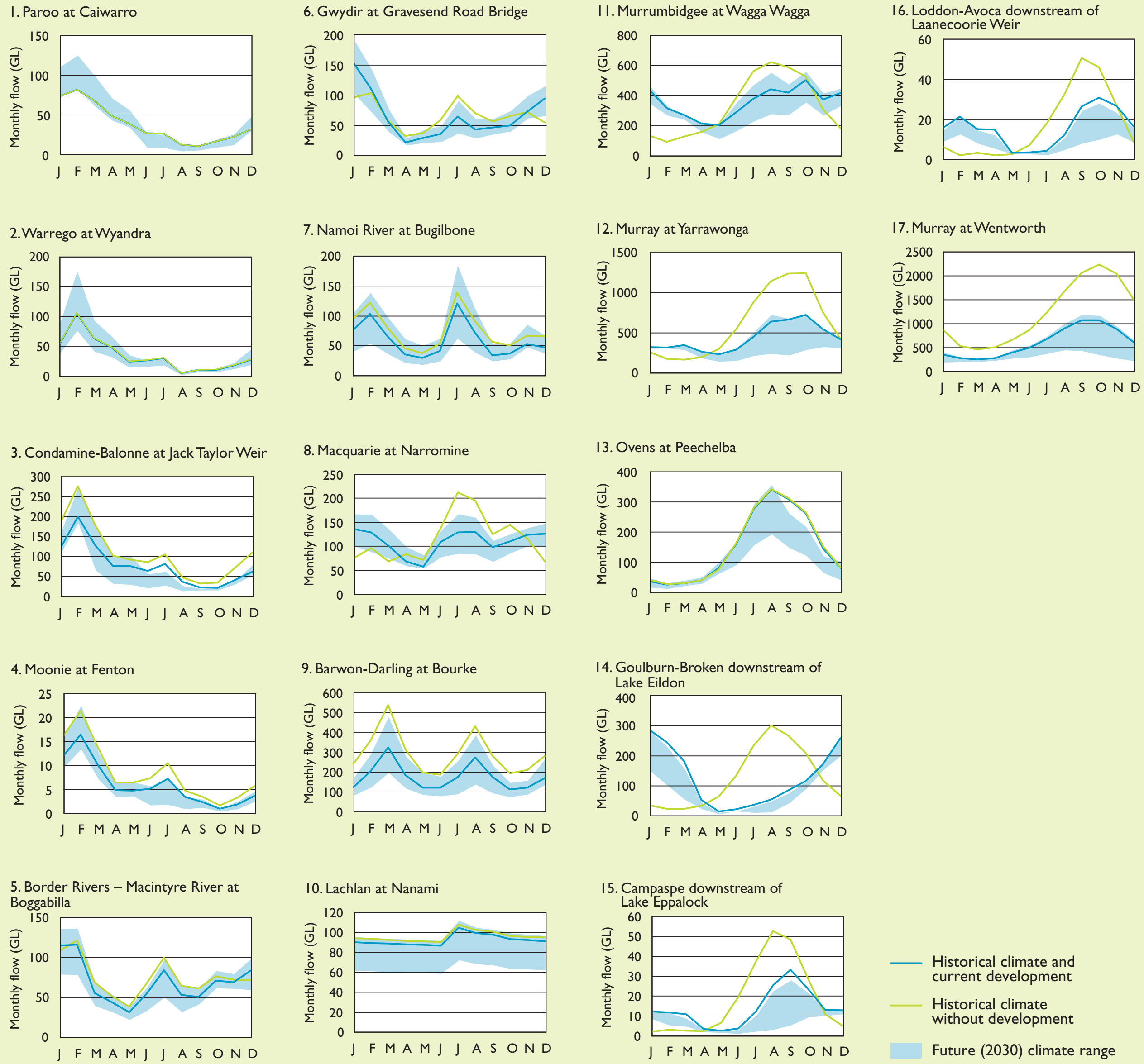
The seasonal patterns in flow and the changes that have occurred to these patterns vary greatly across the MDB due to differences in the climate and differences in water resource management. These changes also differ along the lengths of the major rivers, especially the Murray and Murrumbidgee, reflecting the different influences of regulation and diversion on the flow regime.

In the summer-rainfall dominated areas in the north of the MDB, the irrigation season coincides with high flow periods. In these areas (such as the Condamine-Balonne) water resource development has not altered the seasonality of flow but has altered the amplitude of the seasonal variation by diverting wet season flows. In the major southern rivers, high winter flows are captured in dams for irrigation release in the summer leading to seasonal inversion of flow downstream of major dams such as Hume and Eildon. Further downstream, past the major diversion points, flow seasonality is largely restored but the amplitude of the seasonal variation is greatly reduced due to consumptive use.

Climate change by 2030 could have major additional effects on the seasonality of flow. In the north of the MDB there is the possibility of either overall increases or decreases in flow. The increases are more likely at high-flow times of the year associated with increasingly extreme events. However, it is also at these times of the year that the uncertainty associated with climate change is greatest. At low-flow times of the year, the range in possible flow change due to climate change is much lower. In the south of the MDB flows are generally expected to be lower, although the degree of reduction is uncertain. Once again, it is during the winter high-flow period that the uncertainty is greatest and that the potential for flow reduction is greatest. For example in the Campaspe, there is the potential for the average spring peak flow to be reduced to one-quarter of the current value.

Seasonal patterns of flow at various locations across the MDB indicating the average monthly flows under without-development, current and future conditions. The future conditions reflect the influence of climate change only and show the wide range in possible change particularly during higher flow months





End-of-system flows

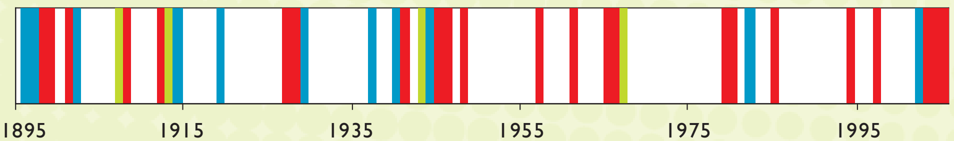
Overall, consumptive water use in the MDB has reduced average annual streamflow at the Murray mouth by 61 percent. At the current level of consumptive water use, and over the 1895 to 2006 climate, the average annual flow to the sea at the barrages has been reduced from 12,233 GL/year to 4733 GL/year. Consumptive water use has also increased the proportion of time for which flow at the Murray mouth ceases. In the absence of water resource development, the river would cease to flow through the mouth for 1 percent of the time under the 111-year historical climate. With the current level of water resource development and use, the river ceases to flow through the mouth for 40 percent of the time. The median 2030 climate would worsen conditions for the Lower Murray – flow at the river mouth would cease 47 percent of the time. The situation would be considerably worse under the dry extreme 2030 climate, with flow at the river mouth ceasing 70 percent of the time.

Water resource development has induced severe drought inflow conditions for the Lower Lakes. Severe drought inflows are defined here as an annual inflow to the Lower Lakes less than 1500 GL. This volume is slightly more that the total of the approximate annual net evaporation from the Lower Lakes (~800 GL) plus the annual volume estimated as necessary to maintain the Murray mouth (~600 GL). This volume is also equivalent to the annual 'dilution flow' (~700 GL) required to ensure adequate water quality for Adelaide water supply from the Murray River plus the approximate annual net evaporation from the Lower Lakes. Annual inflows this low would never occur in the absence of consumptive water use under the historical climate; under these conditions the minimum annual inflow to the Lower Lakes is around 2250 GL.

At current levels of development, these severe drought inflows to the Lower Lakes occur in 9 percent of years – mostly in the first half of the historical sequence. (It is important to note that historically, during the 50-year period 1895 to 1945 when these severe drought inflows to the Lower Lakes did not occur, the level of consumptive water use was far lower than the current level.) Under the median 2030 climate, the frequency would increase to 13 percent of years, and under the dry extreme 2030 climate the frequency would increase further to 33 percent of years.

Water resource development has also nearly doubled the average period between the flood events that are required to flush the Murray mouth and help sustain the lake and estuarine ecosystems, and has more than trebled the maximum period between these events from less than two years to nearly six years. The median 2030 climate would see the average period between these floods at the Murray mouth increase slightly and the maximum period between floods increase to be nearly eight years. Under the dry extreme of the possible climate range by 2030, the average period between these floods at the Murray mouth would increase by over 50 percent (to be over three years) and the maximum period would increase to be over 16 years.

Prevalence of 'drought' inflows to the Lower Lakes on the Murray River at the current level of development under the historical (blue), median 2030 (blue and green) and dry extreme 2030 (blue, green and red) climates



> Mouth of the Murray River with Lake Alexandrina and the Coorong, SA (MDBC)

Flood regimes

Assessment of hydrological changes for the major floodplain forests and wetlands across the MDB reveal major changes in the average and maximum period between beneficial flooding events as a result of water resource development. Changes in the period between flood events indicate potential for significant ecological impacts. This is because of the importance of the temporal pattern of wetting and drying for ecological processes in wetlands and the importance of the temporal patterns of habitat connectivity across the riverine landscape. Altered wetting and drying regimes are likely to alter ecological processes and, ultimately, the composition of the biological community. The changes for some floodplain wetlands are summarised on the accompanying graphs. Some important cases are:

- the average period between environmentally beneficial flooding of the Macquarie Marshes has more than doubled
- the average period between environmentally beneficial flooding of the major floodplains and wetland systems along the Murray River has approximately doubled. Average annual flood volumes are now less than a quarter, and in some cases only a fifth, of the volumes under without-development conditions
- the average period between the floods required to flush the Murray mouth and sustain the ecosystems of the Lower Lakes and the Coorong has nearly doubled.

In addition to these assessments of flooding frequency, other flood-related indicators suggest significant degradation. For example, the proportion of years in which lakes in the Narran Lake Nature Reserve receive sufficient flooding to provide optimal waterbird breeding habitat has been more than halved.

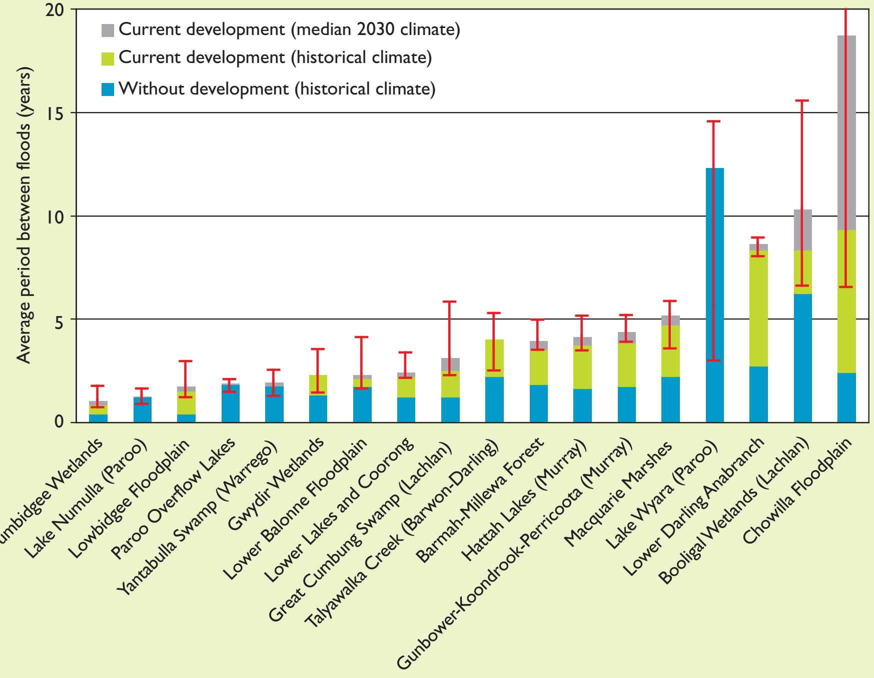
The impacts of climate change by 2030 on environmentally beneficial flooding would, in nearly all regions and especially the highly developed regions, be smaller than those already brought about by water resource development. This would even be the case under the dry extreme 2030 climate.

In spite of this, when the incremental impacts of climate change are superimposed on the existing impacts from water resource development, the ecological consequences could be major. This is because important ecological thresholds may be crossed and the resulting changes may well be largely irreversible. For example, the current average periods between beneficial flooding events for many major wetland systems are already seriously affecting the reproductive opportunities for some waterbird species, particularly colonial breeding species such as Ibis, Herons and Egrets. Any significant increase in these average periods may mean individuals of certain species do not get an opportunity to breed within their lifetime. The population and wider ecosystem consequences of such changes could be catastrophic. This is an important issue that requires additional research to quantify the likelihood of such ecological changes across the MDB.

Under current water sharing arrangements, the median 2030 climate would place substantial additional hydrological stress on the major environmentally valuable floodplains and wetlands across the MDB. These stresses would be greatest where the relative level of surface water use is already high and where the impacts of climate change are predicted to be greatest, in particular, in the Wimmera, Murray, Goulburn-Broken and Murrumbidgee regions.

In the three highest water use regions, current water sharing arrangements would protect water users from much of the climate change impact, and thus transfer a disproportionate share of the climate change impact to the environment. For the Murrumbidgee and Goulburn-Broken regions, this means that much of the impact of climate change would effectively be transferred downstream into the Murray region. In the south of the MDB, current water sharing arrangements offer floodplain wetlands little protection from the expected impacts of climate change. Without changes to water sharing arrangements in these regions, climate change would be likely to lead to irreversible ecological degradation.

Average period between ecologically beneficial flood events for some important floodplains and wetlands under without-development conditions (historical climate), current development conditions (historical climate) and current development conditions (median 2030 climate). The uncertainty range on the future climate values is indicated. Note that for Lake Numalla, the Paroo Overflow Lakes and Lake Wyara, the median 2030 climate would decrease the average period between floods, hence the value is obscured on this chart. Note also the considerable differences in the relative magnitude of the uncertainty range for 2030 climate



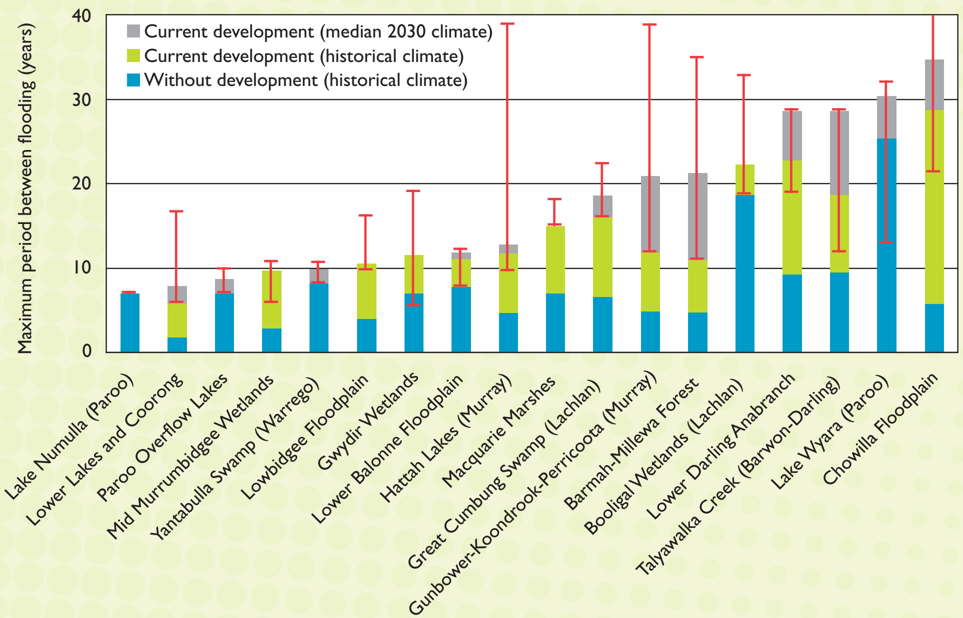
In the north of the MDB, the wetlands dependent on water from the Paroo and Warrego rivers have not been significantly affected by water resource development, and climate change is expected to cause only small changes in the flooding frequency of floodplain wetlands. However, the maximum period between flooding of the terminal wetlands of the Gwydir, Macquarie, Lachlan and Murrumbidgee rivers has increased dramatically by water resource development. The maximum period in some cases is between 10 and 15 years and similar to the reproductive life of many waterbird and fish species that breed in these wetlands. These changes have led to dramatic alterations in populations of key riverine biota and may even lead to regional extinctions. The median 2030 climate would further exacerbate these changes. The incremental changes in flooding regime, while small relative to the changes imposed by water resource development, may have more than simply incremental environmental impacts as previously noted.

The lower Goulburn River, which previously flooded twice every five years on average, now only floods once in ten years on average as a result of water resource development. The maximum period between flooding on the lower Goulburn has increased from 11 to 37 years and this is likely to have had major impacts on floodplain vegetation. In addition to the direct assessments of flood frequency, assessments of flood-related indicators suggest significant degradation. The longest period between floods which provide optimum breeding habitat availability in Back and Clear lakes (part of the Narran Lake Nature Reserve Ramsar site) in the lower Condamine-Balonne region has almost tripled as a result of water resource development, and the proportion of years which provide optimal breeding habitat has been more than halved. For these lakes, climate change is expected to cause only comparatively small changes in flood regimes. Prior to regulation, water levels in the terminal lakes of the Wimmera region – lakes Hindmarsh and Albacutya – were never so low as to be deemed 'shallow' for more than 3 and 8 years respectively. As a result of water resource development, these lakes now remain shallow for up to 8 and 33 years respectively, which in the case of Lake Albacutya, has fundamentally altered its natural character and habitat value. Under the median 2030 climate, Lake Hindmarsh would remain shallow for periods up to 32 years, while Lake Albacutya would essentially be continuously shallow and would never fill entirely.

For the key environmental assets that rely on water from more than one upstream catchment (Barmah-Millewa, Gunbower, Hattah, Chowilla, the Lower Lakes and Coorong and the Lower Darling Anabranch), the impact of water resource development on the average and maximum period between events has also been dramatic. With the exception of the Coorong, regulation has at least doubled the average time between beneficial flood events and the longest single period between critical flooding events has more than doubled for all sites. The most dramatic case is the Chowilla Floodplain for which the maximum period between floods has increased from around 6 years to almost 29 years as a result of water resource development.

The median 2030 climate would increase the duration of the dry periods between important flood events for all these Murray region assets. There would only be relatively small increases in the average period between flooding for most Living Murray 'Icon Sites'[4(e)], but the average period would double for Chowilla Floodplain and Lindsay-Wallpolla Islands to be about 18 years – almost eight times the without-development period. The average annual volumes of environmentally beneficial floods would be close to halved for all the Icon Sites along the Murray River; on average they would be around one-tenth of the volume under without-development conditions.

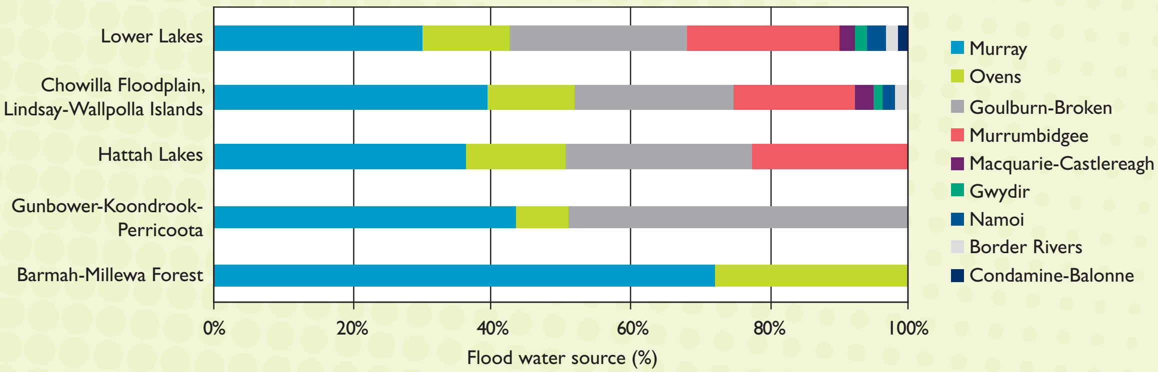
Maximum period between ecologically beneficial flood events for some important floodplains and wetlands under without-development conditions (historical climate), current development conditions (historical climate) and current development conditions (median 2030 climate). The uncertainty range on the future climate values is indicated



> Coombool Swamp upstream from Renmark, Murray region, SA. (CSIRO)

The river modelling quantifies the different relative sources of flood water to Living Murray Icon Sites based on without-development flows under the historical climate. Over three-quarters of the flood waters to Barmah-Millewa Forest are from the Upper Murray and the remainder are from the Ovens. For the Gunbower and Koondrook-Perricoota Forests further downstream, around half the water is sourced from the Goulburn-Broken system (including Campaspe contributions). At Hattah Lakes, the portfolio of sources widens with around one-quarter of the water sourced from the Murrumbidgee. Downstream of the Darling junction, the Barwon-Darling and its tributaries make small (less than 10 percent) contributions to flood waters reaching Icon Sites. Because of the higher flood threshold for Chowilla Floodplain, floods from the Condamine-Balonne region make no appreciable contribution. For the Lower Lakes, the Condamine-Balonne contributes about 1 percent of the flood water under without-development conditions. Given the extremely high relative level of surface use in the Condamine-Balonne, this small fraction will currently be even lower. Importantly, this assessment for the Lower Lakes is for the floods necessary to flush the lakes and the Murray mouth; it is not an assessment for the total flows to the Lower Lakes.

Percentage sources of flood water into Living Murray Icon Sites under without-development conditions



> The Macquarie Marshes, NSW (MDBC)

> Darling River near Bourke, NSW (MDBC)

> Backwaters of the Murray River near Chowilla, upstream from Renmark, SA (CSIRO)

Appendix A: Surface water availability and use

	Paroo	Warrego	Condamine-Balonne	Moonie	Border Rivers	Gwydir	Namoi	Macquarie-Castlereagh	Barwon-Darling	Lachlan	Murrumbidgee	Murray	Ovens	Goulburn-Broken	Campaspe	Loddon-Avoca	Wimmera	Eastern Mt Lofty Ranges	MDB
	GL/y																		
Without-development, historical climate																			
Total inflows	584.9	604.5	1,737.5	151.3	2,076.4	1,105.1	1,872.4	2,561.4	4,858.9	1,456.9	4,751.9	16,854.9	1,970.3	3,396.0	275.1	324.0	273.6	121.8	29,639.6
Total losses	241.5	536.2	1,186.1	54.6	1,246.4	726.5	981.9	1,784.6	1,915.1	1,167.9	2,093.7	4,622.1	194.6	162.9	0.3	201.7	255.1	0.3	17,406.8
Total end-of-system flow	343.4	68.3	551.5	96.7	830.1	378.6	890.5	776.8	2,943.8	289.0	2,658.2	12,232.8	1,775.7	3,233.1	274.8	122.3	18.5	121.5	12,232.8
Average surface water availability	445.0	420.5	1,362.7	98.5	1,207.8	781.6	964.9	1,567.3	2,088.3	1,139.2	4,270.2	11,161.7	1,775.5	3,233.1	274.8	284.8	218.6	120.4	14,493.4
Current development, historical climate																			
Total inflows	576.4	604.5	1,737.4	151.3	2,076.4	1,105.1	1,872.4	2,563.8	3,056.1	1,456.9	4,757.0	12,566.2	1,970.3	3,396.0	782.0	587.6	331.8	122.2	29,779.1
Total losses	250.6	409.7	766.8	45.6	1,126.5	599.6	930.6	1,610.1	1,043.5	927.3	1,019.9	3,496.0	193.3	233.3	21.8	184.1	190.1	5.3	13,719.7
Total surface water diversions	0.2	51.5	712.3	34.0	411.5	316.7	258.1	385.7	229.9	292.3	2,251.2	4,288.2	25.4	1,070.5	342.1	349.3	120.8	6.3	11,145.9
Induced streamflow loss to groundwater	0.0	0.0	11.4	0.0	-0.2	0.0	100.7	-15.0	0.0	29.0	5.3	49.4	0.0	0.1	0.0	0.2	0.0	0.0	180.9
Total end-of-system flow	325.7	143.3	246.9	71.7	538.6	188.9	583.0	582.9	1,782.7	208.5	1,480.5	4,732.6	1,751.6	2,092.1	418.1	54.0	20.9	110.6	4,732.6
Relative level of surface water use	0%	12%	53%	34%	34%	41%	37%	24%	11%	28%	53%	36%	1%	50%	36%	32%	55%	5%	56%
Current development, recent climate																			
Total inflows	576.4	604.5	1,737.4	151.3	2,076.4	1,105.1	1,872.4	2,563.8	3,056.1	1,456.9	3,362.8	8,962.8	1,462.3	2,021.9	506.1	360.5	172.2	95.2	24,627.4
Total losses	250.6	409.7	766.8	45.6	1,126.5	599.6	930.6	1,610.1	1,043.5	927.3	704.7	2,818.9	159.0	164.1	14.0	85.9	95.1	5.4	12,384.5
Total surface water diversions	0.2	51.5	712.3	34.0	411.5	316.7	258.1	385.7	229.9	292.3	1,852.0	3,740.7	25.6	816.3	253.4	253.0	67.8	6.1	9,707.2
Induced streamflow loss to groundwater	0.0	0.0	11.4	0.0	-0.2	0.0	100.7	-15.0	0.0	29.0	6.6	35.8	0.0	-0.1	0.0	0.2	0.0	0.0	168.3
Total end-of-system flow	325.7	143.3	246.9	71.7	538.6	188.9	583.0	582.9	1,782.7	208.5	799.5	2,367.4	1,277.7	1,041.5	238.7	21.4	9.3	83.6	2,367.4
Average surface water availability	445.0	420.5	1,362.7	98.5	1,207.8	781.6	964.9	1,567.3	2,088.3	1,139.2	2,990.1	7,836.4	1,303.2	1,911.2	127.1	142.0	102.8	92.9	10,548.4
Relative level of surface water use	0%	12%	53%	34%	34%	41%	37%	24%	11%	28%	62%	45%	2%	63%	60%	41%	66%	7%	66%

	Paroo	Warrego	Condamine-Balonne	Moonie	Border Rivers	Gwydir	Namoi	Macquarie-Castlereagh	Barwon-Darling	Lachlan	Murrumbidgee	Murray	Ovens	Goulburn-Broken	Campaspe	Loddon-Avoca	Wimmera	Eastern Mount Lofty Ranges	MDB
	GL/y																		
Current development, median 2030 climate																			
Total inflows	564.8	566.3	1,593.3	135.8	1,901.1	1,003.1	1,758.9	2,389.0	2,771.5	1,299.5	4,335.2	10,900.5	1,718.1	2,941.6	712.7	520.4	274.6	100.7	26,886.7
Total losses	240.5	383.0	682.5	41.6	1,022.3	535.1	862.7	1,501.7	935.1	821.9	910.6	3,168.9	175.1	218.0	21.1	149.2	150.5	5.4	12,435.9
Total surface water diversions	0.2	50.1	681.6	31.9	402.9	291.2	254.4	370.5	233.9	268.7	2,197.0	4,113.8	25.4	1,010.7	325.0	329.4	108.3	6.1	10,701.2
Induced streamflow loss to groundwater	0.0	0.0	10.9	0.0	-0.2	-1.0	103.6	-14.5	0.0	27.3	5.4	43.1	0.0	0.0	0.0	0.2	0.0	0.0	174.9
Total end-of-system flow	324.1	133.2	218.3	62.3	476.1	177.8	538.2	531.3	1,602.5	181.6	1,222.2	3,574.7	1,517.6	1,712.9	366.6	41.6	15.8	89.2	3,574.7
Average surface water availability	431.7	392.8	1,248.9	86.6	1,091.8	703.1	915.3	1,449.6	1,867.4	1,011.7	3,880.8	9,606.0	1,542.1	2,792.3	229.7	234.0	172.8	98.8	12,811.4
Relative level of surface water use	0%	13%	55%	37%	37%	41%	39%	25%	13%	29%	57%	40%	2%	54%	42%	35%	63%	6%	60%
Current development, wet extreme 2030 climate																			
Total inflows	806.1	869.9	2,029.2	182.7	2,492.8	1,461.6	2,604.8	3,270.6	4,397.4	1,596.4	5,342.3	13,857.9	1,995.0	3,306.0	767.7	570.5	318.9	118.8	34,103.7
Total losses	307.8	594.7	948.8	54.0	1,369.4	832.5	1,348.1	2,037.2	1,547.8	1,037.9	1,190.7	3,824.8	191.0	237.0	22.7	174.4	179.6	5.5	16,756.3
Total surface water diversions	0.2	58.1	773.4	37.4	445.2	379.2	285.4	432.9	237.3	302.6	2,356.5	4,323.8	25.3	1,061.7	342.7	346.0	120.0	6.2	11,533.9
Induced streamflow loss to groundwater	0.0	0.0	9.2	0.0	-2.0	-1.3	82.8	-18.9	0.0	28.0	6.2	47.4	0.0	0.0	0.0	0.2	0.0	0.0	151.6
Total end-of-system flow	498.2	217.1	297.9	91.3	680.2	251.3	888.5	819.4	2,612.3	227.9	1,788.9	5,661.9	1,778.7	2,007.4	402.3	49.9	19.2	107.1	5,661.9
Average surface water availability	626.5	619.0	1,615.8	122.3	1,426.7	1,049.4	1,336.1	1,966.6	3,055.8	1,211.5	4,816.3	11,990.5	1,802.0	3,146.3	262.7	270.4	206.7	117.1	15,450.3
Relative level of surface water use	0%	9%	48%	31%	31%	36%	28%	21%	8%	27%	49%	34%	1%	51%	38%	33%	58%	5%	53%
Current development, dry extreme 2030 climate																			
Total inflows	483.3	437.8	1,308.7	114.6	1,500.6	788.7	1,295.5	1,974.3	2,042.0	1,000.2	3,464.4	7,422.0	1,103.7	1,892.0	494.4	351.2	172.9	60.3	20,199.7
Total losses	212.1	295.3	542.5	36.5	801.8	414.1	611.6	1,242.6	672.4	610.3	739.2	2,597.5	130.8	176.7	17.4	93.1	96.9	5.4	9,762.2
Total surface water diversions	0.2	45.1	596.3	28.6	343.1	236.1	214.7	323.2	219.3	225.6	1,891.1	3,317.0	26.0	765.3	244.8	233.6	65.8	5.5	8,781.1
Induced streamflow loss to groundwater	0.0	0.0	9.9	0.0	0.1	-0.1	112.4	-13.3	0.0	28.5	11.0	31.6	0.0	-0.1	0.0	0.2	0.0	0.0	180.4
Total end-of-system flow	271.0	97.4	159.9	49.5	355.6	138.6	356.8	421.7	1,150.4	135.7	823.1	1,476.0	946.9	950.0	232.1	24.3	10.2	49.4	1,476.0
Average surface water availability	372.3	292.3	1,004.0	69.7	891.4	554.0	676.5	1,179.9	1,321.0	791.8	3,087.0	6,550.0	973.8	1,787.8	147.7	145.5	102.1	57.6	9,155.5
Relative level of surface water use	0%	15%	60%	41%	38%	43%	48%	26%	17%	32%	62%	46%	3%	63%	57%	38%	64%	10%	69%

	Paroo	Warrego	Condamine-Balonne	Moonie	Border Rivers	Gwydir	Namoi	Macquarie-Castlereagh	Barwon-Darling	Lachlan	Murrumbidgee	Murray	Ovens	Goulburn-Broken	Campaspe	Loddon-Avoca	Wimmera	Eastern Mount Lofty Ranges	MDB
	GL/y																		
Future development, median 2030 climate																			
Total inflows	564.8	566.3	1,589.8	134.3	1,878.6	990.5	1,730.4	2,354.6	2,685.8	1,281.9	4,309.0	10,762.5	1,707.4	2,932.7	708.4	518.3	274.6	97.3	26,643.2
Total losses	240.5	383.0	680.6	41.1	999.2	521.6	829.3	1,461.2	899.0	801.8	900.1	3,137.5	174.6	217.6	20.9	147.8	150.5	5.8	12,207.4
Total surface water diversions	0.2	50.1	680.6	31.9	392.4	283.3	244.8	350.3	230.9	259.9	2,171.3	4,090.0	25.3	1,008.4	324.2	328.5	108.3	6.9	10,587.3
Induced streamflow loss to groundwater	0.0	0.0	10.9	0.0	26.7	12.0	138.2	34.3	0.0	43.5	41.9	52.5	0.0	4.2	0.8	0.9	0.0	0.0	366.1
Total end-of-system flow	324.1	133.2	217.7	61.3	460.2	173.5	518.1	508.7	1,555.9	176.7	1,195.7	3,482.5	1,507.5	1,702.4	362.5	41.1	15.8	84.6	3,482.5
Average surface water availability	431.7	392.8	1,248.9	86.6	1,091.8	703.1	915.3	1,449.6	1,867.4	1,011.7	3,880.8	9,606.0	1,542.1	2,792.3	229.7	234.0	172.8	117.1	12,811.4
Relative level of surface water use	0%	13%	56%	38%	39%	43%	41%	27%	12%	32%	58%	41%	2%	55%	44%	36%	63%	9%	61%
Water use by future farm dams	0.0	0.0	0.0	1.5	22.6	12.7	17.2	34.4	0.0	17.6	20.4	28.5	0.0	9.0	4.3	1.4	0.0	0.6	170.2
Water use by future commercial forestry plantations	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	19.0	0.0	0.0	0.0	0.0	0.0	2.8	27.5
Future development, wet extreme 2030 climate																			
Total inflows	806.1	869.9	2,025.5	180.8	2,468.8	1,447.7	2,568.9	3,232.6	4,284.3	1,578.9	5,313.6	13,687.2	1,984.3	3,297.0	764.2	569.3	318.9	114.9	33,822.4
Total losses	307.8	594.7	946.7	53.3	1,344.2	816.6	1,308.3	1,995.3	1,501.0	1,014.9	1,179.0	3,784.6	191.0	236.6	22.5	173.2	179.6	5.9	16,490.6
Total surface water diversions	0.2	58.1	772.4	37.3	437.6	373.3	281.1	409.3	235.6	297.0	2,340.2	4,295.7	25.2	1,060.1	342.1	345.1	120.0	7.0	11,437.5
Induced streamflow loss to groundwater	0.0	0.0	9.1	0.0	25.8	11.7	119.3	34.6	0.0	44.9	36.3	56.8	0.0	4.3	0.6	0.9	0.0	0.0	344.3
Total end-of-system flow	498.2	217.1	297.3	90.2	661.3	246.1	860.1	793.4	2,547.6	222.2	1,758.1	5,550.0	1,768.1	1,996.0	398.9	50.1	19.2	102.0	5,550.0
Average surface water availability	626.5	619.0	1,615.8	122.3	1,426.7	1,049.4	1,336.1	1,966.6	3,055.8	1,211.5	4,816.3	11,990.5	1,802.0	3,146.3	262.7	270.4	206.7	117.1	15,450.3
Relative level of surface water use	0%	9%	49%	32%	33%	37%	30%	23%	8%	29%	50%	35%	1%	51%	40%	35%	58%	9%	54%
Water use by future farm dams	0.0	0.0	0.0	1.9	24.0	13.9	24.6	38.0	0.0	17.4	21.9	33.7	0.0	9.1	3.5	1.4	0.0	0.7	190.2
Water use by future commercial forestry plantations	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	22.4	0.0	0.0	0.0	0.0	0.0	3.2	32.2
Future development, dry extreme 2030 climate																			
Total inflows	483.3	437.8	1,305.7	113.3	1,481.2	777.5	1,271.7	1,942.9	1,969.7	983.8	3,441.5	7,313.4	1,093.1	1,883.1	489.9	349.3	172.9	57.9	19,991.9
Total losses	212.1	295.3	541.1	36.0	781.1	401.9	583.5	1,203.2	642.3	592.3	729.9	2,574.4	130.6	176.2	16.9	92.2	96.9	5.7	9,564.5
Total surface water diversions	0.2	45.1	595.3	28.5	331.6	227.9	195.4	304.4	215.2	216.6	1,860.9	3,281.1	25.8	761.8	242.9	232.2	65.8	6.1	8,636.9
Induced streamflow loss to groundwater	0.0	0.0	9.8	0.0	27.0	12.9	153.1	34.4	0.0	43.2	46.4	40.7	0.0	4.2	0.9	0.8	0.0	0.0	373.5
Total end-of-system flow	271.0	97.4	159.5	48.8	341.5	134.7	339.6	400.9	1,112.2	131.7	804.3	1,417.1	936.7	940.8	229.2	24.1	10.2	46.1	1,417.1
Average surface water availability	372.3	292.3	1,004.0	69.7	891.4	554.0	676.5	1,179.9	1,321.0	791.8	3,087.0	6,550.0	973.8	1,787.8	147.7	145.5	102.1	117.1	9,155.5
Relative level of surface water use	0%	15%	61%	42%	41%	44%	50%	29%	16%	35%	62%	48%	3%	63%	59%	39%	64%	7%	70%
Water use by future farm dams	0.0	0.0	0.0	1.3	19.4	11.2	12.4	31.4	0.0	16.4	17.1	22.6	0.0	9.0	4.4	1.2	0.0	0.5	146.8
Water use by future commercial forestry plantations	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	15.0	0.0	0.0	0.0	0.0	0.0	1.9	22.3

Appendix B: Surface water reliability of supply

		Historical climate			Wet extreme 2030 climate			Median 2030 climate			Dry extreme 2030 climate		
	Volume at 100%	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation
	GL	percent											
Paroo													
Queensland unsupplemented	0.07	98%	100%	0%	98%	100%	0%	97%	100%	0%	97%	100%	0%
NSW unregulated	0.1	85%	100%	0%	88%	100%	0%	85%	100%	0%	84%	100%	0%
Warrego													
Queensland medium security	2.612	98%	99%	0%	98%	99%	0%	98%	99%	0%	97%	99%	0%
Queensland unsupplemented	90.88	6%	42%	0%	9%	53%	0%	5%	42%	0%	4%	35%	0%
NSW unregulated	8	16%	98%	0%	17%	98%	0%	11%	98%	0%	7%	98%	0%
Condamine-Balonne													
Upper Condamine medium security	30.6	82%	98%	0%	81%	94%	0%	73%	92%	0%	63%	87%	2%
Chinchilla medium security	3.7	98%	100%	0%	98%	100%	0%	97%	99%	0%	91%	97%	0%
St George medium security	71.8	100%	100%	0%	100%	100%	0%	100%	100%	0%	100%	100%	0%
Lower Balonne unsupplemented	600	8%	26%	0%	11%	34%	0%	8%	23%	0%	6%	18%	0%
Middle Condamine unsupplemented	253.5	14%	66%	0%	16%	71%	0%	13%	63%	0%	11%	59%	0%
Nebine unsupplemented	9.75	10%	70%	0%	27%	80%	0%	9%	61%	0%	8%	60%	0%
NSW unregulated	1.7	1%	83%	0%	1%	84%	0%	1%	83%	0%	1%	76%	0%
Moonie													
Queensland unsupplemented	74.72	13%	40%	3%	13%	44%	3%	13%	34%	3%	12%	25%	3%
NSW unregulated	3	4%	18%	5%	6%	19%	4%	4%	18%	5%	3%	14%	5%
Border-Rivers													
NSW general security	264.41	0%	47%	16%	0%	59%	7%	0%	46%	23%	0%	30%	39%
Queensland Glenlyon medium security	82.87	0%	16%	0%	0%	16%	0%	0%	14%	0%	0%	9%	2%
Queensland Coolmunda medium security	18.11	73%	86%	1%	84%	93%	0%	74%	88%	0%	49%	73%	2%
NSW supplementary access	120	34%	72%	5%	41%	77%	4%	33%	73%	5%	27%	64%	8%
Queensland unsupplemented	150	8%	49%	0%	10%	54%	0%	8%	47%	0%	8%	41%	0%
Gwydir													
General security	513.99	29%	55%	1%	43%	72%	0%	22%	49%	1%	12%	32%	3%
Supplementary access	40	34%	72%	5%	41%	77%	4%	33%	73%	5%	27%	64%	8%
Namoi													
Peel general security	30.2	65%	91%	0%	79%	97%	0%	62%	90%	2%	44%	75%	8%
Namoi general security	254.5	66%	87%	0%	87%	99%	0%	61%	81%	0%	40%	62%	0%
Peel supplementary access	2	5%	25%	0%	12%	34%	0%	7%	29%	0%	4%	36%	0%
Namoi supplementary access	117.3	6%	39%	0%	10%	48%	0%	7%	40%	0%	4%	32%	0%

		Historical climate			Wet extreme 2030 climate			Median 2030 climate			Dry extreme 2030 climate		
	Volume at 100%	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation	% of years with 100% allocation	% of years with 50% allocation	% of years with zero allocation
	GL	percent											
Macquarie-Castlereagh													
Macquarie general security	637	34%	56%	7%	46%	70%	4%	32%	50%	7%	23%	39%	13%
Supplementary access	50	11%	60%	1%	11%	73%	1%	11%	56%	1%	11%	49%	1%
Barwon-Darling													
A Class access	312	13%	84%	0%	11%	88%	0%	13%	84%	0%	14%	75%	0%
Lachlan													
Lachlan general security	627.758	0%	71%	8%	0%	73%	8%	0%	64%	14%	0%	43%	23%
Belubula general security	24.14	82%	91%	4%	83%	91%	5%	70%	78%	10%	58%	68%	19%
Murrumbidgee													
General security	2043.432	50%	95%	0%	60%	100%	0%	45%	88%	0%	18%	61%	0%
Supplementary access	162	12%	76%	0%	15%	79%	1%	9%	61%	3%	8%	44%	4%
Murray													
Lower Darling general security	31.4	90%	90%	10%	95%	95%	5%	86%	86%	14%	66%	86%	34%
Lower Darling supplementary access	250	100%	100%	0%	100%	100%	0%	100%	100%	0%	100%	100%	0%
NSW high security	251.2	68%	100%	0%	75%	100%	0%	52%	100%	0%	9%	100%	0%
NSW general security	1671	68%	86%	0%	75%	91%	0%	52%	74%	0%	9%	43%	5%
NSW supplementary access	250	53%	74%	12%	49%	71%	10%	38%	60%	20%	12%	29%	36%
Victoria Low Reliability Water Share	390.7	80%	86%	9%	85%	88%	8%	64%	70%	76%	12%	14%	81%
Victoria High Reliability Water Share	1277.8	100%	100%	0%	100%	100%	0%	97%	100%	0%	58%	88%	3%
SA entitlement	1850	100%	100%	0%	100%	100%	0%	99%	99%	0%	77%	89%	4%
Ovens													
Bulk entitlement	37.234	63%	100%	0%	75%	100%	0%	63%	100%	0%	40%	98%	0%
Goulburn-Broken													
Goulburn High Reliability Water Share	746.1	97%	100%	0%	95%	100%	0%	87%	99%	0%	33%	81%	0%
Broken High Reliability Water Share		88%	92%	0%	86%	92%	0%	83%	91%	0%	54%	71%	0%
Goulburn Low Reliability Water Share	349.8	42%	62%	24%	36%	55%	27%	21%	40%	36%	1%	4%	93%
Broken Low Reliability Water Share		84%	62%	11%	81%	39%	14%	79%	43%	17%	49%	55%	45%
Campaspe													
High Reliability Water Share	262.6	99%		0%	98%		0%	97%		0%	83%		0%
Low Reliability Water Share	108.5	74%		10%	71%		17%	67%		17%	37%		33%
Loddon													
High Reliability Water Share	261	92%		0%	91%		0%	83%		0%	32%		0%
Low Reliability Water Share		42%		24%	36%		27%	21%		36%	1%		93%

Appendix C: Twenty highest priority groundwater management units

Rank	Groundwater management unit	Reporting region	Area of GMU	Current extraction 2004/05	Future extraction 2030	Extraction limit	Required minimum assessment	Actual assessment
			km^2	GL/y				
1	Lower Murrumbidgee (downstream of Narrandera)	Murrumbidgee	33,003	323.8	280.0	280.0	very thorough	very thorough
2	Mid Murrumbidgee Alluvium	Murrumbidgee	1,234	48.2	80.1	8.5	very thorough	moderate to thorough
3	Upper Macquarie Alluvium (upstream of Narromine)	Macquarie-Castlereagh	290	37.0	38.4	4.3	very thorough	simple
4	Upper Murray Alluvium (upstream of Corowa)	Murray	360	30.5	40.5	3.6	very thorough	simple
5	Upper Namoi Alluvium	Namoi	3,771	100.3	122.1	122.1	very thorough	moderate to thorough
6	Cudgegong Valley Alluvium	Macquarie-Castlereagh	38	9.3	13.2	0.5	very thorough	simple
7	Upper Lachlan Alluvium	Lachlan	13,344	72.7	192.0	91.6	very thorough	thorough
8	Lower Lachlan Alluvium	Lachlan	26,074	125.7	96.0	96.0	thorough	thorough
9	Belubula Valley Alluvium	Lachlan	36	5.2	6.3	0.2	thorough	simple
10	Lower Murray Alluvium (downstream of Corowa)	Murray	18,080	73.9	83.7	83.7	thorough	thorough
11	Lower Namoi Alluvium	Namoi	7,592	89.0	86.0	86.0	thorough	thorough
12	Lower Macquarie Alluvium (downstream of Narromine)	Macquarie-Castlereagh	4,134	55.9	69.3	69.3	thorough	moderate to through
13	Lower Gwydir Alluvium	Gwydir	2,513	35.5	32.3	32.3	thorough	moderate to thorough
14	Shepparton WSPA	Goulburn-Broken	6,784	80.7	120.0	203.0	moderate	thorough
15	Toowoomba South Basalt	Condamine-Balonne	1,715	24.0	29.9	35.0	moderate	moderate to thorough
16	Condamine CGMA SA 3	Condamine-Balonne	1,278	32.7	51.7	51.7	moderate	moderate
17	Lachlan Fold Belt	Macquarie-Castlereagh	38,311	42.5	106.3	425.3	moderate	simple
18	Katunga WSPA	Murray	2,124	27.4	40.5	46.5	moderate	thorough
19	Mid Loddon WSPA	Loddon-Avoca	2,337	18.1	37.2	34.0	moderate	thorough
20	Campaspe Deep Lead WSPA	Campaspe	1,095	26.1	31.0	44.0	moderate	thorough

Appendix D: Groundwater use

Region	2004/05 GW use	2004/05 GW use as a percentage of total average water use	2004/05 GW use as percent of total water use in year of lowest surface water use	Possible 2030 GW use	2030 GW use as percent of total average water use	2030 GW use as percent of total water use in year of lowest surface water use
	GL/y	percent		GL/y	percent	
Paroo	0.3	100%	100%	0.9	100%	100%
Warrego	0.9	unknown (very low)	unknown (very low)	unknown (very low)	unknown (very low)	unknown (very low)
Condamine-Balonne	244.4	18%	61%	225.2	25%	69%
Moonie	0.0	<0.1%	81%	0.8	2%	100%
Border Rivers	34.1	8%	26%	124.1	28%	67%
Gwydir	46.2	12%	55%	163.8	36%	85%
Namoi	254.8	49%	78%	470.1	66%	94%
Macquarie-Castlereagh	182.1	33%	84%	410.2	54%	93%
Barwon-Darling	10.1	4%	18%	239.7	50%	86%
Lachlan	236.0	45%	90%	439.7	63%	95%
Murrumbidgee	406.5	17%	26%	851.8	21%	51%
Murray	233.4	5%	8%	727.4	15%	24%
Ovens	12.3	33%	45%	23.0	48%	60%
Goulburn-Broken	92.2	10%	16%	154.3	17%	41%
Campaspe	28.8	9%	12%	32.9	10%	21%
Loddon-Avoca	29.3	9%	14%	58.6	18%	43%
Wimmera	1.8	4%	18%	2.2	4%	18%
Eastern Mount Lofty Ranges	18.8	64%	77%	31.0	74%	86%

Endnotes

1 Project methods report

(a) CSIRO (2007) Overview of project methods. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 12pp.

2 Regional reports

(a) CSIRO (2007) Water availability in the Border Rivers. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 144pp.

(b) CSIRO (2007) Water availability in the Eastern Mount Lofty Ranges. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 104pp.

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

(d) CSIRO (2007) Water availability in the Paroo. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 88pp.

(e) CSIRO (2007) Water availability in the Warrego. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 89pp.

(f) CSIRO (2007) Water Availability in the Wimmera. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 108pp.

(g) CSIRO (2008) Water availability in the Barwon-Darling. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 106pp.

(h) CSIRO (2008) Water availability in the Campaspe. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 120pp.

(i) CSIRO (2008) Water Availability in the Condamine-Balonne. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 169pp.

(j) CSIRO (2008) Water availability in the Goulburn-Broken. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 132pp.

(k) CSIRO (2008) Water availability in the Gwydir. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 134pp.

(l) CSIRO (2008) Water availability in the Lachlan. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 133pp.

(m) CSIRO (2008) Water availability in the Loddon-Avoca. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 132pp.

(n) CSIRO (2008) Water availability in the Macquarie-Castlereagh. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 144pp.

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Enquiries

More information about the project can be found at www.csiro.au/mdbsy. This information includes the full terms of reference for the project, an overview of the project methods and all project reports.

Contact Us

Phone: 1300 363 400
+61 3 9545 2176

Email: enquiries@csiro.au

Web: www.csiro.au

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Z00 34050