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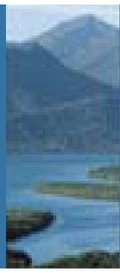

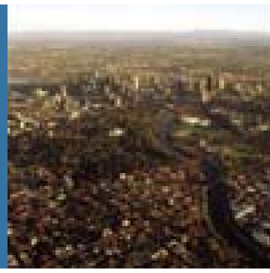

Water for a Healthy Country

# The Shared Water Resources of the Murray-Darling Basin

Part I in a two part series on the shared water resources of the Murray-Darling Basin prepared for the Murray-Darling Basin Commission

**February 2006**

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MURRAY-DARLING BASIN COMMISSION

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# Foreword

This report and its companion report *Risks to the Shared Water Resources of the Murray-Darling Basin* have been prepared by CSIRO to inform discussion on matters that have the potential to affect the shared water resources of the Basin.

The Murray-Darling Basin Ministerial Council is implementing a number of major strategies to improve the environmental and economic sustainability of the Murray-Darling Basin. These strategies include the Cap on Diversions, which is a limit on the volume of water which can be diverted from the Basin rivers for consumptive uses and the Living Murray, which is, as a first step, undertaking actions to achieve environmental benefits for six significant ecological assets along the River Murray. The success of both these strategies, as well as the Ministerial Council's other Basin strategies, is dependent upon the quantity and quality of water in the Basin's rivers.

In 2004, the Ministerial Council directed the Murray-Darling Basin Commission to investigate possible risks to the shared water resources of the Basin. The Commission identified six risks it considered warranted immediate investigation – climate change, increased numbers of farm dams, increased groundwater use, bushfires, afforestation (large scale tree plantings) and reduced return water flow from irrigation. These two reports produced by the CSIRO are a compilation of information on the shared water resources and on the six risks of immediate concern.

Work is continuing through the Commission and its partner governments to better understand how the six risks might impact upon the Basin's shared water resources, to identify actions the governments and communities of the Basin can take to reduce the level of risk or lessen the potential impact and to identify other potential risks.

This work is an important part of the Murray-Darling Basin Ministerial Council and Commission's business and it is essential for the sustainable management of the shared water resources of the Murray-Darling Basin.

Wendy Craik
Chief Executive
Murray-Darling Basin Commission

# Contents

# Summary

This is the first of two reports on the shared water resources of the Murray-Darling Basin. It provides an overview of the hydrology of the Murray-Darling Basin and a summary of the links between the Basin hydrology and the key strategies of the Murray-Darling Basin Ministerial Council.

The second report, *Risks to the Shared Water Resources of the Murray-Darling Basin*, is a summary of recent preliminary work to improve our understanding of potential future changes to the shared water resources of the Basin and the risks those changes might pose.

In an average year the total water input into the Murray-Darling Basin is 508,000 GL. The vast majority of this is evaporated or transpired by plants. About 24,000 GL remains as run off and flows into the streams of the Murray-Darling Basin. There is also flow into the groundwater systems of the Basin. The Basin's groundwater and streams are referred to as "shared water resources" as they flow across catchments and across States.

Australia experiences higher river flow variability than any other continent and the Murray-Darling Basin is no exception. The majority of the Basin's rainfall and run off is in the southeast and as a result riverflows in the southeast are the least variable. As one moves westward and northward potential evapotranspiration exceeds run off and as a result run off decreases substantially. In the north, run off is more dependent on large rainfall events and is therefore episodic.

To overcome the high variability in flow there has been considerable public and private investment in water storage. Storages in the Murray-Darling Basin have a total capacity of about 25,000 GL, which is equivalent to an average year's run off. The storages and other infrastructure on the River Murray and its tributaries allow water to be stored and released when most needed by irrigators. This has resulted in changed flow patterns in the regulated lower parts of the Basin. The River Murray, for example, now has its highest flows in summer compared with spring peaks under natural conditions. Flow volumes have also changed, with the mean annual flow of many of the Basin's rivers now less than under natural conditions.

The volume and quality groundwater systems of the Basin reflect variations in landscape, geology, and recharge and groundwater flow conditions. In the southeast, rainfall exceeds potential evapotranspiration in most winters, so diffuse, wide area groundwater recharge from soil drainage is fairly steady. Recharge will increase during prolonged wet periods and decrease during prolonged dry periods. In the north, large floods over wide areas will recharge the near-surface aquifers but a single event is less important than a prolonged wet period. The connectivity between groundwater and surface water is complex. Some rivers gain water from groundwater and others lose.

Groundwater is important at a Basin-scale not just because of its interaction with surface water but because of the ability of the groundwater to mobilise salt. Many soils and aquifers of the Murray-Darling Basin are naturally saline.

To understand hydrological consequences of resource management strategies, we must improve three areas of knowledge:

- measuring water balances and water accounts;
- understanding environmental and other values of water use; and
- frameworks and models that integrate hydrology with water use values for a river basin with highly variable flows.

Potential risks to the shared resources have implications for effective management strategies. The Murray-Darling Basin Ministerial Council is assessing these risks. A summary of preliminary work on the risks to the shared water resources is the subject of the second report in this series.

# Introduction

The Murray-Darling Basin occupies about 1.06 million square kilometres, approximately 14% of Australia. With an average rainfall of about 480 mm, the total water input into the Basin in an average year is 508,000 GL. Most of the rain falling on the Basin is evaporated or transpired by plants. Of the rainfall that is not evaporated or transpired, some recharges the groundwater and the remainder flows into streams as run off. Both the groundwater and the streams (or surface water) of the Basin flow across catchments and across States and as such they are shared water resources.

The National Land and Water Resources Audit (2000) estimated basin run off into streams (surface water) to be, on average, 23,850 GL/year[1].

The quantity added to the Basin groundwater resources is considerably harder to estimate. State water agencies estimate the Basin's groundwater sustainable yield (which is intended to be an estimate of how much water can be sustainably extracted from the Basin's groundwater store) for 2002–03 at 2,356 GL[2].

In addition to run off from within the Basin, water is also transferred in from outside the Basin. Inter-Basin transfers occur from the Snowy River to the Murray and Murrumbidgee and from the Glenelg River to the Wimmera River in Victoria. These transfers average 1,200 GL/year[3].

The shared water resources of the Basin are stored in dams, where some water is lost to evaporation, and is diverted for irrigation. The shared water resources flow into wetlands and across floodplains. In some cases surface water drains into groundwater aquifers and in other cases is recharged by groundwater aquifers. Ultimately, the shared water resources discharge into the sea at the Murray mouth in South Australia, although whether this happens in a given year depends upon the amount of rainfall in the Basin.

A schematic diagram of the shared water resources of the Basin is provided in Figure 1.

There is considerable pressure on the shared water resources of the Basin. Demand for water for consumptive use is increasing at the same time that the health of rivers, wetlands and other water dependent ecosystems is decreasing.

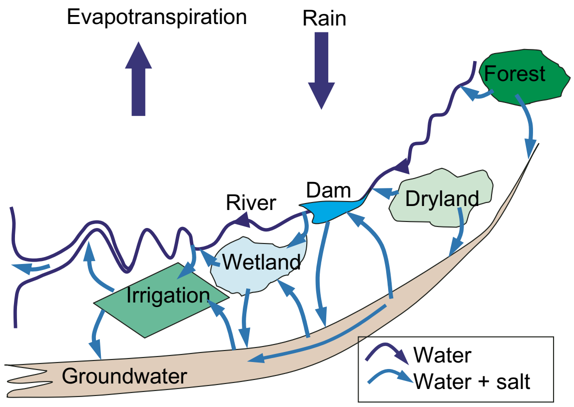


**Figure 1. Schematic representation of water resource movement patterns in the Basin.**

To add further complications, there are a number of significant changes to the Basin environment which have the potential to alter the quantity and quality of the Basin's shared water resources, that is, they pose a risk to the shared water resources.

The purpose of this report is to bring together available information to describe:

- The shared water resources of the Basin;
- The key strategies that the Murray-Darling Basin Commission (MDBC) has developed to better manage the shared resources of the Basin; and
- The potential risks to the shared water resources of the Basin (see Part II of this series).

## A whole-of-basin approach

The Murray-Darling Basin is a natural hydrologic unit. The boundaries of the Basin are well-defined for surface water though less well defined and different for groundwater. Very nearly all the water flowing into and out of the Basin is easy to identify (though perhaps hard to measure accurately). The first consequence of this natural unit is we can draw up a balance sheet in which we have accounted for more or less all the water.

Secondly, what happens in one part of the Basin affects what happens elsewhere. Direct effects include the downstream impact of floods generated upstream on rivers, wetlands and even the mouth.

Indirectly, management of one catchment may be affected by another even though water cannot flow directly between the two. A flood in the Darling can be used to supply water to South Australia and to help maintain flow out at the River Murray mouth, though this opportunity is infrequent and flows in the Darling are small compared to those in the Murray.

In the longer term, land use change or climate change that will enhance or diminish long-term flows from one part of the Basin will impact the opportunities for management in all parts of the Basin. Some other parts of the Basin are poorly connected; for example, little water flows from the Lachlan into the Murrumbidgee and Murray.

Thirdly, although the components of a water balance are easy to identify in principle, many components are hard to measure accurately. A water balance can help improve the estimates of poorly measured components. The requirement that all water entering minus all the water leaving the Basin must equal the change in storage within the Basin can help constrain the estimates of many components of a water balance. A whole-of-basin approach improves accounting.

Numerical models used to predict and manage flows within the Basin must either explicitly take a whole-of-basin systems approach, or, if they deal with only a part of the Basin, must treat the rest of the Basin as a source of imports and a destination for exports of water. The imports and exports must be estimated, so the view is implicitly whole-of-basin.

Finally, a whole-of-basin systems approach allows for smarter and more informed planning and implementation.

### A whole-of-basin approach

- Balances inputs and outputs.
- Explains connections between catchments and between surface and groundwater.
- Explains poorly connected or disconnected hydrological elements.
- Improves water accounting.
- Indicates the relevant scale or scales for addressing specific questions.

## Structure of report

In this review we first consider the influence of the key climate drivers of rain and potential evapotranspiration, how these determine the run off and the flow of rivers, and how they vary in the different regions of the Basin, and with time. The impact on river flow of diversions for irrigation and other uses is then examined.

We next consider groundwater in the different regions of the Basin, its interaction with the surface waters and its use.

Having established the hydrological picture at the whole-of-basin scale, we turn to the relation of the main processes to MDBC strategies, and identify what more we need to know in order to better implement these strategies. We conclude with some suggestions for addressing these knowledge gaps.

# Surface water

## The main hydrological drivers

With an average annual rainfall of about 480 mm, approximately 508,000 GL/year of water falls on the Basin. Rainfall varies significantly from the wetter and less variable east (up to about 2,000 mm at the wettest point) to the drier and more variable west (about 200 mm) (Figures 2 and 3). Rainfall also varies from south to north with increasing summer dominance and variability (Figure 3). Furthermore, rain in the northern part of the Basin is often monsoonal rainfall of high intensity and short duration.

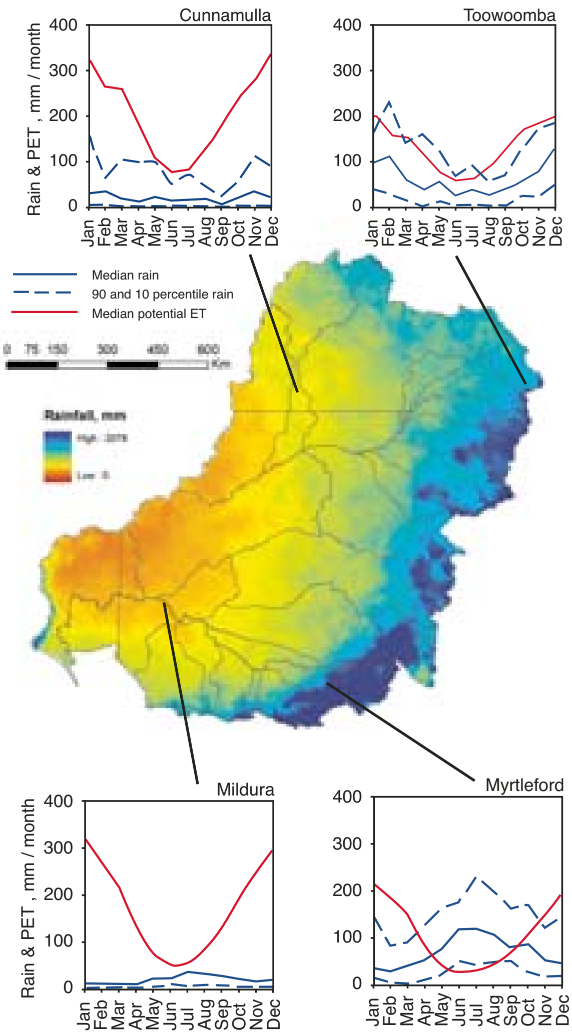


**Figure 2. Median annual rainfall with superimposed median monthly pan evaporation and median 90 and 10 percentile rainfalls for the SE, NE, NW and SW corners of the Basin (Source: SILO datasets[4]).**

Most rain is evaporated or transpired at or near where it falls. Figure 4 shows the median potential evapotranspiration, increasing from southeast to northwest.

Rain exceeds potential evapotranspiration only in the southeast and so this area generates most of the run off (Figure 5), mostly in winter. Run off decreases and becomes more variable away from

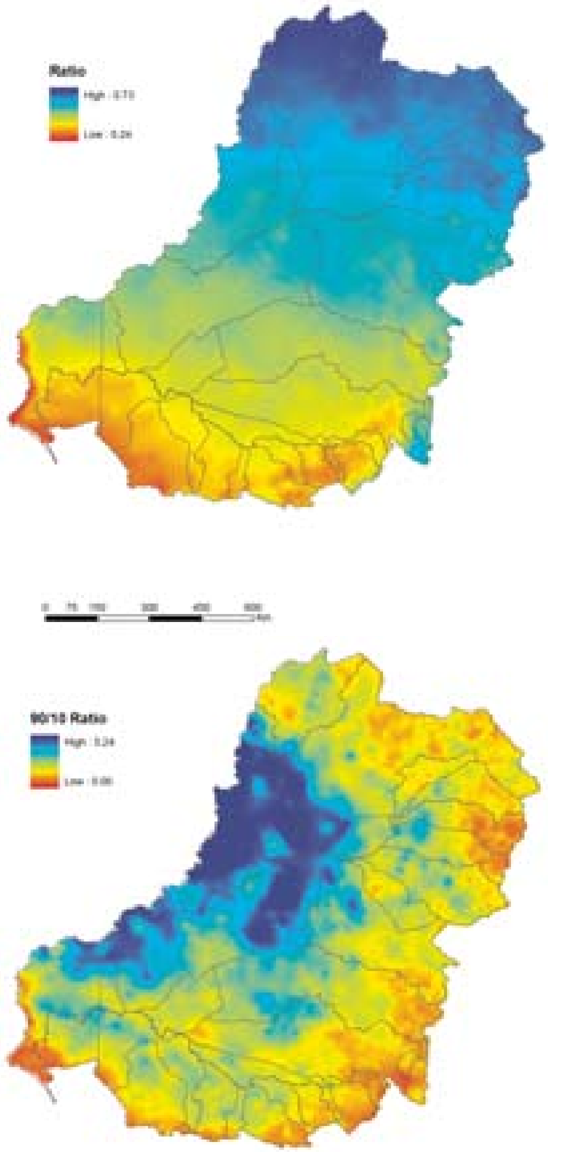


**Figure 3. Summer rainfall dominance (proportion of rain falling in summer, top) and variability (ratio of 90 to 10 percentile rain, bottom) (Source: SILO datasets[4]).**

the southeast. In the southwest it is still winter dominated but much less in volume. In the north run off is more dependent on big rain events and hence is more episodic. The total is less than in the southeast. Overall, average run off is estimated at 23,850 GL/year, or about 5% of the total rainfall falling in the Basin (which is a much smaller proportion than most major river basins around the world[5]).

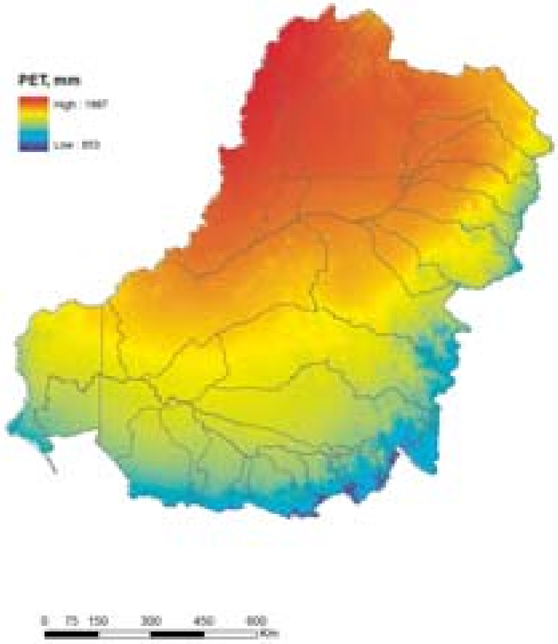


**Figure 4. Potential evapotranspiration (Source: SILO datasets[4]).**

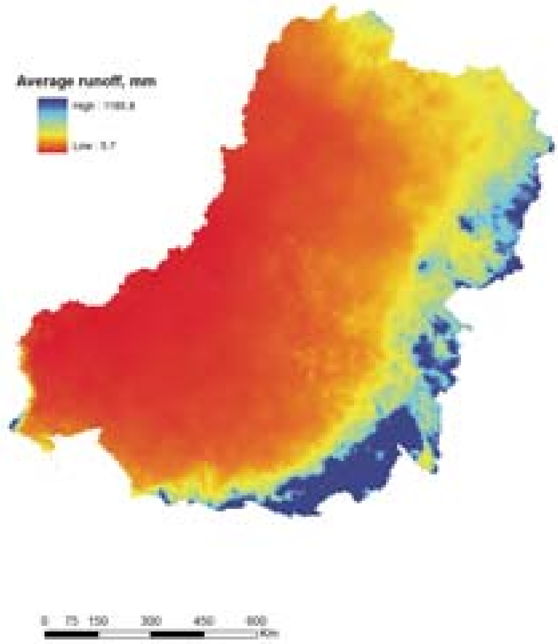


**Figure 5. Annual average run off, calculated as the difference between rainfall and actual evapotranspiration (Source: SILO datasets[4]).**

## The water balance

The principle of the 'water balance' underpins our understanding of catchment hydrology. It states that water cannot be created or destroyed, and therefore we can close a full water balance account if we know all imports, exports and storage changes.

Over a period of time, the amount of water stored within a catchment (in groundwater, soil moisture, or on the surface) will equal the difference between the amount of water entering the catchment (as rainfall, snow, hail and fog) and the amount of water leaving it (evaporated to the atmosphere, or flowing out in streams or beneath the surface as groundwater).

The water balance concept can help us to determine total water use in a catchment (called evapotranspiration) from measurements of rainfall and streamflow, if groundwater flows can be ignored. Over long periods, we can assume that storage changes are comparatively small and therefore total water use equals rainfall minus streamflow.

# The consequences for rivers

Because the majority of the Basin's rainfall is in the southeast, river flows are least variable in the southeast, and become more variable westward and northward. The further northwest, the more rivers lose flow in lower reaches through evapotranspiration.

The Basin also becomes considerably flatter westwards and as a result rivers break into distributaries.

Distributaries are river branches that flow away from and thus reduce the flow in the main channel. In some cases (for example, the Edwards River and its distributaries, and the Yanco Creek) the distributary flow returns to the main rivers. In other cases (such as the Willandra Creek system of distributaries from the Lachlan, and the Narran River distributary of the Culgoa) the flow does not return to the main rivers, and often end in wetlands5. Some rivers, such as the Avoca and Wimmera in the southwest and the Paroo in the northwest, also fail to reach the Murray and the Darling. In the north of the Basin, many streams from the upland areas disappear into the sandy alluvial soils before reaching the main river valley and may recharge perched water tables[6].

The River Murray is unusual in maintaining high flow for a long distance, because tributary inflows more or less balance losses.

Figures 6 and 7 show the variability in annual flow and median annual flow of some selected rivers of the Basin. Variability increases to the northwest (Maranoa-Culgoa, Namoi, Darling) and is not related to river size. Variability is more extreme if monthly flows are considered. On a global scale Australia experiences higher river flow variability than any other continent[5]. The Murray-Darling is no exception to this, in spite of the fact that much of the river system in the south is now highly regulated.

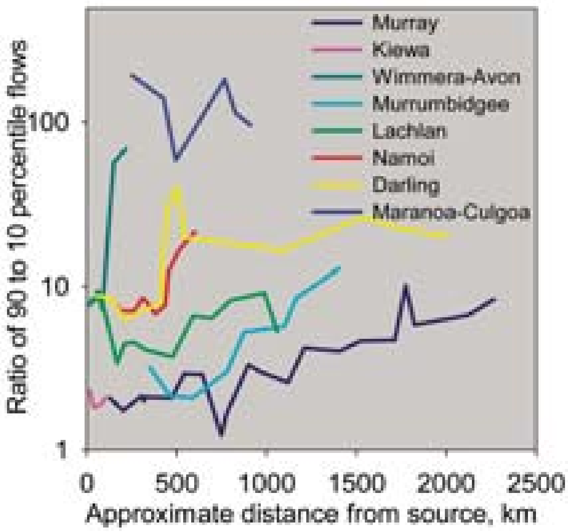


**Figure 6. Variation in annual flow (ratio of 90th to 10th percentile flows) as a function of distance from source (Source: New South Wales PINEENA database[7], Watershed in Queensland[8] and the Victorian Water Data Warehouse[9]).**

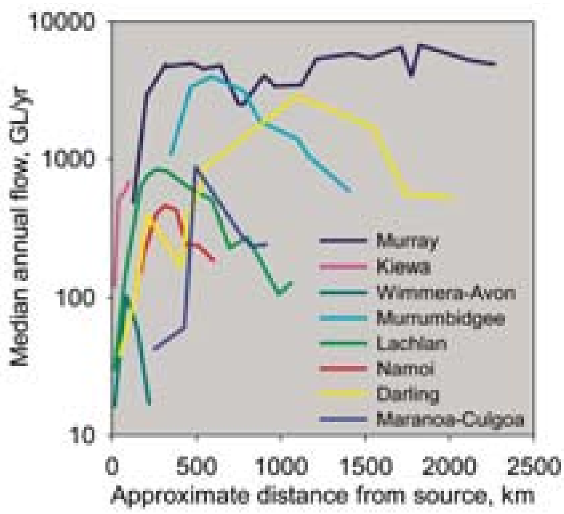


**Figure 7. Median annual flow as a function of distance from source (Data sources as for Figure 6).**

## Flow regulation

To overcome the high variability in flow there has been considerable public and private investment in water storage in the Murray-Darling Basin.

Artificial flow regulation for diversion and other purposes occurs from the many dams in the headwaters of the Murray-Darling Basin (Figure 8), which have a total capacity of about 25,000 GL[1] (about one year's run off), and the many weirs along the rivers, especially in the southern part of the Basin[5,6]. Natural storages are also used to regulate flow. Lake Victoria on the Murray and the Menindee Lakes on the Darling are natural features used as temporary storages[5,6], to be released when required to maintain flow or dilute saline flows in the lower Murray.

In Queensland, where there are few large upstream water storages, low reliability of surface water supply has led to increased use of the groundwater resource[6], and the construction of large private off-stream storages (ring-tanks)[10].

The large storages and other infrastructure in the River Murray and its tributaries allow water to be stored and to be released when needed by irrigators. This has profoundly changed flow patterns in the regulated lower parts of the Basin. Flows are now not primarily determined by rainfall, but by the balance between water orders from upstream storages and take-offs at diversion points. The river


**Figure 8. Distribution of storages greater than 10 GL. The storages in the Lower Murray and Lower Darling catchments are Lake Victoria and the Menindee Lakes (Source: MDBC Water Audit Monitoring Reports[1]).**

system is effectively a delivery channel rather than a natural system, and this has already caused a wide range of impacts on flows, water quality and river health. Some examples of changes in flow pattern, water quality and ecosystem health are:

- The River Murray now has its highest flows in summer when water is ordered by downstream irrigators compared with spring peaks under natural conditions. The frequency of moderate floods has decreased, whereas low flow periods are more frequent.
- Salinity levels in the river have risen and algal blooms have increased in line with the increased frequency of periods of low flow.
- The invasion of carp and the decline of native fish species in the rivers are almost certainly related to changed flow patterns.
- The current deterioration of wetlands and riparian forests along the lower Murray and Murrumbidgee Rivers can largely be attributed to changed flooding regimes with some wetland and river forest areas being permanently inundated and others no longer receiving floods.

Due to diversion, the mean annual flow of many of the Basin's rivers is now less than under natural conditions (Figure 9). The mean annual discharge from the Murray mouth for the last ten years was about 2,700 GL1, whereas under natural conditions it is estimated to have been about 12,000 GL. The only significant exceptions to the reduced flows are in the upper reaches of the Murray and Murrumbidgee rivers where flows have been increased as a result of diversions from other rivers through the Snowy Mountains Scheme[5].

Regulation has also reduced flow in all the major northern rivers except the Gwydir (Figure 10). The Gwydir River end-of-system flows are greater under current than under natural conditions because more flows are now routed down the Mehi, Moomim and Carole Channels, which reach the Barwon River.

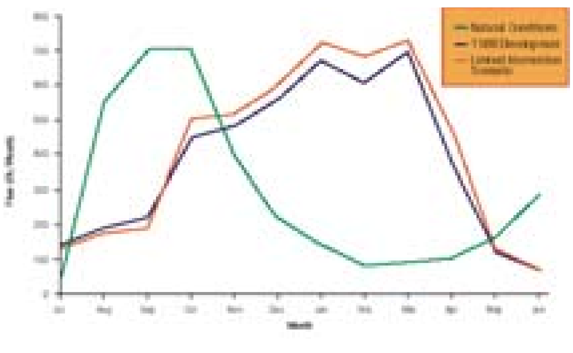

**Figure 9. Change in seasonality of flow of the Murray (Source: Crabb[5]).**

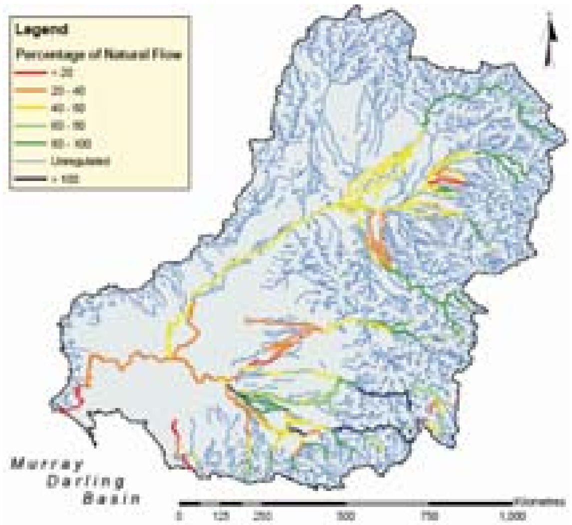


**Figure 10. Regulated river links showing the proportion of flow lost at reservoirs or off-takes and gains due to releases from hydroelectric schemes and some irrigation canal inflow (Source: DeRose *et al.*[11]).**

## Evaporation from open water

The total open water evaporation from major water bodies within the Basin is in the order of 3,000 GL/year. This is a significant component of the average run off of 23,850 GL/year.

The major storages combined evaporate about 1,300 GL/year1 (annual average – with a high in 1998-99 of about 1,600 GL and a low in 2002–03 of about 800 GL), with the Menindee Lakes accounting for about 460 GL/year and Lake Victoria a further 120 GL/year – these are also shallow and in a hot, dry climate. The artificial storages are generally deeper and in cooler, wetter climates. The largest, Lake Hume, accounts for about 60 GL/year.

The largest single contributor to evaporation within the Murray-Darling system are the Lower Lakes in South Australia (Albert and Alexandrina), about 750 GL/year (annual average)[12]. The Lower Lakes are shallow, and in a warm, dry climate that enhances evaporation.

Evaporation from the Murrumbidgee below Burrinjuck to the confluence with the Murray has been estimated at about 70–80 GL/year[13]. The total from all the major rivers in the Basin is probably in the order of ten times that amount or approximately, 1000 GL/year.

Major private storages for cotton irrigation in the northern catchments will also add to these figures[10], but the authors did not have access to reliable estimates of this source of evaporation.

## Irrigation: the greatest water user

Irrigated agriculture covers a total of almost 1.5 million ha in the Basin and is the single greatest water user. Total diversions in the Basin are about 11,000 GL per year; about half of annual River Murray stream flow. Around 95% of this diversion is for irrigation[1]. Water diverted from the Murray and Murrumbidgee Rivers accounts for about 80% of all the water diverted in the Basin.

The main features of irrigation can be considered in terms of four regions, characterised by four main industries with different patterns of water use (Figure 11).

- Pasture in the southeast. Often flood irrigated, often for much of the year. 550–750 mm applied water is common[15,16]. Diversions are based on annual water entitlements. Many unlined channels result in seepage, and there is good potential for improving conveyance efficiencies (currently about 80%).
- Rice in the Murray and Murrumbidgee. Flooded (standing water) for about three months in the summer. Applied water averages more than 1000 mm[15,16]. Diversions are based on annual water entitlements. Again, there are many unlined channels[15], and scope for improving conveyance efficiencies.

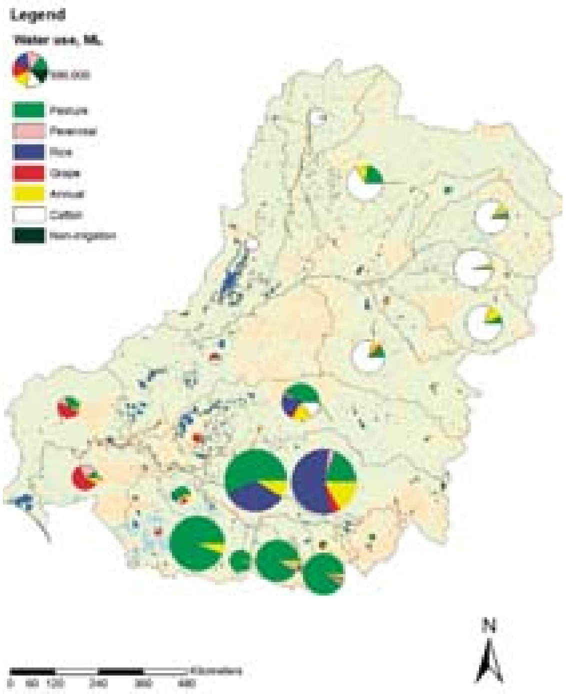


**Figure 11. Major irrigation water uses (estimated) by sub-catchment in the Murray-Darling Basin (Source: based on Bryan and Marvanek[14]).**

- Lower Murray is smaller and dominated by grapes and perennial horticulture, with water mostly applied by sprinkler or micro systems[16]. Water use varies, with an average of 600 mm[15]. Diversions are based on annual water entitlements. Unlined channels on sandy soils result in some of the lowest conveyance efficiencies in the Murray-Darling Basin (56% in Wimmera Mallee)[15], with much scope for gains. Other areas have piped delivery and conveyance efficiencies of greater than 90%. Much of the system is being upgraded.
- Northern (Darling) catchments are dominated by cotton. Water use is around 700 mm[15]. Diversions are based on licences which: limit the volume that may be pumped in a year; stipulate the size of pumps and other pumping rules; and set a commence-to-pump threshold such as a river height[1]. Unlined channels on heavy clays are thought to be fairly efficient.

Some fresh groundwater is extracted for irrigation, and drainage from irrigated crops adds to groundwater and sometimes also to salinity problems in shallow aquifers: groundwater recharge from irrigation is estimated at 200 GL/year in the Coleambally, Murrumbidgee and Murray irrigation areas. The impacts differ in the four regions:

- Pasture in the southeast uses some groundwater and adds to groundwater with consequent rises in watertables and salinity. Salinity is historically and currently a serious problem in areas of northern Victoria and the Riverina[16].
- Rice uses little groundwater in proportion to overall use. It adds to groundwater, causing rises in watertables. The consequent impacts on salinity are a serious problem in parts of the Murrumbidgee and Riverina[16].
- Little groundwater is used in the Lower Murray[16] because of its salinity; drainage adds to groundwater locally and increases the salinity problem.
- There is substantial groundwater use in some northern catchments[1,6], amounting to about 31% of total use across the Queensland part of the Basin in 1999–2003, compared to about 11% across the Basin as a whole. Some watertables are declining due to high rates of use. There are few reliable data on deep drainage and recharge, but some recent estimates indicate that this may be higher than previously thought.

## Overall water account

A rough account of the major components of surface run off (annual average for the years 1994–95 to 2002–03) is summarised in Table 1. Other evapotranspiration refers to water lost from wetlands and floodplains. There is no actual figure available for evapotranspiration from floodplains and wetlands so it is estimated as being the water remaining once diversions, discharge at the Murray mouth and open water evaporation are accounted for.

**Table 1. Major components of surface run off.**

| Component | GL/year |
|---|---|
| Run off and transfers in | + 25,000 |
| Diversion | - 11,000 |
| Discharge at mouth | - 3,000 |
| Evaporation (open water) | - 3,000 |
| Other evapotranspiration * | - 8,000 |

* Other evapotranspiration includes consumption in wetlands and on floodplains.

# Groundwater

Groundwater is a major component of the overall hydrology of the Murray-Darling Basin[5,17]. Surface water recharges groundwater aquifers over wide areas by drainage from the surface, or by leakage from one aquifer to another. Recharge can also be concentrated from rivers and lakes.

Discharge from groundwater aquifers can similarly be over a wide area, with groundwater transpired directly by surface vegetation, or concentrated as flows into rivers or springs. Water may take several months to flow from the source of the Darling to the mouth of the Murray, but groundwater flow – and hence the time to respond to hydrologic changes such as land clearing and climate change – can take from years (small local aquifers) to thousands of years (large regional systems).

Over-extraction of groundwater is potentially a risk to the shared water resources of the Basin and this is discussed in more detail later in this report. Groundwater is also important for salinity management. The groundwater in the Murray-Darling Basin varies in salinity, and the more saline groundwaters are of concern where they discharge to the surface or into a river.

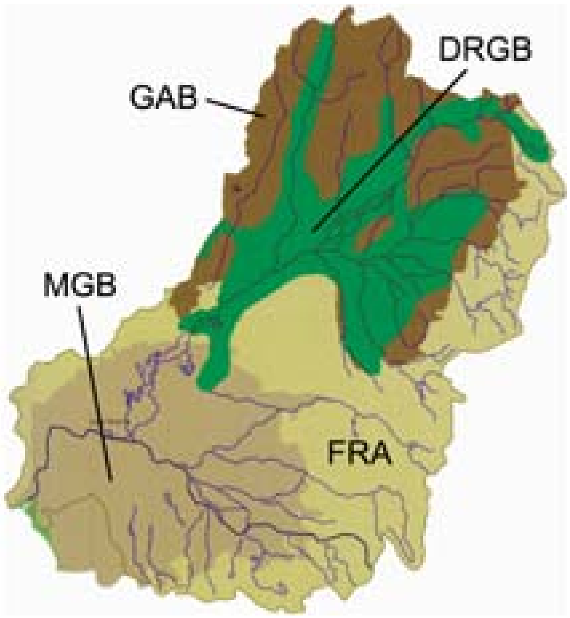


**Figure 12. General distribution of the Great Artesian Basin (GAB), Murray Groundwater Basin (MGB), the Darling Regional Groundwater Basin (DRGB) and fractured rock aquifers (FRA) (Source: Breckwoldt *et al.*[6]).**

## Groundwater systems

The volume and quality of groundwater varies greatly across the Basin[5,6,17], reflecting variations in the landscape, the geology and the conditions of recharge and groundwater flow (Table 2). Large regional groundwater systems, extending for hundreds of kilometres, occur in the younger sedimentary environments of the Murray Geological Basin in the southwest of the Murray-Darling Basin, and under the broad Darling River plains in the north (Figure 12). The Murray Geological Basin comprises many aquifers including the Renmark-Calivil-Lachlan aquifers, the Murray Group Limestone and the Loxton – Parilla Sands. The northern aquifers include the Gunnedah-Narrabri Formations and the Great Artesian Basin.

The Great Artesian Basin is the largest regional groundwater flow system[5,6,17], and lies mainly outside the Murray-Darling Basin. These aquifers recharge around the margin of the Murray-Darling Basin and to its north, with groundwater flowing generally westerly out of the Murray-Darling Basin surface water catchment to discharge in Central Australia. The Great Artesian Basin does not comprise a significant groundwater resource within the Murray-Darling Basin and is not considered further in this document.

In contrast, the smallest (local) groundwater flow systems generally occur in the hilly uplands of the rim of the Basin[17], and elsewhere where there are fairly abrupt, localised changes in landscape relief (Figure 12). Although individual fractured rock aquifers are much smaller and more localized, in total they cover a larger area than the other aquifer systems. They occur on a scale of one or more kilometres, and are relatively responsive (on a scale of decades) to changes in water availability.

**Table 2. Summary of the main groundwater systems in the Murray-Darling Basin**[5,6,17,18]

| System | Aquifer Groups | Recharge | Discharge | Salinity | Use | Groundwater levels |
|---|---|---|---|---|---|---|
| Great Artesian Basin | Many aquifers, up to 3,000 m total thickness | Eastern margin, some seepage from overlying Darling system | To west of Basin, to mound springs, some upward flow of high-pressure parts to overlying aquifers | Mostly fresh, becoming saline towards west | Not significant | |
| Darling | Gunnedah and Narrabri Formations | Eastern margin, seepage from overlying sediments, and from rivers | Rivers and direct to vegetation ET | Mostly fresh, more saline in west overlain by generally saline groundwater (Narrabri Formation) | Gunnedah formation heavily allocated, and is an important resource for major irrigated agricultural enterprises in the sub-catchments of Border Rivers, Gwydir River, Namoi River, Macquarie River and Condamine River | Falling in areas of extraction, rising in some areas where irrigation is from surface water, rising in minor areas around the margins of the Basin due to land clearing |
| Murray Geological Basin | – Renmark-Calivil-Lachlan aquifers,<br>– Murray Group Limestone,<br>– Loxton – Parilla Sands | Eastern margin (Renmark-Calivil-Lachlan), western margin (Murray Limestone) downward seepage, rivers | Rivers and direct to vegetation ET.<br>Loxton – Parilla Sands discharges into Murray in the SA Riverland | Fresh in recharging areas, highly saline in discharge areas. Renmark-Calivil-Lachlan overlain by more saline groundwater. Major contributor of salinity to Lower Murray (salt interception schemes) | Considerable in North-central Victoria, Murray and Murrumbidgee regions of NSW, where aquifers are under stress. Irrigation development in Upper Lachlan<br>Some irrigation from Murray Group Limestone | Rising in some areas of Renmark-Calivil due to higher recharge from land clearing for agriculture<br>Rising in parts of Murray Group Limestone and Loxton – Parilla Sands |
| Fractured rock aquifers | Many groups in East and centre of Basin | Downward seepage | Watercourses and direct to vegetation ET | Varies. | Locally important for irrigation, but smaller volumes than regional aquifers | |
| Local aquifers | Many small groups across Basin (various types including fractured rock) | Downward seepage | Watercourses and direct to vegetation ET | Often fresh but can vary | | |

# Groundwater and surface connectivity

Groundwater is recharged from and returns to the surface, sometimes over wide areas where it can be consumed directly by vegetation, or contribute to river flow. The connection is important for management of diversions and environmental allocations, since groundwater extraction can affect river flows and vice-versa.

## Recharge

Groundwater is recharged from the surface, some from rain percolating over wide areas, some from rivers in small zones of high recharge. Groundwater generally follows long-term multiple year cycles, except for small, local, near surface aquifers which respond quite quickly to episodic events like an abnormally wet year or a cyclonic event.

In many places recharge is from a river and, so long as the river flows (which is most of the time for major rivers), recharge will be fairly steady. In the southeast, rain exceeds potential evapotranspiration in most winters, so diffuse, wide area recharge from soil drainage is fairly steady (i.e. all through the winter, not just a single large event) but will increase and decrease with general climate cycles. Episodic events are features primarily of the semi-arid areas and to a lesser extent the drier part of sub-humid zones.

In the north, large floods over wider areas will recharge the Darling near-surface aquifers, but again a single event is less important than a prolonged wet period.

## Connections to rivers

The amount of flow in unregulated rivers that is estimated to come from groundwater varies considerably from 4% to 76%[19]. In other cases (such as the mid-Murrumbidgee) most of the extracted groundwater is estimated to come from the river[20].

Rivers that receive flow from groundwater are called gaining rivers, whereas rivers that leak water to the aquifer are losing rivers. Others can gain and lose depending on the season and other conditions. A river and aquifer may also be connected (that is, there is continuously saturated ground/rock between the base of the river and the water table) or disconnected (Figure 13). Connected rivers can be gaining or losing, but disconnected rivers are always losing. Whether a river is gaining or losing, connected or disconnected depends on the topography, geology and climate, and can vary in time as well as in location.

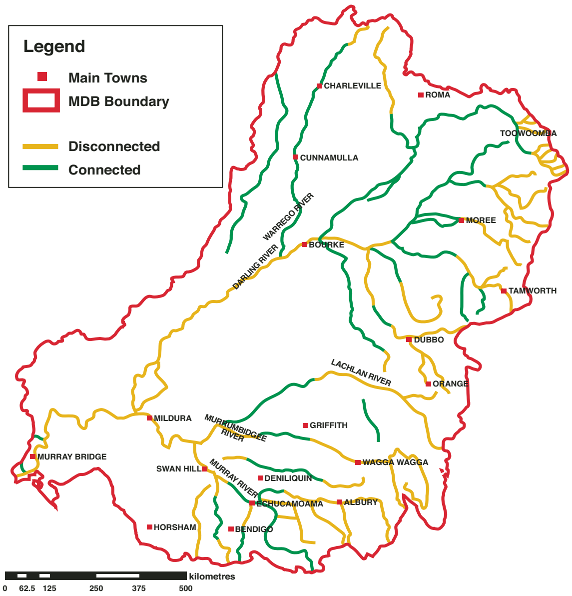


**Figure 13. Connected and disconnected rivers in the Murray-Darling Basin. Some reaches may alternate between connected and disconnected in greater detail than shown (Source: Evans *et al.*[18]).**

Groundwater use reduces water levels and can affect streamflow as well as groundwater levels, particularly in connected rivers.

# Groundwater use and management

Groundwater is an important resource in the Basin. It has historically been poorly defined and undervalued. In some areas it is the only potable water, such as in the Mallee in South Australia. Across the Basin it constitutes around 10–15% of the total volume of water used and is increasingly important in dry periods. It also supports valuable ecosystems. The relative usage of groundwater and surface water by each State is shown in Figure 14.

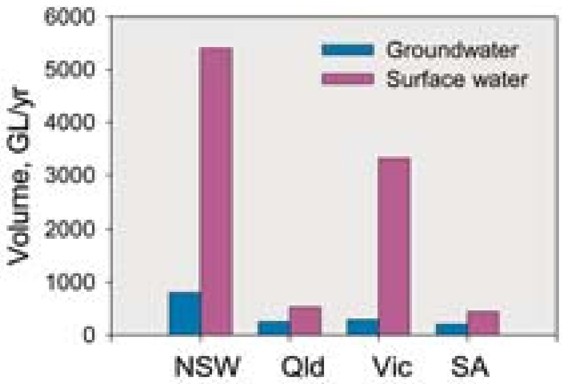


**Figure 14. Use of groundwater and surfacewater by State (Source: Evans *et al.*[18]).**

Groundwater is managed in 72 Groundwater Management Units, across the Murray-Darling Basin, excluding those of the Great Artesian Basin[19]. These are defined by State governments. Outside these management units are Unincorporated Areas, which are generally low yielding and although they contain large reserves of groundwater they have low potential for development.

## Current use

Sustainable yield is defined as the amount of water that can be extracted while remaining in long term balance with other inflows and outflows. It should be noted that the very extraction of groundwater must entail increase in inflows or reduction in other outflows so the balance can be maintained.

In 2002–03 around 50% of the Groundwater Management Units were over-allocated, and in around 15% actual use was above sustainable yield estimates (sometimes substantially). In a further 5%, use was at sustainable yield estimates[21].

Overall, about 1,632 GL of groundwater was taken from Groundwater Management Units in 2002–03, excluding the Great Artesian Basin and the unincorporated aquifers but including the aquifers in the south east of South Australia[22]. This was 724 GL less than the estimated total sustainable yield, and 1,236 GL less than the volume of groundwater allocated. In addition, groundwater in unincorporated aquifers was used at less than sustainable yield estimates.

Use, yield and allocation of groundwater for 2002–03 are shown in Figure 15.

## Trends in use

Groundwater use across the Murray-Darling Basin has increased since groundwater reporting began at the Basin level in 1999–2000. There is ongoing development of groundwater resources for irrigation using existing entitlements, either from the transfer market and/or from unused entitlements ('sleeper licences')[19].

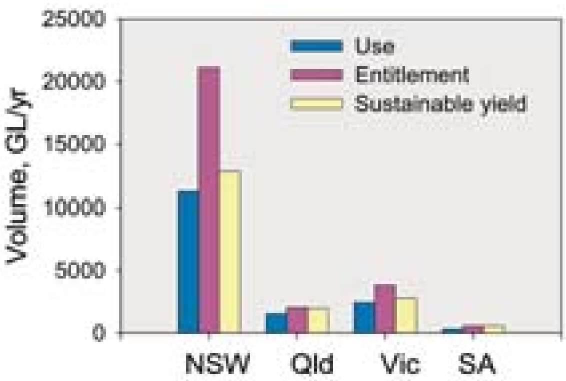


**Figure 15. Summary of groundwater use, yield and allocation, by State in 2002–03 (Source Evans *et al*[18]).**

The recent, extended drought has increased use sharply, with a 22%/year increase from 2000–01 to 2002–03 across metered Groundwater Management Units where use was greater than 10,000 ML/year. The increase varied from 73%/year to 23%/year in different management units.

Whilst the 2002–03 drought and new developments have had a major impact on groundwater use, it is unclear whether future use will decline to pre-drought levels. Investment in infrastructure to extract larger volumes of groundwater (for example, new bores) may mean that the higher levels of groundwater use will remain. Future groundwater use will be influenced by the regulatory and policy environment, market forces, social behaviours and aquifer characteristics.

If the rate of increase seen in the last few years were to continue it would lead to use equaling the sustainable yield limit of about 2,100 GL/year by 2016–17. Worst case predictions indicate use increasing to nearly 4,000 GL/year by 2020–21 if regulatory actions do not keep use within sustainable levels[21].

# Salinity

Groundwater is important to the Basin not just because of its interaction with surface water but because of the ability of groundwater to mobilise salt. Many soils and aquifers of the Murray-Darling Basin are naturally saline and, as a result, many rivers are also naturally saline. Irrigation use and salt interception schemes modify the natural pattern. Salinity in the Basin falls into four broad regions[23].

- The Lower Murray adds the largest natural salt load to the River Murray. Here, the river has always effectively acted as a drain for the saline regional groundwater. Irrigation development has exacerbated this salt load by causing large groundwater mounds not far from the river. In addition, the salt load from clearing for dryland agriculture 50–90 years ago is expected to exceed that from the irrigation impact in 100 years further compounding the impacts. Saline groundwater inflows not only affect river water quality but also floodplain vegetation and wetlands. About 40% of Murray floodplain vegetation in South Australia has been recently mapped as degraded. Salt interception schemes, irrigation zoning and improved water use efficiency have led to about a 200 EC improvement in water quality over the last 20 years. Thus, while groundwater levels, apart from the mature groundwater mounds, are generally rising near the river, salt loads have decreased. Protection and rehabilitation of floodplains will require decreasing their stores of salt and could lead to deteriorating water quality in the river, unless combined effectively with groundwater pumping.

- Most irrigation areas on the River Murray alluvial plains are salt sinks relative to the river. The large volumes of water diverted for irrigation contain salt. Some salt returns via base flow or drainage returns, with the amount dependent on the amount of surface drainage, depth of drainage and groundwater salinity. However, much salt remains in soils, shallow groundwater and evaporation basins or is diverted to wetlands. The main exception has been the Kerang area, where irrigation development on a natural groundwater discharge area, combined with regional drainage, led to salt exports being about six times greater than imports of salt. Over the last 15 years, salt loads in this region have decreased due to water re-use, diversion to evaporation basins, salt harvesting, improved irrigation practices and decreased irrigation.
- In the upland areas of the Murray Basin, the local fractured rock groundwater systems follow climatic trends with higher salt loads following high rainfall years. The larger intermediate and regional alluvial systems have increasing groundwater trends, resulting in overall increasing trends in salt exports to the rivers in southern NSW. In either case, the salt outputs from medium rainfall areas (500–800 mm) generally exceed salt inputs by 3-fold to 15-fold.
- The northern Murray-Darling Basin shows no trend in stream salinity. For many streams, the output of salt is less than salt inputs from rainfall. The likely, but unquantified, sinks for the difference are deep alluvial aquifers or salt diverted for irrigation and stored in the soil. Groundwater trends are mixed – they are falling in some areas of groundwater irrigation, rising in some areas where surface water is used for irrigation. Monitoring is generally too sparse to identify trends in dryland areas. The summer dominant rainfall, the heavier soils and differences in land use may all lead to salinity developing more slowly in this region.

# The overall system

Strategies to balance consumptive and environmental uses of water must take into account regional differences in flows and variability. In general, more management options are available in the southeast of the Basin, where there are larger and steadier flows and more storages. In the north, fewer options are available to implement the strategies.

In summary, the natural hydrological system of the Murray-Darling Basin is characterised spatially by:

- climate (rain and potential evapotranspiration totals, variability and rainfall summer/winter dominance) changing from southeast to north or west;
- surface water characteristics that change evenly from southeast to northwest (see Figures 16 and 17);
- aquifers that are complex in local detail, but broadly fall into four major groups – the Murray Groundwater Basin in the southwest, the deeper Great Artesian Basin and the shallower Darling Aquifers (Gunnedah and Narrabri Formations) in the north, and fractured rock aquifers elsewhere;
- salinity that broadly falls into four major regions – the highly saline discharge zones of the Lower Murray, the salt sinks of the irrigation areas of the riverine plains, the salt exporting local aquifers of the Murray Basin uplands, and the northern regions which show a mixture of effects with no overall trend.

The main temporal characteristics are:

- considerable climate variability (which also varies spatially, increasing to the northwest) on timescales from seasonally to decades and longer;
- extreme wet events which lead to extensive floods and, in some aquifers, episodic recharge;
- longer wet periods and droughts which lead to general increases and decreases in streamflow and productivity of both terrestrial and aquatic ecosystems, and more muted responses in groundwater systems.

Superimposed on these natural characteristics are artificial changes to the hydrology:

- land use change, which has in many places increased the run off to streams and recharge to aquifers (through removal of deep rooted native vegetation), though other changes such as increased farm dams threaten to decrease run off to streams (Part II report);
- storages, which are larger in the south, and lead to fewer floods and low flows, and to changes to the seasonal pattern of flows;
- diversions, which reduce flows and also remove salt – most irrigation areas are salt sinks. The effect of diversions is greater in the south, where 80% of the water is used; in the north they reduce peak flows and change flow variability.

There is thus no simple pattern, spatially or temporally, to the hydrology of the Murray-Darling Basin. Rather, it is a complex system of overlapping influences, some varying evenly, some changing abruptly.

## The surface water trend

Evapotranspiration is limited by available energy. At low rainfall there is more than enough energy to remove the water but at high rainfall there is water in excess of that which can be removed. Budyko curves[24] (Figure 17) show this relationship.

The catchments in the Basin form a trend in evapotranspiration from the southeast to the northwest. They fall between the empirical curves for forested catchments (upper dotted line) and grassy catchments (lower dotted line). Other catchments not plotted also fall into the SE-NW trend. Many world catchments, and many Australian coastal catchments, plot on these diagrams close to the dotted lines in the top right hand corner – that is, they have a greater proportion of run off than catchments in the Basin.

To show how the trend in Figure 16 influences partitioning of the rainfall into evapotranspiration and run off, Figure 17 shows this partitioning schematically for three catchments selected from the wet, middle and dry parts of the trend in Figure 16. The much greater run off and discharge of the southeast (Goulburn) catchment is immediately apparent. The Avoca has no discharge and little irrigation, with most water being consumed as evapotranspiration in the terminal wetland system. The Gwydir is intermediate.

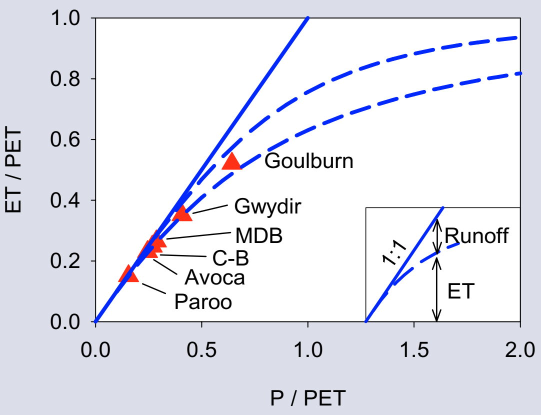


**Figure 16. Budyko curves for several catchments in the Basin (C-B is Condamine-Balonne; MDB is Basin average). The inset figure shows that normalised ET is the amount given by a the Y axis value of a line or point, and normalised run off is the difference between the normalised ET and the 1:1 line (Source: Budyko[24]).**

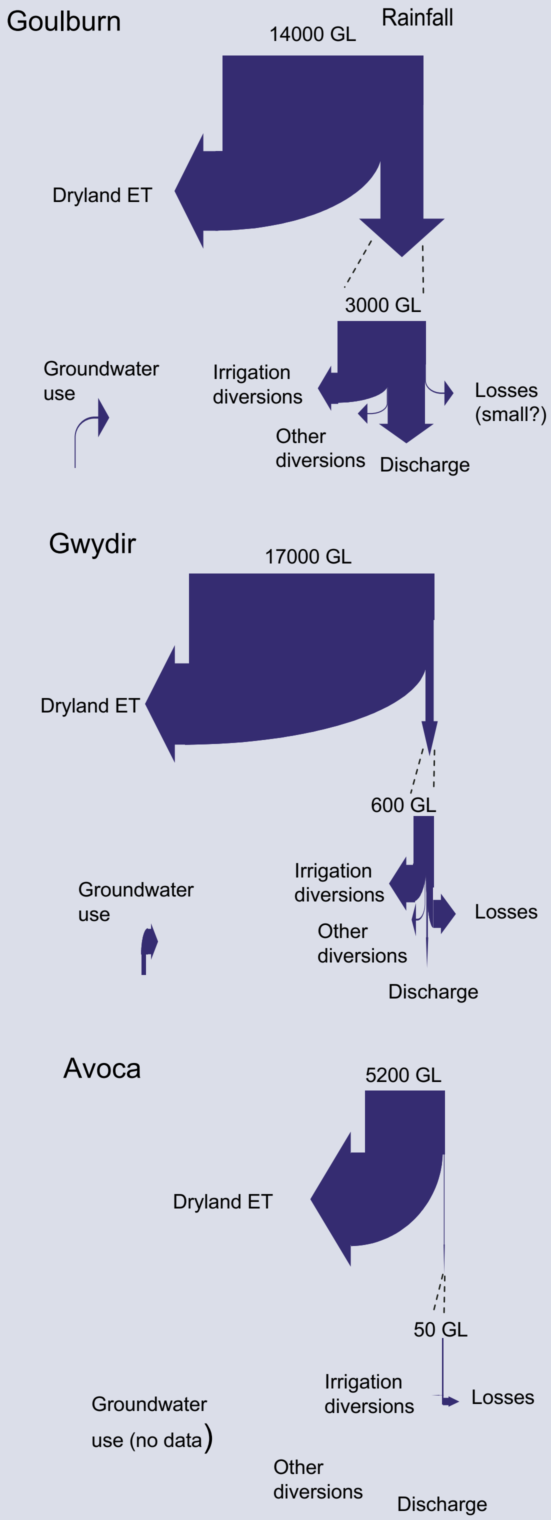


**Figure 17. Approximate catchment water flows for Gwydir, Goulburn and Avoca, based mainly on SILO rain datasets[4], water audit monitoring reports1, and river gauging data from the New South Wales Pineena database[7] and the Victorian Water Data Warehouse[9]. Losses were too small to estimate reliably for Goulburn.**

# Hydrology framework and the MDBC strategies

In this section, we review the existing strategies of the Murray-Darling Basin Commission (MDBC) in the light of the Basin hydrology.

## The MDBC strategies

The major strategies agreed by the MDB Ministerial Council on the advice of the MDBC to manage the shared water resource are the Basin Salinity Management Strategy[25], the Cap[26], The Living Murray[27], the Native Fish Strategy[28] and the Sustainable Rivers Audit[29]. With the exception of The Living Murray, all apply across the Murray-Darling Basin.

The context for and general aim of the strategies was described by Goss[30], at the 2001 River Symposium:

> The early 1990s saw the Commission formally adopt water quality and flow policies… (such as) the 'Cap'… (which) recognised the finite nature of water resources in the Basin and sought to introduce a balance between off-stream use of water and protection of the riverine environment…..
>
> While significant progress has been made, there are pressures that are causing great concern in the community, and conflict both within and outside the Basin. Water quality and ecosystem health continue to decline as a consequence of past – and in some cases continuing - management mistakes; competition for use of scarce water resources is increasing, and resources are often used beyond their sustainable capacity. Radical changes in management and use of Basin resources are required in order to maintain healthy ecosystems and productive land use.

### The Basin Salinity Management Strategy

The 1988 Murray-Darling Basin Salinity and Drainage Strategy[25] has led to a reduction of salinity in the River Murray (Figure 18). This was achieved through a combination of measures, including salt interception schemes.

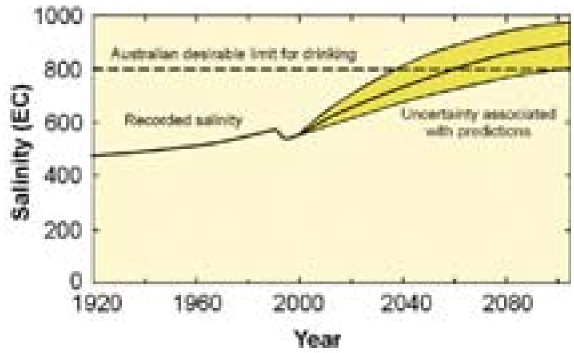


**Figure 18. Salinity of the River Murray at Morgan in South Australia (Source: MDBC[25]).**

Despite these gains, the 1999 Basin Salinity Audit predicted that 'business as usual' will lead to reversal of these improvements within 20–30 years and median salinity levels would exceed 800 EC at Morgan in South Australia within 50–100 years. In addition, increasing salinities were expected for tributaries, and increasing areas of saline land in the east and south.

The revised Basin Salinity Management Strategy was released in 2001 with the objectives of:

- maintaining the water quality of the shared water resources of the Basin;
- controlling rises in salt loads to tributary streams;
- controlling land degradation and protecting important agricultural land, terrestrial ecosystems, cultural heritage and built infrastructure; and
- maximizing net benefits from salinity control.

In particular:

- the Basin salinity target is to maintain the salinity at Morgan at less than 800 EC for 95% of the time;
- the end-of-valley target is to maintain the salinity and salt load at stations near the end of each major valley to less than the target values at least the given percentage of time (50%, 80%, 95%).

## Cap on Diversions

The Cap on Diversions[26] was introduced in 1995, and made permanent in 1997, as a first step in striking a balance between consumptive and instream uses in the Basin and to help ensure the security of supply to existing diverters.

As shown Figure 19, water use has grown, particularly since the 1950s, almost to the volume of the natural flow to the sea. The associated changes to river health are the reason for introducing the Cap (as described by Goss, see above).

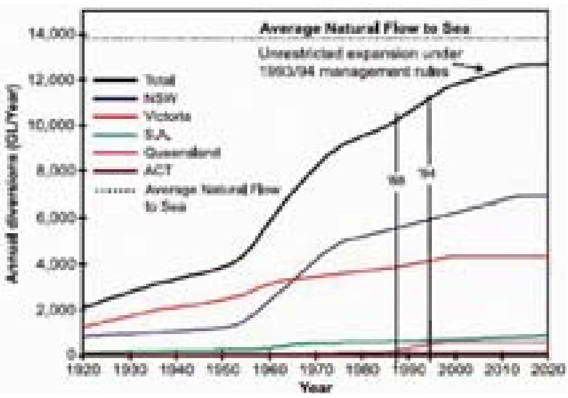


**Figure 19. Water use and the Cap (Source: Crabb[5]).**

## The Living Murray

The Living Murray[27] initiative was established in 2002, with a "first step" implementation agreed in 2003 to:

- address the declining health of the River Murray system (the Living Murray First Step decision);
- achieve specific environmental objectives and outcomes for six significant ecological assets; Barmah-Millewa Forest, Gunbower and Koondrook-Perricoota Forests, Hattah Lakes, Chowilla floodplain (including Lindsay-Wallpolla), the Murray Mouth, Coorong and Lower Lakes, and the River Murray Channel.

## Native Fish Strategy

The goal of the Native Fish Strategy[28] is to rehabilitate native fish communities in the Basin back to 60% of their estimated pre-European settlement levels after 50 years of implementation. The strategy has several objectives which involve flow regulation, and in-stream and riparian habitats, as well as other objectives which are not directly related to the hydrology (including alien fish, aquaculture, and community involvement).

## Sustainable Rivers Audit

The Sustainable Rivers Audit (SRA)[29] is not a strategy but rather is a comprehensive study of river health undertaken across the Murray-Darling Basin. The SRA will sample ecological indicators to reveal the health of each river valley in the Basin and provide a benchmark for follow up monitoring studies. The SRA will provide scientific information to inform longer-term river management and water resource planning.

The SRA aims to:

- determine the ecological condition of the rivers of the Murray-Darling Basin;
- observe how river health may vary across the Basin's 23 river valleys and change over time;
- standardise river assessment programs across the state and territory boundaries of the Murray-Darling Basin to allow for meaningful comparisons of river condition;
- provide scientific information to better inform community discussion about river management issues;
- complement other initiatives such as The Living Murray, The Native Fish Strategy and the Cap on water diversions;
- raise community awareness about the condition and importance of river health.

# Hydrology implications

When irrigation was first developed in the Murray, the first 1,000 GL/year diverted had a modest impact on the 12,000 GL/year which naturally flowed to the end of the Murray system (that is, was discharged at the Murray mouth).

Today, a change of 1,000 GL/year could be the difference between some discharge from the mouth of the Murray and none.

Each of the strategies described in the preceding section are influenced by and may have an influence on flows in the Murray-Darling Basin. This is summarised in Table 3.

## Opportunities and tensions

In some cases, the strategies have similar implications for changes to flows and management of storages – The Living Murray, the Native Fish Strategy and the Sustainable Rivers Audit, for example, are seeking to inform changes to flows to

**Table 3: Broad hydrology implications of MDBC strategies**

| Strategy | Changes to flow | Changes to timing of flows | Changes to storages and releases |
|---|---|---|---|
| Basin Salinity Management Strategy | Increase flows to dilute low/salty flows | Timed for dilution - often low flows in summer | Managed for dilution flows –especially Menindee Lakes and Lake Victoria |
| The Cap | No further increase to diversions, other changes not prevented | Not directly demanded, but not prevented | Not directly demanded, but not prevented |
| The Living Murray | Enhanced floods, reduced low flows | More winter/early spring flows, lower summer flows | Managed for environmental releases, timed to enhance floods especially in spring |
| Interstate Water Trade | More flows downstream? | Little change unless an "Environmental Manager" may trade – then more winter/early spring flows | Little change unless an "Environmental Manager" may bank water in storages and trade – then releases reflect environmental demands |
| Native Fish Strategy and Sustainable Rivers Audit | Enhanced floods, reduced low flows | More winter/early spring flows, lower summer flows | Managed for environmental releases, timed to enhance floods especially in spring – cold release water a problem |

better mimic the natural flow patterns. The Cap does not directly imply or demand changes, other than preventing further diversions.

Prospects of managing flows to satisfy more than one strategy include:

- Not all the water allocated to an environmental site is used there. For example, the 2000–01 flood of the Barmah-Millewa forest was enhanced with a 341 GL environmental allocation. However, only about 150 GL of that was actually consumed in the forest. Unused environmental allocations or return flows could be used downstream for further environmental allocations or for salinity dilution flows.

In some cases, however, there are tensions amongst the strategies:

- Large-scale afforestation in higher-rainfall areas of the major catchments may decrease mean annual water yield. This could decrease the dilution of salt loads from other parts of the catchment. This may lead to an increase in salinity at target points in the river. The effect will vary in time as the water yield impact may occur faster than the groundwater and salt load impacts.
- One of the main causes of high salinity in the Lower Murray is the high salt load contributed from wide saline floodplains. Saline flows are initiated by major floods but continue until well after these floods have receded. A strategy for addressing this may be a dilution flow from further upstream, coinciding with the saline return flow. This has been considered in moves to harmonise the Basin Salinity Management Strategy and The Living Murray decision, including future salt interception schemes.
- Environmental flows may have a salinity disbenefit as floods release salts from saline floodplains. The additional water and salt leaching may have beneficial environmental impacts but the trade-off is decreased water quality.
- Increasing water flows into significant ecological assets will often involve acting quickly to enhance natural floods but this may conflict with requirements under the Native Fish Strategy to avoid rapid rises and falls of river height, which plants and other biota cannot respond to quickly, leading to reductions in food for fish. Also, quick releases of large water volumes cause problems because they are generally cold, which also affects the downstream ecology. Rapid releases and high flows can also move or erode the river bed and other channel features.

# Recommendations for further capacity development

The hydrology of the Basin is understood well in broad outline. But a basin in which water resources are in such high demand, requires careful and sophisticated management, with attention to the interactions amongst regions and processes. This in turn demands high quality understanding and data, and the ability to predict accurately and precisely the consequences of actions. In many areas, we need better information and a higher level of understanding than we currently have.

Ideally, a detailed water account, quantifying all uses of water with reasonable confidence is required. Currently, we cannot provide such an account to the level of detail required. Furthermore, since all uses are valued (no water is wasted) we must establish which uses we value most – and currently we have not done this quantitatively and defensibly.

We do not have a clear understanding of the relationship between flood volumes and the areas of floodplain, forests and wetlands inundated. Nor do we know how much water is required for various environmental targets. The Living Murray first step decision was based on our best estimate with current information, but much must be done to increase our confidence in the quantitative links between water regimes and ecological outcomes.

The cascading effects of floods to particular assets must be understood better. Can the recession water from one flood (say, to the Barmah-Millewa forest) be used again downstream? Will the flow be sufficient? Will the quality be compromised by blackwater events?

Systems models of hydrology must broaden in scope and consider the river health consequences of changes to flow.

We do not know what water management regimes lead to the maximum environmental benefit across all the strategies. In adopting market based approaches we must quantitatively weigh up environmental benefit against profit from production. Currently we lack the information to do this.

Our hydrology understanding and data are not uniform across the Basin, nor across the processes. River flows and diversions are not well quantified in northern catchments because flow gauges are too few and far between. Groundwater flows, sustainable extraction/yield limits and recharge rates are not well quantified, especially in northern aquifers, and surface-groundwater connections and flows between them are not well quantified.

In irrigation areas, return flows must be better quantified, as must the impact of improved irrigation practices and adoption of recycling systems on the return flows. Better data on actual water use, losses and pathways from farm to the irrigation system levels are required.

These gaps converge to three basic areas of improved hydrological knowledge needed for the sustainable management of the Basin:

- better measurements, leading to better water balances and water accounts;
- understanding the environmental benefit and other values that result from water use;
- frameworks and hence models that integrate the hydrology with water use and the benefit that results, and do so for a river basin with highly variable flows.

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