STATE OF THE DARLING
Interim Hydrology Report

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For the Murray-Darling Basin Commission

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Glossary

Average	The arithmetic average of a series of numbers.
Calibrate	The adjustment of an instrument or calculation according to independent measures made by a standard instrument or process.
Cap	The Murray Darling Basin Cap on diversions.
Diversion	The removal of water from the river by a means of a man made structure.
Entitlement	The maximum volume of water that may be diverted by a user subject to resource availability.
Floodplain Harvesting	The capture of water on the farm via floodplain flows or rainfall excess
Gauging Station	Location at a stream channel where discharge of water is measured.
Hillside Dam	Storages constructed on hillsides and small gullies.
Jurisdiction	The relevant controlling authority for water resource management within the State.
Off Allocation	Flows in excess or orders from a regulated storage.
Overland Flow	The capture of water on the farm via floodplain flows or rainfall excess.
Rainfall Harvesting	The capture of water on the farm from rainfall excess.
Ringtank	A man made or lagoon storage used to temporarily store water on the floodplain.
Regulated	Condition whereby stream flow is constrained by a dam.
Schedule F	Schedule F of the Murray Darling Basin Agreement defines the requirements for Cap auditing and compliance.
Unregulated	Condition whereby streams flow into another stream with no intervening dam.
Unsupplemented	Flows in excess or orders from a regulated storage.
Water Balance	Accounting for the volume of inputs and outputs for a specified duration and region such that the sum of the inputs equals the sum of the outputs.

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FOREWORD

Much of the data presented in this report has been sourced from existing data sets and state agency based hydrologic modelling. In the case of New South Wales, model results have been provided for the natural and water sharing plan rule scenarios. In the case of Queensland, model results have been provided for the natural (pre development) and moratorium scenarios. Differences in model results from previous publications is due to improved inflow data sets and differences in time periods that the models have been run over. At the time of writing this report many of the models have yet to be updated to include the current drought sequence. The most recent year of modelled data provided was 2003. A discussion with respect to the usefulness and limitations of hydrologic models is included in Appendix 1 of this report.

Usage information presented in this report has frequently been expressed in terms of long-term averages. These represent level of use for the current or expected level of license utilisation over the full range of climatic variability. Information relating to an individual yearly usage has not been presented as that approach is insufficient to show the long-term distribution of the Darling Basin resource.

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EXECUTIVE SUMMARY

This report provides an overview of the natural hydrology of the Darling Basin, the development that has occurred, and the effect this is having on river flows and groundwater resources.

The Darling Basin is twice the size of the Murray Basin, but it drains a much more arid area. A large part of the flow in the Darling's tributary rivers also finishes up in terminal wetland areas, rather than in the Darling itself. As a result, flows in the Darling and its tributary rivers are much smaller and more variable than flows in the Murray and its tributaries.

Climate records also show that the system can experience long periods when rainfalls, and consequently river flows and groundwater recharge, are much lower than average. The much more arid nature of the Darling Basin means that the impact of these climate variations on river flows and groundwater are greater than they are in the Murray. It also means that climate variability may be an even more important consideration with respect to the management decisions made by farmers and governments.

Large-scale water infrastructure development commenced in the 1960s, and there are now major dams in the headwaters of all major NSW tributaries, and the Border Rivers. However, these dams only control about 30% of the Basins flows, considerably less than is controlled by dams in the Murray. Their regulation of flows is restricted to the eastern tributaries, a short portion of the Balonne River, and the last 200 kilometres of the Darling below Menindee Lakes.

More recently, there has been major private investment in large storages on irrigation farms. The total volume of these storages now rivals that of the headwaters dams, and they capture much of the water that enters the Basin's rivers downstream of the dams. This feature of water infrastructure in the Darling Basin sets it apart from the Murray. Current estimates indicate that there are also very large volumes of hillside dams that capture large volumes of runoff before it reaches the Basin's rivers, although there is doubt about the precision of these hillside dam estimates.

The total surface area of these shallow on farm storages is large, and evaporation rates in the Basin are high. The result is that evaporation from them is now a major cause of loss of water from the system. There are also large losses from Menindee Lakes. The end result is that evaporation from water storages is now estimated to be about 2,000,000 Megalitres per annum, which is equal to about 25% of the average flow in the Basin's rivers.

The effects of water infrastructure and extraction of water on river flows in the Basin include:

- *Loss of flow volume*
  There have been reductions in average flows in the lower sections of all major Darling tributaries that range from about 20% to more than 50%. This has reduced average flows into the Darling by about one third. Flows in the Darling are further reduced by local extractions and by evaporations from Menindee Lakes. The result is that average outflows to the Murray are now less than half the volume they would be under natural conditions. Reductions in average flow

volumes in the Darling are remarkably similar in percentage terms to reductions in Murray flows.

- *Loss of flood events*
  There have been large reductions in the size and frequency of floods in all rivers on which there has been major irrigation development. For example, floods that would have been expected to occur on average once every 2 years at the end of the Culgoa will now only occur once every 5 years.

Some of these hydrologic changes can be associated with specific issues in the basin. For example:

- *Wetlands drying*
  There have been major reductions in average volume of flows, and the frequency of major inflows into the large end of system wetlands of the Gwydir, Macquarie, and the Condamine/Narran. The number of days when wetlands along the Barwon-Darling are joined to the river, and are receiving water, have also dropped – in most cases by a third or more.

- *Fish migration problems*
  Migration of fish along the Barwon-Darling is now only possible when flows are high enough to drown out the many weirs that now exist. The effect of dams and water use has reduced the frequency of drown outs, and greatly exacerbated the effect of weirs on migration opportunities.

There are also a number of future risks to flows in the Basin. These include:

- *Climate change*
  Current assessments indicate that reductions in average flows of 20% or more may occur by 2030.

- *Continued increases in surface water use*
  Water Sharing Plans for NSW unregulated rivers and Queensland's Water Resource Plans both provide diversion limits through either specification of volumes or rules. However, in some plans the level of current usage is below these limits, and as a consequence there is limited scope for further increases in surface water use. The actual extent of this increase in unknown, with advice from Queensland agency staff indicating that the increase in Queensland is small. It should be noted that the impacts of this increase in usage with respect to surface water pumped diversions has already been incorporated into the Queensland modelling results presented in this report.

- Both New South Wales and Queensland plans also do not allow increases in floodplain harvesting diversions. Queensland plans go further by also including rainfall harvesting in this definition. Despite these plans there still appears to be some opportunity for further growth in the capture of overland flows and runoff from rainfall. However, initiatives are underway in both states to attempt to monitor these forms of water use.

- *Current and future groundwater use*
  Use of groundwater from aquifers may impact on surface water flows, and possibly outflows to other surface ecosystems such as wetlands. In most instances, the full extent of these impacts is not realised for 10 to 20 years. It is likely that the impact of recent groundwater development has yet to be felt. In addition, in many Basin groundwater sources, current entitlements and use

remain well below the extraction limits (sustainable yields) identified by jurisdictions.

Although groundwater occurs throughout the Basin, good quality, useable supplies are limited in their extent. The major aquifers that can be used for irrigation extend up to 300kms from the lower slopes of the Great Dividing Range. They occur in the major tributary of the Macquarie, Namoi, Gwydir, Border Rivers, and Condamine and Balonne systems. Good quantities and yields of groundwater are found in relatively coarse-grained alluvial deposits, and where the Great Artesian Basin (GAB) outcrops to the east. The quality of the water is high relatively close to the rivers, but deteriorates down the long flow path of these systems.

Relatively small volumes of good quality water is also found in the upland alluvial valleys of the Condamine, and in the upland NSW valleys, and also in a very narrow band associated with the Darling River itself. Fresh water is also sources from the fractured basalts around Toowoomba, and on the eastern edge of the Basin in NSW.

Groundwater yields from the GAB are high, and although the water quality is generally not suitable for large-scale irrigation, this supply is critical for domestic and stock use for much of the western Basin area.

Elsewhere in the Basin groundwater yields are very low, and the water tends to be quite saline, limiting its use, at best, to supplying stock.

In NSW, Groundwater Management Areas (GMAs) have been delineated and extraction limits established across most of the Basin. Water management plans will be in place for all of these in the next few years. In the major resource aquifers, entitlements are being reduced to within these extraction limits. The historic "over-allocation" will then be remedied. Actual use above the extraction limits that prevailed in the 1990s appears to be declining, and will continue to do so as the plan are implemented. At present, in three zones of the Upper Namoi, the Gwydir, and the Miscellaneous Tributaries of the Barwon Region, use remains above the extraction limits. NSW advises that the Macro groundwater planning process has identified approximately 12 groundwater systems that are over-allocated. These are to be embargoed shortly and a decision on how to manage the over-allocation is due to made by DNR next year.

In Queensland, there are 26 GMAs. There remains significant "over-allocation" in most of the Condamine GMAs, and in some of the Upper Condamine and tributary GMAs. In 11 of the 13 over-allocated systems, use also exceeds the assigned extraction limits. There are 9 Queensland GMAs with management plans in place, and a formal water resource plan is in place for the Queensland Great Artesian Basin. Queensland may consider reducing entitlements closer to extraction limits as part of a formal water resource planning process. In the meantime, it is attempting to reduce actual extractions by applying annual announced allocations. These announcements are set in consultation with groundwater users, and the announcements required in some systems to restrict average use to the extraction limits have yet to be applied.

In most systems in the Basin where there is significant pumping, localised groundwater level declines are being detected, even where the overall extraction remains within the extraction limit. This is an inevitable result of uneven resource distribution across most GMAs, and the uneven distribution of pumping. This is a concern, not only for resource access in the longer term, but also if these declines are causing the migration of poorer quality surrounding groundwater into the fresh aquifers. These declines can also cause an increase in the losses from, or a reduction in discharge to, connected rivers or other surface water bodies. The consideration of surface water connectivity within the basin is patchy, and lack of monitoring and research into these impacts is hindering their successful management.

Even if overall extractions are eventually limited to within the current extraction limits, and mechanisms are put in place to manage local water level and quality impacts, climate variability and climate change will continue to pose a risk to groundwater supply in the future. The degree to which recharge, and therefore extraction limits, will be affected by these phenomena has not been assessed.

The overall impact of water use development on the hydrology of rivers and aquifers in the Basin has been substantial, and changes are comparable in scale with those that have occurred in the Murray. However, there are important differences in the nature of some of these changes, and their potential impacts, resulting from both the more arid character of the Basin, and the differences in the style of water use development. While there would seem to be as much justification for greater effort to address the impacts of water use development as there is in the Murray, the form this should take will need to be tailored to the Darling Basin's different circumstances.

1 INTRODUCTION

1.1 Purpose and content of the report

This report provides an overview of the hydrology, both surface and groundwater, of the Darling Basin, the development that has occurred and the effect this is having on river flows and groundwater resources.

The report uses information drawn from existing publications, reports prepared for the Murray Darling Basin Commission, and assessments undertaken by the state agencies.

It does not draw conclusions about the consequences of changes in river and groundwater flows on the environment, or whether these are justified by the social and economic benefits that have arisen from use of water. It does however make some references to such issues and provides some statistics related to components of hydrology thought to be important to maintenance of the Basin's environment assets.

Information about the natural and current hydrology of the Darling Basin is presented in a series of maps in the accompanying Darling Basin Hydrology Atlas (MDBC 2006). The Atlas provides further information about matters referred to in this report. The maps in the atlas examine the following issues:

- Map 1. Infrastructure
- Map 2. Diversions and Evaporative Losses
- Map 3. Mean Flows
- Map 4. Changes in Flow Volume, Variability and High and Low Flows
- Map 5. Wetlands
- Map 6. Fish Passage at Weirs
- Map 7. Blue-Green Algae
- Map 8. Groundwater Use, Entitlement and Extraction Limit
- Map 9 Growth in Groundwater Use and Associated Risk to Surface Water Flows

Greater detail with respect to the technical aspects and issues associated with both data and tools used to describe the hydrology of the Darling Basin can also be found in the in the State of the Darling Hydrology Technical Report Appendix (MDBC 2006).

A complimentary report identifying environmental and economic values and assets of the Basin and their associated water resource dependencies is currently in production.

1.2 Data and information

1.2.1 Surface water

Information about surface water in this document has been taken from a wide range of publications and sources. Data about flows and water use has also been drawn from recent computer modelling.

Data drawn from models has been used to allow the long-term hydrologic effects of development and water use to be assessed in a consistent and detailed way.

River flows in the Darling are the result of the complex interaction of many variable factors. These include climate, the development of dams and other water control structures, the expansion of irrigation and other forms of water use and changes to water management and water use rules. This means that it is not valid to say recent river flows are a good indication of future flows. It is also not valid to compare records of river flows from the earlier times with recent river flows and say that all differences result from water use development, or that lack of any significant difference is a sign that no change has occurred.

This is where computer models come into play. They allow the calculation of river flows that would have occurred under a given set of water resource development and use conditions over any period for which climate and streamflow data is available. This has allowed sets of "natural" flows and "current" flows for the same period to be calculated each location (usually from 1890 to 2002) and compared in this report.

"Natural" flows, or as commonly referred to in the Queensland portion of the Basin, "Pre-Development" flows, are the flows that would have occurred without dams or any human use of water. Current development flows are the flows that would have occurred had all existing dams and infrastructure, and current cropping and water management practices, been in place for the whole modelled time period. The long term modelled flows for these two scenarios are used for comparative purposes.

Computer models of river systems are, necessarily, simplified representations of the many complicated interactions between the many factors that affect river flows. However, the complex and variable nature of the basin's hydrology, and the changing scale and effect of water use development, mean modelling is the most reliable way to assess the impact current development and management arrangements would have on long-term flow outcomes.

Some of the models used to provide data for this report have come in for criticism in the past, when data they provided has been introduced into debates about water management. This has resulted in a variety of model reviews and revisions that should have made them more reliable for the purposes of this report.

A discussion of models and their strengths and weaknesses is included in the State of the Darling Hydrology Technical Report Appendix (MDBC 2006) that has been produced to supplement this document.

1.2.2 Groundwater

The groundwater information provided in this report focuses on quantity management and the hydrogeology relating to this. It does not cover the important issue of salinity. This has been dealt with comprehensively elsewhere, and strategies for its management are included in the Murray-Darling Basin Salinity Management Strategy. Nor does the report deal in any detail with groundwater quality or contamination, except insofar as quantity management may affect it.

Over the past five years, the MDBC has commissioned several very detailed groundwater reports for the Murray Darling Basin, covering the entire Basin's status generally (Ife & Skelt, 2004), a summary of the groundwater status in the Darling Basin (Ife & Skelt, 2005), and analyses of surface water/groundwater interactions in the Basin (SKM, 2002 & 2003; MDBC, 2004 & 2005; REM, 2006). As discussed, the purpose of this document is to provide a very brief summary of the hydrology and hydrogeology of the Darling Basin that can be understood by a non-technical audience, as a basis for discussion of future basin sustainability initiatives. As such, the groundwater information in this report takes some of the key outputs of these more comprehensive existing reports, directly reproduces them in part, and synthesises the findings. NSW and Queensland water agencies have provided updated data and information, in particular relating to sustainable yields, use, entitlements, and surface water/groundwater connectivity. Commentary is then provided on this information. No additional analysis has been undertaken in the preparation of the groundwater aspects of this summary report.

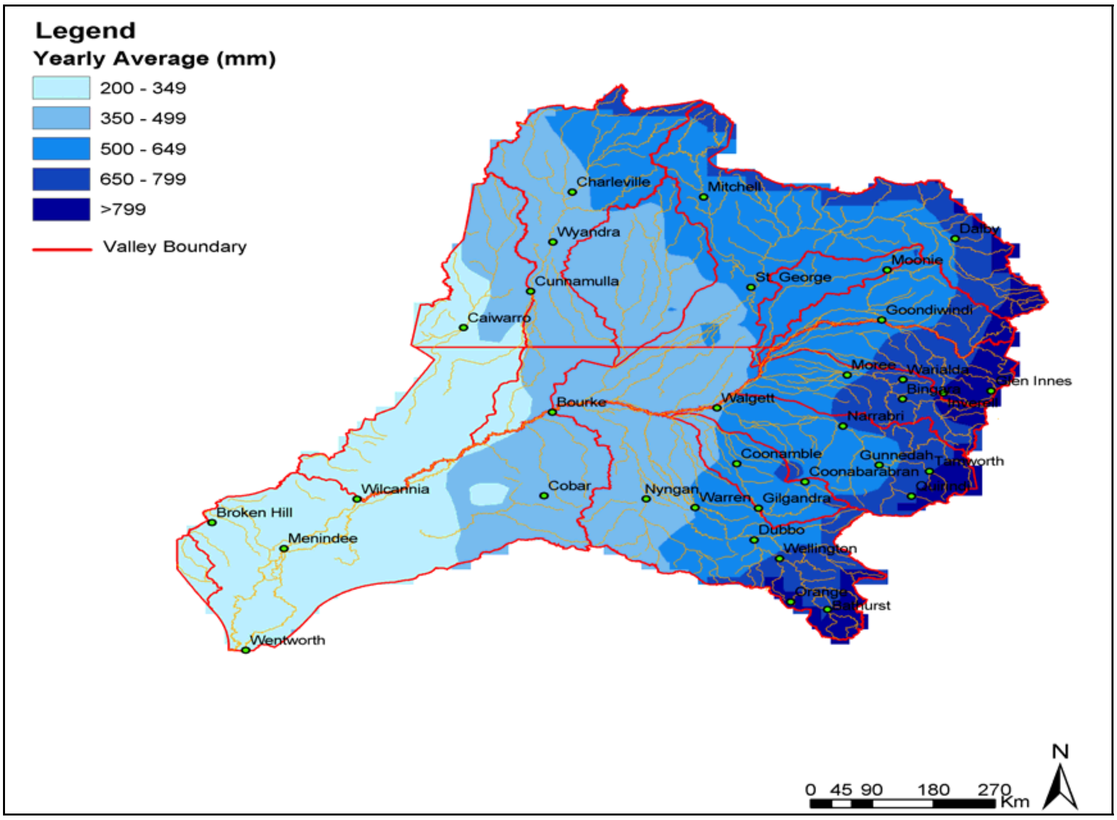
2 SURFACE WATER

2.1 The Natural Setting

2.1.1 Climate

Much of the Darling Basin can be classified as arid (Slatyer R and Perry R. 1969). Average annual rainfall exceeds 1000 mm in just a few small areas along the Basin's eastern boundary. Rainfall over most of the Basin is less than 600 mm and drops to just 250 mm along the Basin's western boundary (see Figure 1).

Figure 1 - Average Annual Rainfall

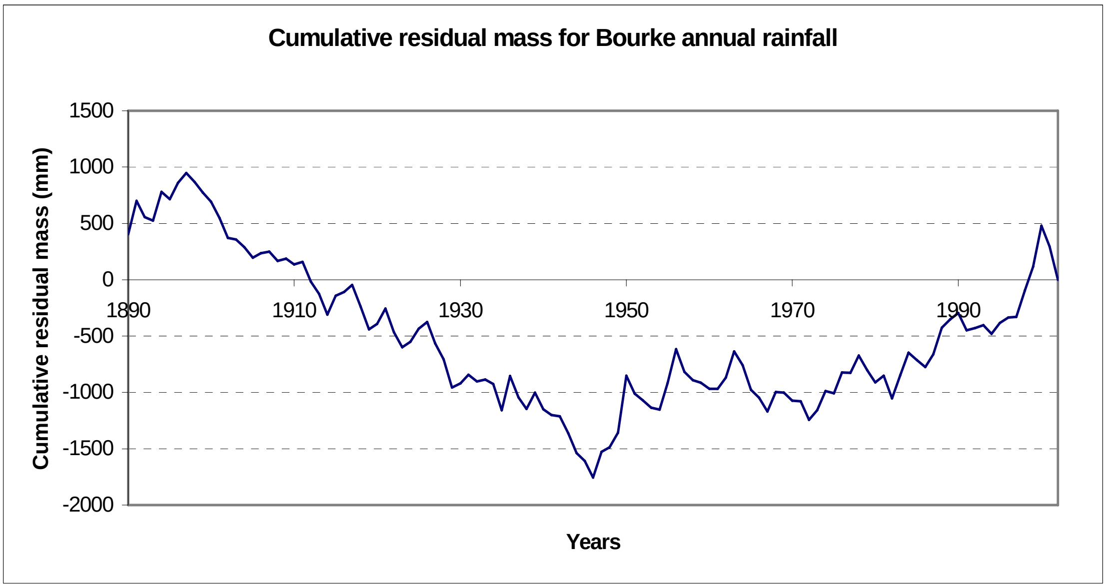


However, these averages conceal some large variations. The highest annual rainfall experienced over the last 100 years along the eastern edge of the basin is about 1800mm and the lowest just 600mm. Along the Basin's western edge, the highest annual recorded rainfall is 700 mm and the lowest less than 100mm.

Rainfall rates also exhibit long periods of relatively wet years and dry years. An examination of rainfalls at Bourke demonstrates this. The average rainfall for Bourke between 1890 and 2000 was 352 mm. However, between 1898 and 1946 it was just 296mm, between 1947 and 2000 it was 393 mm. This change in rainfall shows up clearly in the "cumulative residual mass curve for Bourke in Figure 2. This plot shows how far total rainfalls since the beginning of the analysed period have deviated from the mean rainfall over the entire period (which is 1890 to 2000). A downward slope on the line indicates periods when rainfalls were less than average and an upward slope that they were greater than average.

The plot shows the variations from average were fairly persistent for the first half or the 20th century and for the second half of the 20th century, and that within each of these periods there were also shorter multi-year periods of very dry conditions and very wet conditions. This effect, and its impact on the Basin's hydrology, is discussed in section 2.2.2.

Figure 2 -Bourke rainfalls – cumulative deviations from the mean.



Rainfall in the Basin also shows some seasonal variability. In the upper section of the Basin, the area that produces most of the runoff, rainfall is summer dominated. For example, the ratio of average rainfall between November and April to rainfall between May and October for Toowoomba is 1.9, Mungindi 1.6 and Tamworth 1.3. The middle section of the basin shows no significant seasonal variation. The ratio for Mudgee is 1.1 and Menindee 1.0. This means that Toowoomba has approximately twice as much rainfall in summer as in winter, whereas Menindee has approximately the same rainfall in both seasons. Only in south-western corner of the Basin is rainfall winter dominated, with Wentworth's rainfall being approximately 43% more in winter than in summer (summer/winter ratio 0.7). This is in marked contrast to the Murray system, which is dominated by winter rainfalls. For example winter rainfalls are approximately 67% higher in winter than in summer at Albury (summer/winter ratio is 0.6).

Evaporation rates are high right across the Basin, and everywhere average annual evaporation rates exceed average annual rainfalls. In the east of the Basin, annual evaporation averages about 1400mm. It rises to 2400mm in the far west.

2.1.2 Geography

The Darling Basin, which is the area shown in Figure 1, covers an area of 699,000 square kilometres, and makes up 70% of the total area of the Murray-Darling Basin. Approximately one third is in Queensland and two thirds in New South Wales. The Basin covers about half the total area of New South Wales and one tenth the total area of Queensland. The distance from its northern most point to its most southern is approximately 1,100 kilometres, and it is a similar distance from its most eastern to its most western edge.

The main trunk of the river system rises in the Great Dividing Range, close to the border of New South Wales and Queensland, and travels south-west for 2,700 kilometres before it empties into the Murray at Wentworth. This makes it the longest river in Australia. Over this distance it changes name from the Macintyre, to the Barwon and lastly to the Darling immediately downstream of the Culgoa junction.

The Darling system receives most of its water from runoff from the relatively high rainfall, low evaporation Great Dividing Range, along its eastern edge. This runoff feeds the Macintyre and a series of major tributary streams, the Gwydir, Namoi, and Macquarie/Bogan systems. These travel in a mostly north-westerly direction and enter the south west flowing main stem of the Upper Darling between Mungindi and Bourke. Another series of rivers drains the northern section of the basin. These rivers travel south and also intersect the Darling upstream of Bourke. They generally drain a lower rainfall, higher evaporation area of the Basin. The Condamine/Balonne, whose catchment includes part of the Great Dividing Range around Toowoomba, is the only one of these northern tributaries that contributes substantial flows to the Darling.

The Darling Basin is flatter and much less mountainous than the neighbouring Murray basin. Some 60% of the Darling Basin is less than 300 metres above sea level. Nowhere does it rise more than 1,500 metres above sea level. Even its eastern Great Dividing Range edge is often less than 1000 metres above sea level. Only a few areas along its northern and western edges rise above 500 metres. At Wentworth, the Darling is just 50 metres above sea level.

The low land slopes that characterise most of the Basin mean that the Darling and its major tributaries are very low gradient/low energy rivers over the majority of their length. This, coupled with very variable rainfall and runoff, has meant that most of the Darlings tributaries have formed “inland deltas” in their lower reaches. The downstream portions of the Condamine-Balonne, Gwydir, Namoi, Macquarie, and Paroo are all classified as “distributary” (Thoms et al 2004). This means that they become a series of branching channels that distribute their flows across large areas especially during flood times.

This distribution of water has created some major wetland areas, notably the Gwydir Wetlands, the Macquarie Marshes, the Narran Lake wetlands and the Paroo Overflow. It has also meant that much of the flow in the upper portions of many of the Darling’s tributaries never makes it through to the Darling and on down to the Murray River.

2.2 The natural flow regime

2.2.1 Flow volumes

The estimated average annual runoff into all rivers in the Murray Darling Basin is approximately 24,000 Gigalitres (Department of Environment and Heritage 2001). The same Department of Environment and Heritage report estimates the average runoff into rivers in the Darling Basin at approximately 7,000 Gigalitres, which is slightly less than the total of “mid system” flows in Table 1. Even if the Table 1 figure is assumed to be more accurate, runoff into rivers in the Darling Basin is just 30% of total runoff in the Murray-Darling Basin, despite the Darling Basin accounting for 70% of the Murray-Darling’s total area. The Darling runoff figure also equates to an average of just 11mm across the Basin.

As already discussed, much of the flow in the Darling's tributaries finishes up in wetlands, or is lost as seepage and evaporation from channels and floodplains, before it enters the main stem of the Darling system. The data in Table 1 demonstrates this. The total inflow to the Darling from its tributary rivers is only a little more than half the total "mid-river" flow in the tributaries. The "mid river flow" is the estimated average annual flow in each tributary river at the point at which additional downstream inflows of water are often exceed by the loss of flow by evaporation and through seepage to groundwater.

The ratio of mid river flow to inflow to the Darling varies greatly from tributary to tributary. The low ratios for the Gwydir, Macquarie, Condamine-Balonne, Paroo, and Warrego demonstrate that the channel systems in their lower reaches are particularly "inefficient". By contrast, the channel systems in the lower reaches of the Namoi and Moonie are relatively efficient. Because of this, and because they sometimes receive significant inflow from the downstream sections of their catchments during periods of high rainfall, their average inflow to the Darling exceeds their average mid-river flow.

Table 1 – Average annual "mid river" flows and inflows to the Darling under natural conditions

Darling Tributary	**Mid river flow** *(Gigalitres per annum)*	**Average inflow to Darling** *(Gigalitres per annum)*	**Inflow as a % of mid system flow**	**Inflows as a % of total inflows from Darling tributaries**
Border Rivers	1421	862	61%	20.9%
Moonie River	101	119	118%	2.9%
Gwydir system	895	493 [d]	55% [d]	12.0% [d]
Namoi River	844	949	112%	23.1%
Castlereagh River	283 [a]	71	25%	1.7%
Condamine/Balonne system	1372	621	45%	15.1%
Macquarie/ Bogan system	1523 [a]	888	58%	21.6%
Total of Darling tributaries upstream of Bourke	***6439***	***4003***	***62%***	***97.3%***
Warrego R	393	39	10%	0.9%
Paroo R	500	61	12%	1.5%
Local Darling catchment	106 [b]	13 [c]	12% [c]	0.3%
Total of all Darling tributaries	***7438***	4116	***55%***	***100%***

Notes

[a] Castlereagh and Bogan flows from Water Resources of the Castlereagh, Macquarie, and Bogan Valley Department of Water Resources NSW 1991.

[b] Local Darling runoff from the National Land and Water Audit .

[c] Assumed proportion of runoff reaching Darling is the same as the Paroo

All other data from computer models

[d] Estimates of the loss of Gwydir system flows reaching the Darling may be in error because of uncertainty about the division of flows between the Gwydir R and its effluent systems under natural conditions before construction of diversion weirs and regulators.

The lack of any significant additional inflow downstream of Bourke means that flows in the Darling decrease substantially downstream of Bourke (see Table 2). In fact, under natural conditions, average annual flows into the Murray from the Darling are just 59% of average annual flows in the Darling at Bourke.

Table 2 – Average annual Darling River flows – natural conditions

Location	Bourke	Upstream Menindee	Inflows to Murray
Average flow *(Gigalitres per annum)*	3720	2898	2182

2.2.2 Flow variability

The natural variability of flows in the Darling and its tributaries is significant. For example, the maximum flow recorded in the Darling at Bourke, prior to significant water resource development upstream, was 352,000 Megalitres per day in August 1950. However, the river has also stopped flowing for long periods. In 1902, there was no flow for 272 days at Walgett and for 362 days at Menindee (Water Resources Commission 1974). At Menindee, between 1885 and 1960, which is prior to any large scale water use, the Darling River ceased to flow on 48 occasions.

Even compared to the rivers in the Murray Basin, the rivers of the Darling Basin are highly variable. An analysis of annual discharge records indicated that the minimum annual discharge recorded for the 3 major sources of Murray water, the Upper Murray, the Murrumbidgee and the Goulburn had never dropped below 25% of each river's average annual discharge (MDBMC 1987). The maximum recorded annual flows for these rivers were between 200% and 350% of the annual average. By contrast, the minimum annual discharges recorded in the 3 major sources of water for the Darling system, the Namoi, Culgoa and Border Rivers were all well below 10% of their average discharge and their maximum annual flows between 400% and 800% of their average annual flow.

These short-term extremes can have dramatic consequences. However, it is now becoming clear, that river flows and groundwater replenishments in eastern Australia are subject to major variations over much longer periods. These can have effects that present a serious risk to long-term socio-economic sustainability as they may result in extended periods of low income for agricultural producers and towns. They also need to be factored into assessments of the long-term environmental sustainability of current levels of water use and decisions about tolerable future levels of use. This is especially so in more arid river systems like the Darling Basin, where the rainfall "surplus" that becomes river flows, or moves into deep aquifers, is so low and its occurrence is infrequent.

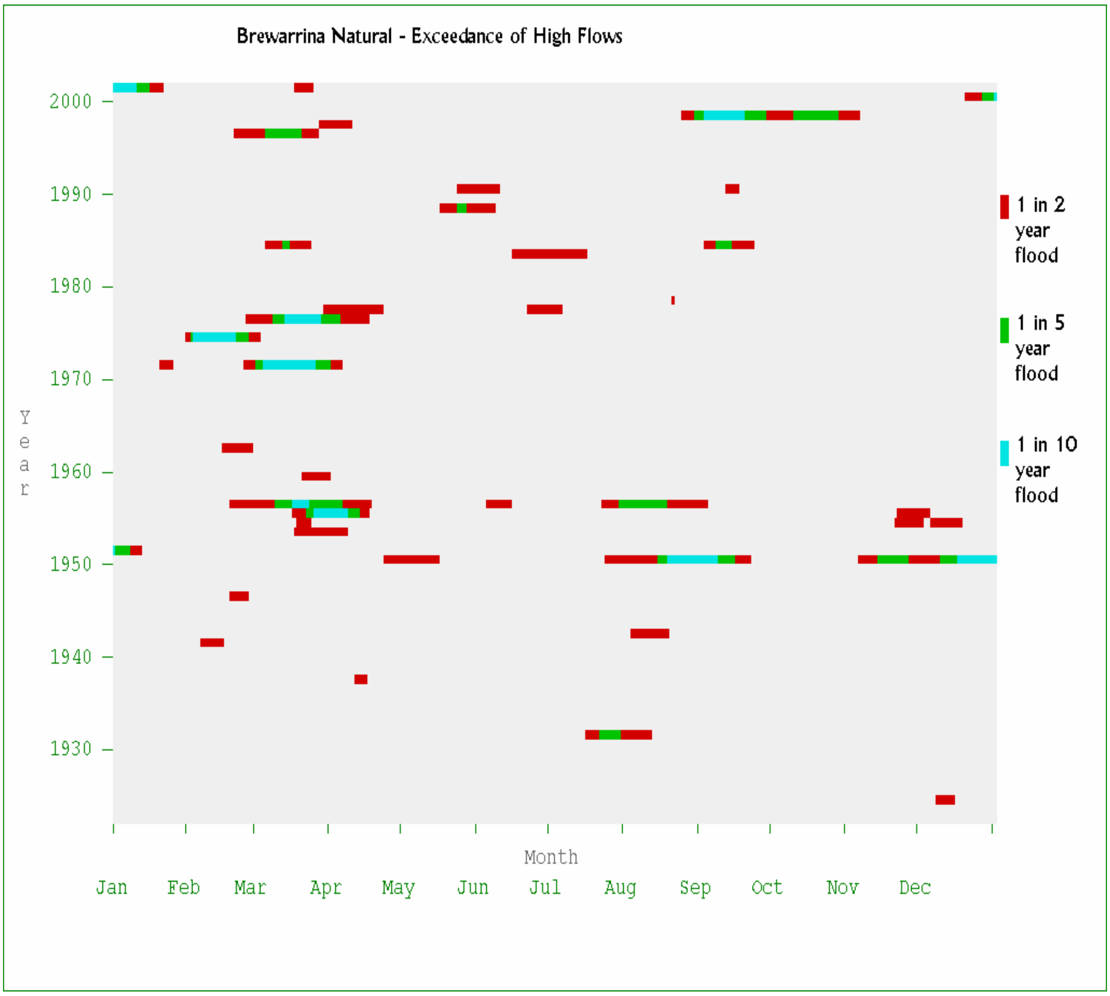
The influence that the El Nino/Southern Oscillation (ENSO) effect has is now well known and reasonably well understood. ENSO effects are now thought to be responsible for many of the drought and flood periods that are experienced in eastern Australia. Numerous researchers have explored the effect of ENSO on flows in the Murray-Darling, and many farmers now take note of predictions based on Southern Oscillation Index (SOI) values. ENSO cycles appear to operate over 3 to 8 year periods.

However, it is clear that there are even longer-term variations in the climate of eastern Australia and that these can have major effects on rainfall and river flows. The causes and mechanisms responsible for these longer period shifts are not as well understood or widely appreciated as ENSO. Some are now being assessed (Verdon D. and Franks S. 2006) and it seems that there is evidence that these mechanisms regularly cause substantial shifts that last decades.

One of the most abrupt recent changes appears to have occurred in the late 1940's, an effect that appears in the rainfalls for Bourke shown Figure 2. A check of the "natural" flows for Bourke (i.e. flows corrected for the effect of dams and water use upstream) shows how significant the change was to flows in the Darling system. The average annual "natural" flow for the period 1922 to 2002 is 10,200 Megalitres per day. However, between 1922 and 1949, it was 40% lower, at just 5,900 Megalitres per day, and between 1950 and 2000 it was 25% higher, at 12,700 Megalitres per day.

A graphic example of this change can also be seen in the occurrence of floods. Figure 3 shows the periods when the Darling would be in flood under natural conditions over the period for which modelling data is available (1922 to 2002). The lack of floods in the period prior to 1949 is immediately apparent.

Figure 3 – Occurrence of floods in the Darling at Brewarrina – natural conditions.



Floods are of course just one part of the flow regime. However, a look at flows across these same periods (see Table 3) shows the full range of flows was affected.

Table 3 – Bourke flow statistics

All flows in Megalitres per day	**1922 to 2002**	**1922 to 1949**	**1950 to 2000**
High flow (the flow exceeded 10% of the time)	24,700	17,200	30,300
Median (the flow exceeded 50% of the time)	2,800	1,900	3,500
Low flow (the flow exceeded 90% of the time)	200	150	250

This means that viewing the hydrologic records for rivers in the Darling Basin as a single homogenous set of data could prove misleading for policy makers and farmers. In many cases it would be sensible to break the record up into periods of wet and dry when assessing the robustness of public and private water management strategies, policy settings and investment decisions.

2.3 Water Supply Infrastructure

The first weirs were constructed across the Darling River in the late 19th Century, but it was not until the late 1950's that construction of large-scale water supply infrastructure commenced in the Basin. Keepit Dam was the first major water supply dam constructed. It was completed in 1960. Over the next 30 years, another 10 large dams were constructed on the Darling's major tributaries, primarily to supply water for irrigation.

The total volume of major dams on the Darling's tributaries is 5,129 Gigalitres, equivalent to about 70% of the average annual runoff in the Basin. However, because the storages are constructed in the upper reaches of each system, only about 2,000 Gigalitres, or about 30% of runoff in the Basin, actually passes through a major dam. (Note that this runoff figure excludes Beardmore Dam on the Balonne River. This is because it is small relative to average annual Condamine - Balonne flows and therefore captures and stores only a small percentage of total Condamine-Balonne runoff.)

In the Darling Basin above Menindee, the augmentation of natural river flows by release of water from major dams (river regulation) is restricted to the main channels and a few effluents of the Macintyre, Gwydir, Namoi and Macquarie, and to a short section of the Condamine-Balonne system. No regulated supply is provided to the Barwon and upper Darling. The sections of rivers that are regulated are shown on Map 1 in the accompanying Atlas.

The ratio of major dam size to total runoff and the proportion of flows regulated by dams in the Darling Basin above Menindee are both much lower than in the Murray system. This means that a relatively high proportion of the flows in the Darling River above Menindee, and even in most of its regulated tributaries, are the direct result of runoff from rainfall and groundwater inflows rather than releases from dams.

The conversion of Menindee Lakes into water storages was completed in 1968. The Lakes are the largest water storage in the Darling Basin at over 2,000 Gigalitres.

Most of the water regulated by the Lakes is used to supplement supply to the Murray system.

There are a number of town water supply dams in the Basin. The most significant dams are those that supply the major towns of Toowoomba, Tamworth, Bathurst, and Orange. The total volume of these dams, and the amount of water they provide, is very small compared to the major dams used primarily to supply water for irrigation.

There are also many weirs in the Darling Basin. The volumes of the major weirs have been included in Table 4. The storage capacity of weirs is however not a very good indicator of their effect on flows. Many of the weirs are fixed crest structures, installed to provide reserves of water for domestic purposes and stock watering. Most of the time, they have little effect on streamflows. Several major weirs, such as Tareelaroi Weir on the Gwydir, have however been installed to allow diversion of flows to effluent streams. Some also have operable gates, which allows them to store and later release water. The effect of these diversion weirs on flow distribution within a river system can be significant.

Most irrigation water in the northern valleys is used for broad acre crop production, chiefly cotton, and nearly all the infrastructure that moves water from rivers to farms has been privately financed. The high value of cotton, abundance of irrigable land and high proportion of natural river flows remaining in rivers encouraged many farmers to construct large on farm storages and divert water into them during high flows to augment the supply available from major dams. These storages are all termed “ring tanks” in this report, even though some have been constructed in natural depressions and by blocking off billabongs, rather than by building an above ground ring of walls. From the mid 1980’s, this practice spread to the Barwon-Darling and the unregulated portions of the Condamine Balonne.

The total volume of on farm storages in the upper Darling basin is now equivalent to 60% of the total volume of major dams.

There are also many “hillside dams” in the Basin. They are generally small, but there are many of them. They are built on hillsides, sloping areas and in small gullies to capture runoff from rainfall or, in a few cases, flows from springs, before it enters well defined stream channels. Numbers and volumes have never been systematically assessed. The estimates included in Table 4 are drawn from a study conducted for the Murray Darling Basin Commission (Agrecon 2005). However, this study was based on projections from small sample areas and there is some doubt about the accuracy of the data at the larger scale.

Table 4 – Volumes of major dams and weirs and farm storages

All volumes in Gigalitres

Valley	Major Dams	Town water supply dams	Weirs	Ring Tanks	Hillside Dams
Border Rivers	641	[d]	15	459	119 [c]
Moonie	0	[d]	[d]	[e]	125 [c]
Gwydir	1362	[d]	16	351	84 [c]
Namoi	882	6	23	190	402 [c]
Macquarie	2056	79	21	110	264 [c]
Condamine Balonne	188	29	51	1582	334 [c]
Nebine	0	0	[d]	[d]	[d]
Warrego	0	[d]	10	[d]	19 [c]
Paroo	0	0	[d]	[d]	[d]
Barwon Darling	0	[d]	35 [a]	298	[d]
Total above Menindee Lakes	***5129***	***114*** [f]	***171*** [f]	***2990*** [f]	***1347*** [c]
Lower Darling	2050	24	[e]	160 [b]	[d]
Total Darling Basin	***7179***	***138*** [f]	***171*** [f]	***3150*** [f]	***1347*** [c]

Notes

[a] Estimate only, but believed to be within 10 Gigalitres of actual.

[b] The estimated volume of on farm storages in the Lower Darling is only for Tandou Limited's farm. Other on farm storages are believed to exist, however it is understood that their volume is relatively small.

[c] There is some doubt about the reliability of hillside storage data.

[d] No estimate available but believed to be a relatively small volume.

[e] No estimate available.

[f] See notes for individual valleys in this columm

2.4 Water use

2.4.1 Extractions

Total average annual surface water use in the Darling Basin is estimated to be approximately 3,200 Gigalitres. Details of the volumes and sources of water use in each valley can be found in Table 5 at the end of this section and also on Map 2 in the Atlas.

The majority of this water use (79%) occurs as extraction of water direct from rivers. This is primarily for irrigation, but some is also taken for stock, domestic and town water uses.

In all major irrigation valleys in New South Wales, other than the Barwon-Darling, most river extractions come from "regulated flows". This means that they come from flows that are, at least in part, supplemented by water releases from headwaters dams. The dam releases, and extraction from "regulated flows", occur when water is needed for crops or other purposes. This means the vast majority of dam releases and extraction from regulated flows occurs in the summer months.

Regulated flow extractions in Queensland are only significant in the Border Rivers and a small section of the Condamine system.

Extraction of water from natural flow events (termed off-allocation in New South Wales and unsupplemented in Queensland) is a significant source of supply in all regulated rivers in the system. These flows events and consequent extractions can occur anytime of the year. The volume taken depends on the duration of the flow event, the capacity of pumps and channels used to extract the water, the volume of storage available in storages on farms (ring tanks) and any limits set by extraction licences.

Water is also extracted from most unregulated rivers in the Basin. The largest volumes are taken from the Condamine in Queensland and from the Barwon Darling in New South Wales. Most of the unregulated water taken in these two systems is taken via large pumps or diversion channels at any time of the year that flows occur, and stored in ring tanks for later use on crops. Significant volumes of unregulated water are also taken for this purpose from Cox's Creek and the Mooki River in the Namoi Valley. A smaller amount of water is also taken from rivers and applied direct to crops.

In most other unregulated rivers, water is generally taken from rivers and applied direct to crops (without the use of ring tank storage). The volumes taken in this manner are minor compared to the volumes extracted from the regulated rivers and the Condamine and Barwon-Darling systems. The timing of extractions is driven by climate and crop water needs, as water storages on farms are generally few and small. This means that the demand for water from these unregulated rivers is greatest during drier periods in summer, which is also when flows are lowest.

There are several other ways water is collected for use on farms in the Basin including:

- Systems constructed to capture the excess flood irrigation water (tailwater) from the lower ends of fields. These same systems can also be used to capture runoff caused by rainfall, some of which would otherwise have entered the river system. This "rainfall harvesting" can be a significant source of water in wet summer seasons.

- Capture of water that is travelling across floodplains in high flow times is also a significant source of water in wetter years. The potential for future increases in floodplain harvesting is discussed in section 2.7.2.1.

- Extraction from hillside dams. This is believed to be a significant and growing source of water in some upland areas of the Basin (see section 2.7.2.2). There is however some doubt about the accuracy of existing estimates of water use from this source.

Table 5 – Average annual surface water use in the Darling Basin

Water use volumes in Gigalitres per annum

Valley	**Town and stock and domestic extraction**	**Other river system extractions**				**Total river system extraction**	% of total river system extractions	**Extraction from Hillside Dams** [c]	**Total surface water use**	% of total surface water use in the Basin
		Extractions from rivers	Floodplain harvesting	Rainfall harvesting	Total other					
Border Rivers	5	400	13 [d]	[a]	413	418	*14%*	24 [c]	**442**	*14%*
Moonie	0.2	30	4 [d]	0 [e]	34	34	*1%*	25 [c]	**59**	*2%*
Gwydir	14	318	82 [d]	15 [e]	415	429	*15%*	17 [c]	**446**	*14%*
Namoi/Peel	13	346	14 [d]	74 [e]	434	447	*15%*	80 [c]	**527**	*16%*
Macquarie	45	412	[a]	[a]	412	457	*16%*	53 [c]	**510**	*16%*
Condamine Balonne	16	533	144 [d]	[a]	677	693	*24%*	67 [c]	**760**	*24%*
Nebine	0.2	5	0.8 [d]	0 [e]	5.8	6	*0%*	[b]	**6**	*0%*
Warrego	0.1	49	0 [d]	0 [e]	49	49	*2%*	4 [c]	**53**	*2%*
Paroo	0.2	0	0 [d]	0 [e]	0	0.2	*0%*	[b]	**0.2**	*0%*
Barwon Darling	18	198	13 [d]	29 [e]	240	258	*9%*	[b]	**258**	*8%*
Total Darling above Menindee	***112***	***2291***	***271*** [d]	***118*** [e]	***2680***	***2792***	***95%***	***270*** [c]	***3062***	***96%***
Lower Darling	11	122	[a].	[a]	122	133	*5%*	[b]	**133**	*4%*
Total Darling Basin	***123***	***2413***	***271*** [d]	***118*** [e]	***2802***	***2925***		***270*** [c]	***3195***	
% of total water use	***4%***	***76%***	***8%*** [d]	***4%*** [e]	***88%***	***92%***		***8%*** [c]		

Notes

[a] Not calculated by computer models for these valleys.

[b] No data but probably very small.

[c] The accuracy of estimates of water use from hillside dams is likely to be poor.

[d] The accuracy of estimates of floodplain harvesting may be poor (see section 2.7.2.1).

[e] The accuracy of estimates of rainfall harvesting may be poor (see section 2.7.2.4).

It should also be noted that the Queensland figures represent "full utilisation" of current infrastructure and allocations. This may be somewhat above actual current use as discussed in Section 2.7.3 of this report, however no data is available to determine what overestimation, if any, there is. Advice from Queensland DNRW is that any differences for the Condamine and Border Rivers should be small.

Note

While surface water losses include groundwater recharge and losses from river channels these are not reported here, as the IQQM assessment of these losses was considered inadequate. The IQQM models make no explicit representation of the connection between surface water and groundwater systems, or of the way in which flows between them vary depending on their relative water level. This means that recharge calculations will not reflect the variability that occurs in the real world. Underestimation of diversions may also be resulting in a compensating overestimation of river losses. Conversely failure to account for small ungauged tributary inflow might also result in a underestimation of river losses.

2.4.2 Net Evaporation losses

Net evaporation losses from storages in the Darling Basin are large. These losses are listed in Table 6 and are illustrated on Map 2 in the Atlas. The data in Table 6 indicates a total of nearly 2,000 Gigalitres per annum. However, two provisos must be borne in mind when considering these numbers:

- The water that evaporates from ring tanks is water that is already included in the water extraction data referred to in Table 5. This means that the evaporation losses from ring tanks in Table 6 are not an impact on river flows that is additional to the impact of water extractions.
- There is doubt about the validity of the assessment of hillside storage sizes, and therefore doubt about the evaporation calculations included in the table.

However, even with these provisos, it is apparent that evaporation losses add significantly to the impact water use development has had on river flows in the Darling. Other conclusions that can be drawn are:

- evaporation is a much more significant contributor to water use "inefficiencies" and loss of river flows in the Darling than in the Murray system, because of the much greater use of ring tanks to store water, and losses from Menindee,
- evaporation losses from major headwaters dams in the Upper Darling are small relative to evaporation losses from on farm water storages (i.e. ring tanks and hillside dams), and
- evaporation losses from Menindee Lakes (393 Gigalitres/annum) are much less than total evaporations from on farm water storages upstream of Menindee.

Table 6 – Average annual net evaporation losses

Evaporation volumes in Gigalitres per annum

Valley	Major Dams	Hillside Dams [a].	Ring Tanks	Total
Border Rivers	29	55 [a]	125	209
Moonie	0	78 [a]	0	78
Gwydir	31	49 [a]	109	189
Namoi/Peel	52	187 [a]	52	291
Macquarie	56	128 [a]	56	240
Condamine Balonne	57[b]	214 [a]	194	465
Nebine	0	0	0	0
Warrego	0	16 [a]	0	16
Paroo	0	0	0	0
Barwon Darling	0	0	94	94
Total upper Darling Basin	***225***	***727 [a]***	***630***	***1582***
Lower Darling	393	0	20	413
Total Darling Basin	***618***	***727 [a]***	***650***	***1995***

Note

[a] There is some doubt concerning hillside dam sizes. This also means there is doubt about the accuracy of these evaporation estimates. Whether these figures are net or gross evaporation has not been clarified.

[b] This figure includes all the small weirs. Annual Losses from Beardmore Dam, Leslie Dam, Jack Taylor Weir, Moolabah Weir and Buckinbah Weir combined are approximately 40 GL.

Any judgement about the efficiency of Menindee needs to take into consideration that the majority of the water supplied from the Lakes is used along the Murray not the Darling. Calculation of the contribution Menindee makes to Murray supplies would require a computer model assessment of the reduction in supply that would result from elimination of the Lakes. This has not been done for this report.

2.5 Current flows

> ***Note***
>
> *Data from computer models has been used to assess the "current" flow volumes and flow variability referred to in this section of the report and on related maps. These assessments do not take into account the effects of water extractions and infrastructure development in rivers upstream of the major headwaters dams, or on tributaries to the sections of river that are represented in the models. They also do not take into account the additional seepage losses or the loss of flows that may be resulting from growing levels of groundwater extractions. In some cases this may mean that the reductions in flow volumes could be somewhat higher than those reported here and also that there could be some additional but probably more minor changes to flow variability.*

2.5.1 Flow Volumes

Water use, and evaporation from major dams, ring tanks, and hillside dams all result in reductions in streamflow.

Most major dams in the basin are very deep, and evaporation losses from them are generally quite small compared to the volumes flowing through them (see section2.4.2). This means they have relatively little effect on average annual flow volumes. Even evaporation from the very large headwaters dams, like Copeton and Burrendong, only reduces average annual flows below them by a few percent.

There are two exceptions to this general rule. The most notable is Menindee Lakes. The average flows below the Lakes are 23% less than the flows immediately upstream of them because of evaporation. This happens because the lakes are shallow and are in a very high evaporation region. Several of the smaller headwaters dams in the Basin (Windamere, Split Rock and Glenlyon) also lose similar proportions of their inflows to evaporation. In part, this occurs because their catchments and inflows are small relative to the volume of the dams. Windamere and Split Rock are also primarily used as "backup" sources of water. Water is not taken from them in large volumes until well into a drought, which means they are held at high levels for long periods.

In all Darling tributaries with major irrigation industries, large-scale irrigation development is in the lower reaches of the system. This means that average annual flows in all major irrigation valleys, at least as far downstream as their "mid river" maximum flow point, are only 3% to 15% less than under natural conditions (see Map 3 in Atlas).

The situation with end of system flows is quite different as shown in Table 7.

Table 7 – Current tributary inflows to Darling and reduction from natural.

All volumes in Gigalitres per annum

	Average inflow to Darling *(Gigalitres per annum*		
River /System	**Natural**	**Current**	**% Reduction Natural to Current**
Total Border Rivers	862	574	33%
Moonie R	119	87	27%
Total Gwydir system	493 [a]	196	60% [a]
Namoi R	949	779	18%
Castlereagh R	71	71	0%
Macquarie/Bogan system	888	634	29%
Condamine –Balonne system	621	293	53%
Total inflows to Darling upstream of Bourke	***4003***	***2634***	***34%***
Warrego R	39	31	20%
Paroo R	61	61	0%
Local Darling Catchment	13	13	0%
Total Inflows to Darling	***4116***	***2738***	***34%***

[a] *Estimates of the loss of Gwydir system flows reaching the Darling may be in error because of uncertainty about the division of flows between the Gwydir R and its effluent systems under natural conditions before construction of diversion weirs and regulators. Therefore, the estimate of the reduction from natural to current may also be in error.*

The reductions in tributary contributions are the major cause of loss of flows in the Darling. However, water extractions from the Darling and evaporation from Menindee Lakes add significantly to the loss in flow volume as you move downstream, as shown in Table 8.

Table 8 – Average annual flows in Darling River under current conditions

All volumes in Gigalitres per annum

Location	Natural	Current	% reduction Natural to Current
Bourke	3720	2357	37%
Upstream of Menindee Lakes	2898	1693	42%
Inflows to Murray	2182	963	56%

The reductions in flow volume in the Darling are very similar to the reductions in flow volume in the Murray River. For example flows in the Murray at Euston, which is downstream of all major Murray tributaries except the Darling, are now about 51% less than natural while flows at the South Australian Border, downstream of the Darling, are 56% less than natural (MDBC 1990).

The proportional reductions in streamflows that result from dams and water use are much greater during dry periods than during wet periods as shown by the figures in Table 9. The reason this occurs is, that during dry periods, dams spill less often and flows that exceed the capacity of farmers off river storages are less frequent. The end result is that a greater proportion of system inflows are taken for use.

Table 9 – Reductions in average flow volumes for wet and dry periods.

All volumes in Gigalitres per annum

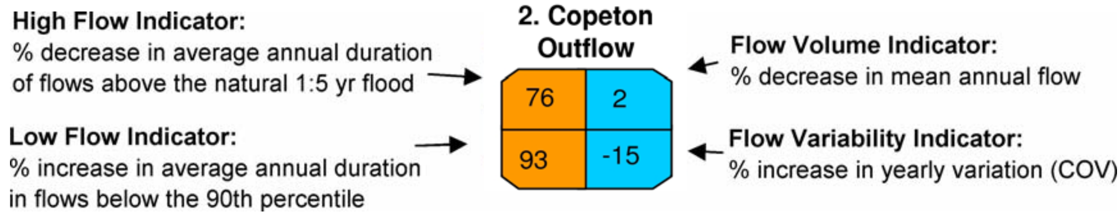
Location	"Dry" (1922 To 1949)			"Wet" (1950 to 2000)		
	Natural	Current	Reduction	Natural	Current	Reduction
End of Namoi River system	511	350	32%	1152	977	15%
Darling River at Bourke	2114	904	57%	4593	3116	32%

2.5.2 Flow Variability

Flow variability is affected by the capture of water in major dams, the pattern of release of water from these dams and by the extraction of water throughout the Basin. These combine to produce changes in flow variability that differ, in both scale and type, across the Basin.

Water supply dams in the Basin capture water during times of high flow and release it during periods when natural river flows are insufficient to meet demands for water. The overall effect of this is to dampen out flow variability immediately downstream of the dam. In the areas immediately downstream of dams, the proportion of time the river spends in flood and high flow is reduced and, in most instances, the time it spends in low flow is also reduced.

Map 4 in the Atlas illustrates changes to four flow regime indicators throughout the Basin. An example of these indicators is presented on the adjoining page. A positive number indicates a drier regime, that is a decrease in flow volume, a decrease in high flows, an increase in periods of low flows and an increase in yearly variability. The top left hand indicator for each location on Map 4 of the Atlas shows the change in the average time flows are above the 1 in 5 year flood level. The indicators of Map 4 also show that there has been a major reduction (ranging from 23% to 91%) in the time above the 1 in 5 year flood level below all major dams. As can be seen, there has been a 76 percent decrease in the time spent above the 1 in 5 year food level downstream of Copeton Dam.



Other statistics, such as flood frequency, also demonstrate this. For example, flood levels that, under natural conditions, would have been expected to occur on average once every 5 years now can only be expected to occur once every 25 years downstream of Copeton Dam, and once every 12 years downstream of Pindari Dam.

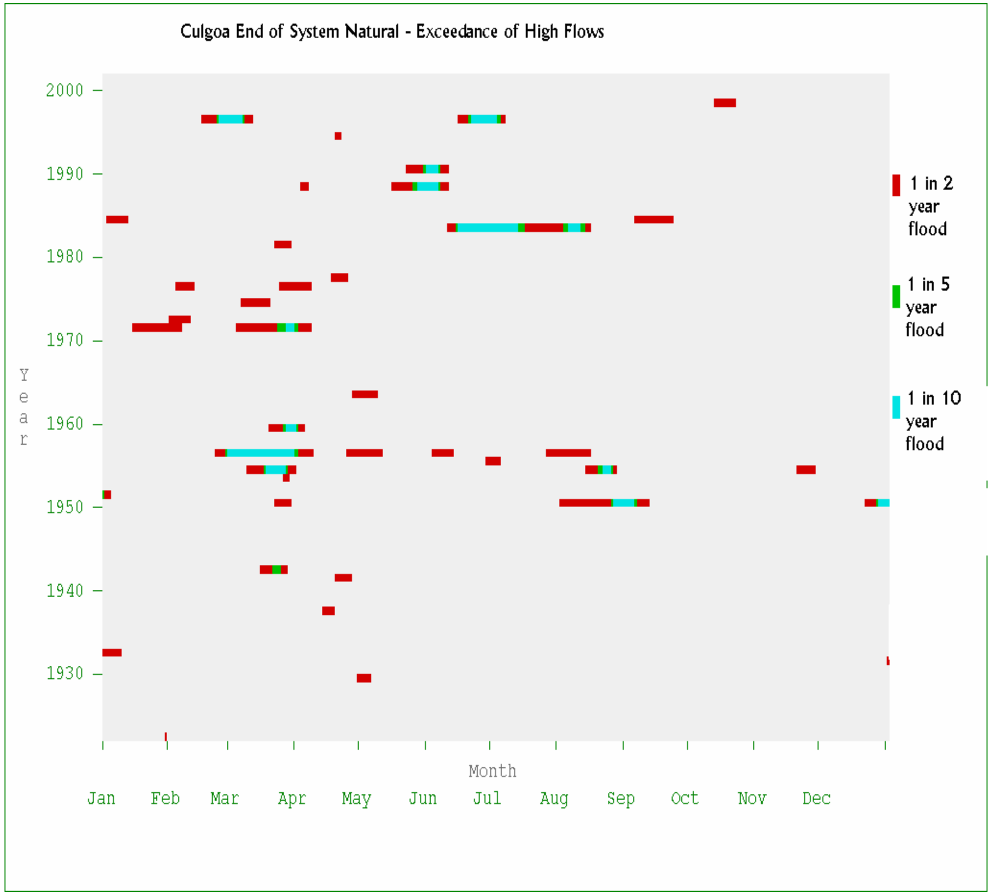
The bottom left hand indicator for each location on Map 4 of the Atlas shows the change in the average time below the 90th percentile natural flow. Map 4 shows that the percentage of time the river spends below this natural 90th percentile level is substantially reduced downstream of Keepit, Coolmunda, Pindari, Split Rock and Burrendong Dams. In contrast, the percentage of time the river spends below the 90th percentile increases in the case of Copeton Outflow. This may be a result of minimum release requirements being less that the 90th percentile natural flow.

As well as reductions in flows below the 90th percentile at dam outlets, the rivers below most of these dams now seldom stop flowing completely. The situation below Glenlyon and Windamere is however different. These dams have increased the proportion of time the rivers downstream of them spend in low flow. This has occurred because these dams are used primarily as backup storages, and are most often not required to release water.

As indicated in section 2.3, about two thirds of flows in the Darling Basin do not pass through a major headwaters storage. One result of this is that, as you move downstream from the major headwaters dams, tributary inflows dampen down the effect of dams on both flood flows and low flows. A good example of this is shown by the data for the Macintyre at Goondiwindi on Map 4 of the Atlas.

As you move downstream of the “mid river” maximum flow point in all Darling tributaries with major irrigation industries, water extractions start to significantly reduce flows. This further reduces the occurrence of high flows, particularly in the Condamine-Balonne, Gwydir and Border Rivers, where ring tank volumes are large and substantial volumes of water can often be taken and stored on farm. Extractions also increase the occurrence of low flows (those below the 90th percentile) and reverse the effect of releases of water from any major dams that may be in the system. As a result, the flows occurring in the downstream sections of most Darling tributaries are lower, for a greater proportion of the time, than they would be under natural conditions most of the time, that is, the proportion of time the rivers spend in low flows is increased.

Figure 4 shows this in relation to high flows at the end of the Culgoa River, which is the main channel feeding water from the Condamine-Balonne system into the Darling River. A similar trend is observed for the Mehi River as shown in Figure 5. Floods clearly occur much less often as a result of water use upstream. The periods without floods are also greatly extended.



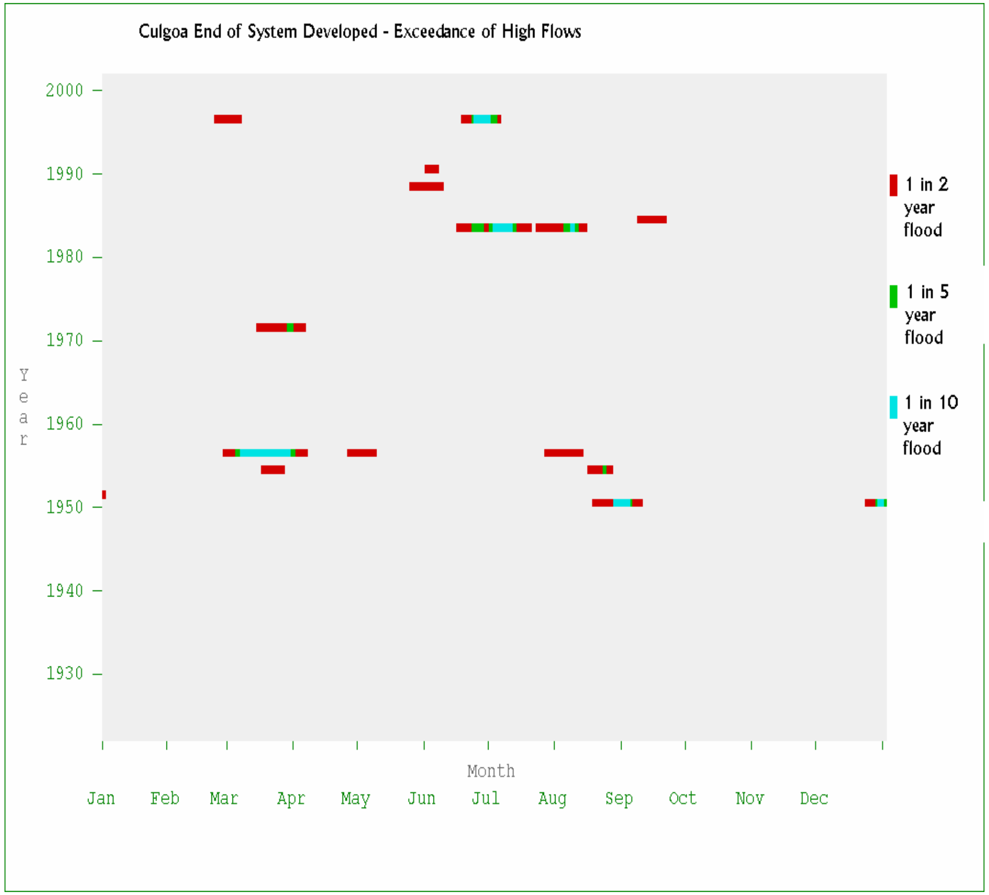


Figure 4 – Occurrence of floods at the end of the Culgoa River under natural conditions and current conditions.

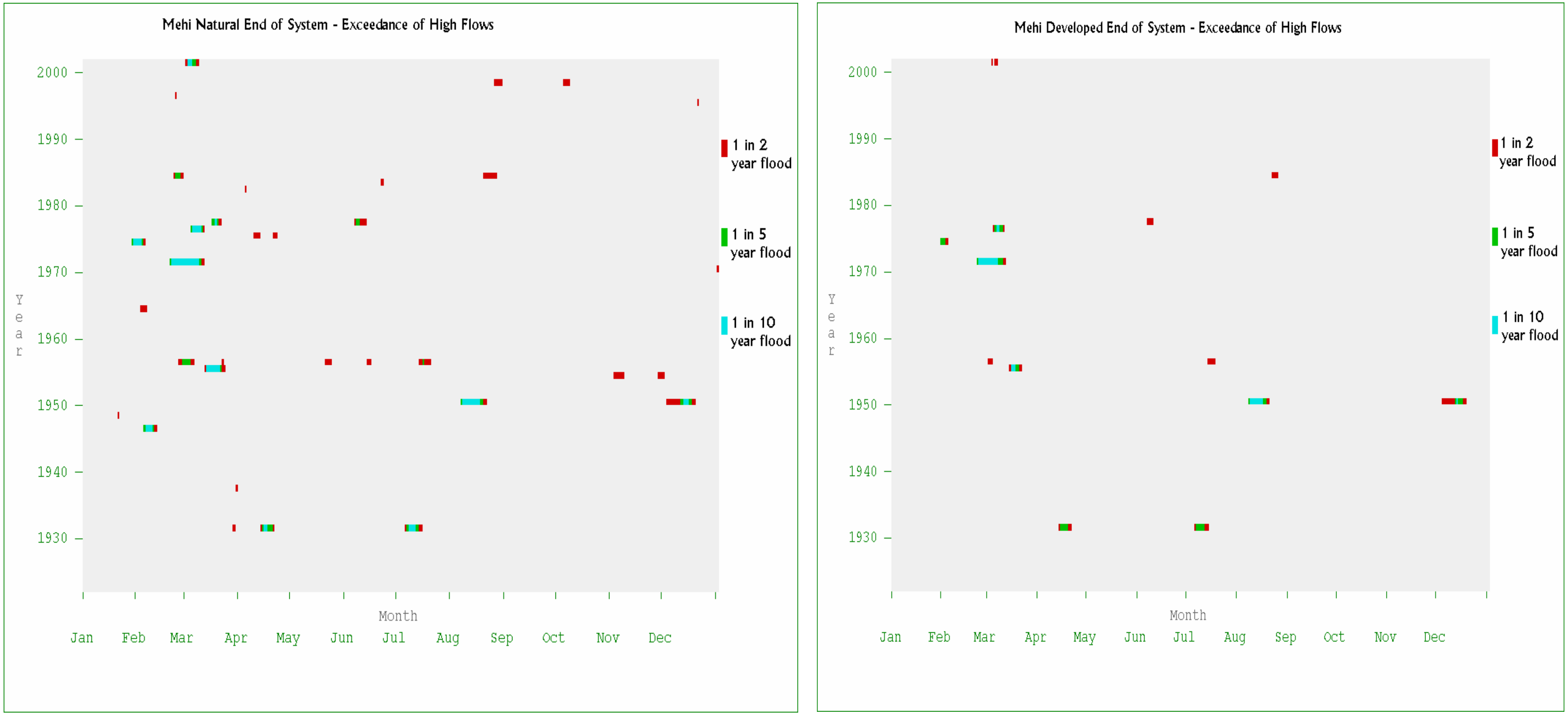


Figure 5 - Occurrence of floods at the end of the Mehi River under natural and current conditions.

Flow variabilities in the Darling show the combined effect of all upstream dams and water extractions plus the effect of extractions along the Darling itself, and below Menindee, the effect of evaporation losses from the Lakes.

Note that the low flow figures for Bourke and Wilcannia are almost certainly incorrect because they are based on estimated Bogan inflows under current conditions that appear to be well in excess of those actually occurring during low flow periods.

A comparison of the occurrence of flood flows at the end of the Darling (see Figure 6) with the occurrence of flood flows under current conditions (see Figure 7) gives a clear indication of the scale of change to the natural flow regime produced by water development and water use in the Darling Basin.

Figure 6 - Occurrence of floods at the end of the Darling River under natural conditions.

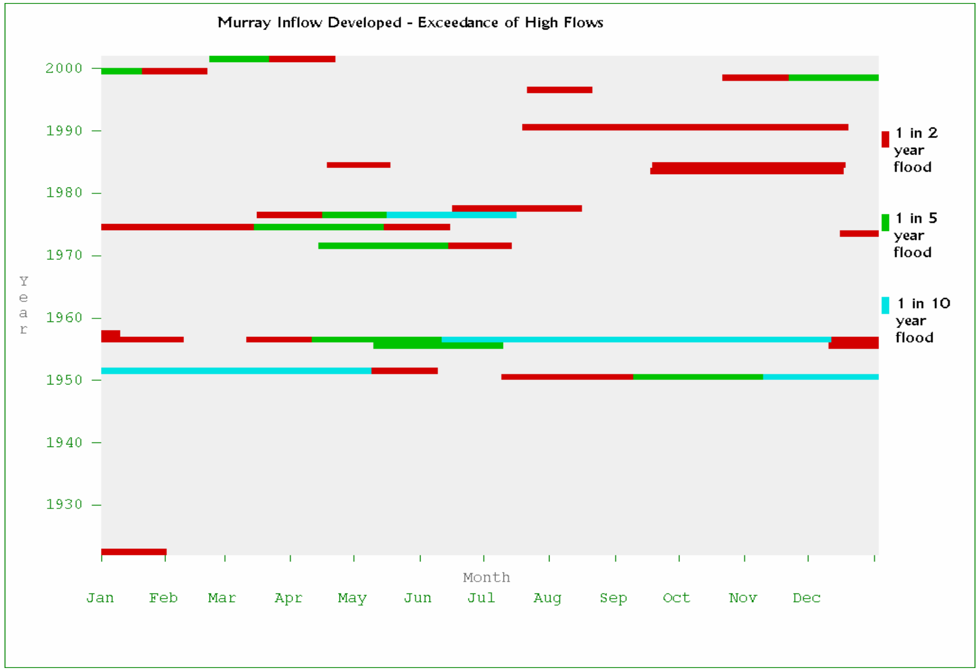
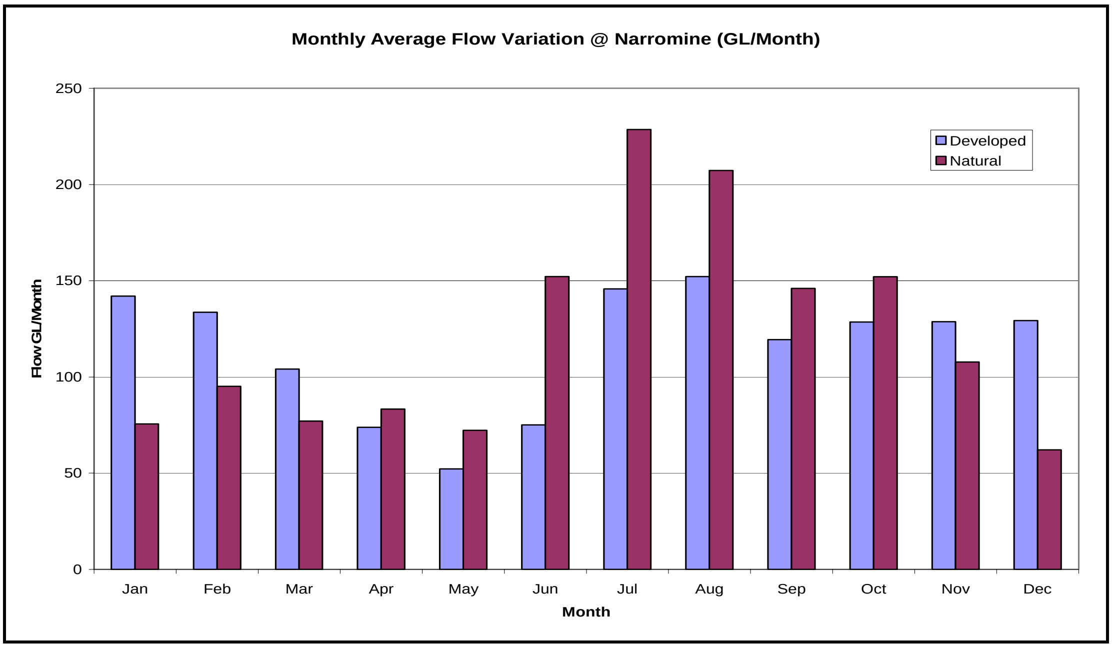


Figure 7 - Occurrence of floods at the end of the Darling River under current conditions

A variability issue that is important in the Murray system is the change in "seasonality" of flows. This occurs because flows in the Murray and its tributaries are winter dominated, water supply needs are greatest in summer, and most inflows are controlled by dams. The result is that the majority of flows now pass down the Murray and its major tributaries in summer rather than in winter.

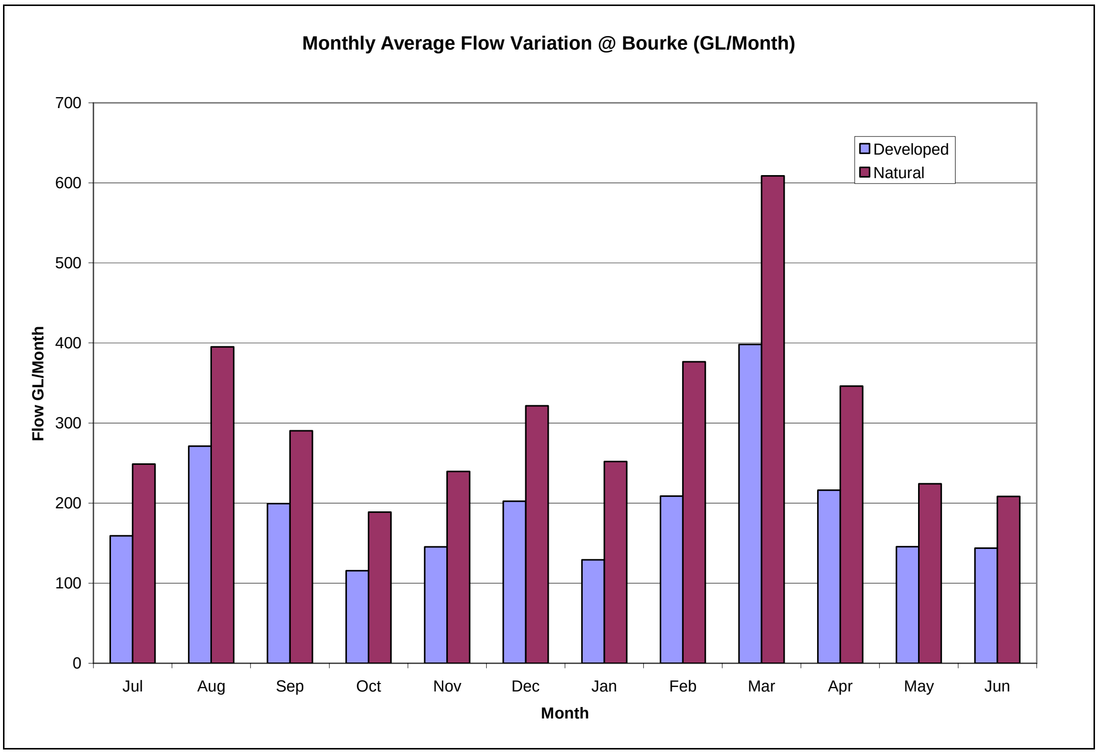
Changes in the seasonality of flows are not nearly so marked in the Darling or its major tributaries. This is because natural river flows are more evenly spread through the year, and also because dams control a lower proportion of inflows. Even in the Macquarie, where most flow naturally occurred in the winter, the impact of dam releases is a relatively minor shift that has resulted in average flows at Narromine mid system flows becoming more evenly spread throughout the year (see Figure 8).

Figure 8 – Monthly mid system flows in the Macquarie, Natural and Current (developed) conditions.



The seasonal pattern of flows in the Darling has changed very little as shown in Figure 9. All that has happened is that there has been a fairly uniform reduction in flows in all months.

Figure 9 - Monthly flows in the Darling for Natural and Current (developed) conditions



2.6 River flow change and specific river health issues

As already stated, this report does not draw conclusions about the consequences of hydrologic changes on river health and the environment. However, data concerning several flow change parameters that may be indicators of the importance of hydrologic change to three major issues (wetlands, fish and blue-green algae blooms) have been included for the information of readers.

2.6.1 Wetlands

Large wetlands occur in the lower sections of the Gwydir, Macquarie, Condamine-Balonne (in particular the Narran system), Paroo, and Warrego river valleys. Some of these wetlands are Ramsar listed. Little of the water that enters these "end of system" wetlands makes its way through to the Darling. The degree of change in average flow volume upstream of these wetlands should, therefore, be a good indicator of the extent to which their watering regimes have changed. Natural and current average inflow volumes are shown in Table 10. Map 5 in the Atlas also illustrates changes to wetland inflow regimes. The Paroo and Warrego are not included as flow changes are minimal. One point worth noting is that the data indicates that water use impacts on inflows will be greater during drier climate phases (indicated by data for 1922 to 1949) than during wetter phases (indicated by data for 1950 to 2000).

Table 10 – Average annual inflows to selected terminal wetland systems

All volumes in Gigalitres per annum

Wetland	Period	Wetland Inflows		
		Natural	Current	Change
Narran Lakes	1922 to 2000	184	89	-52%
	"Dry"1922 to 1949	134	43	-68%
	"Wet"1950 to 2000	213	116	-46%
Gwydir	1922 to 2000	464	354	-24%
	"Dry"1922 to 1949	332	230	-31%
	"Wet"1950 to 2000	534	420	-21%
Macquarie	1922 to 2000	286	223	-22%
	"Dry"1922 to 1949	220	148	-33%
	"Wet"1950 to 2000	321	263	-18%

Other wetlands occur adjacent to major river channels. Water enters them through effluent channels when flows in the major river reach a sufficiently high level. A large number of these wetlands occur along the Barwon-Darling. Map 5 in the Atlas details the change in the average number of days each year when flows exceeded the level required for inflows to wetlands to occur.

2.6.2 Fish

There are many aspects of hydrologic change that can affect fish populations. Data about some of these, such as flow volumes and changes to the frequency of high and low flows, have already been discussed. There is one other factor that has been identified by fish scientists, and that is the effect that flow changes may be having on fish migration for breeding and other purposes.

A number of fish species present in the basin are believed to seek to migrate upstream, particularly in response to increases in flows. The many weirs built along the Darling, and on most tributary streams, have created barriers to this movement (Gehrke P and Harris J 2004). Fish can only travel across these weirs when flow levels are high enough to "drown out" the weirs. Concern about this issue led to management rules that prohibit pumping of water from high flows in the Namoi, Gwydir and Barwon-Darling if the pumping will affect the drowning out of Bourke and Brewarrina weirs.

Map 6 in the Atlas shows the maximum interval between drown out events under natural and current conditions. This shows that reductions in flows have significantly compounded the barrier effect of weirs. Fishways and other structural modifications to weirs can reduce or eliminate these barrier effects. A fishway is currently being constructed at Brewarrina Weir.

2.6.3 Blue-Green Algae

Algae of many types are always present in the rivers in the Darling Basin. Occasionally a combination factors such as temperature, nutrients and river flows can trigger a rapid increase in the numbers of one or more species, resulting in an algal bloom. The most troublesome and well known of these are blue green algae (cyanobacterial) blooms. Some cyanobacteria produce toxins that are dangerous to animals and humans.

The bloom that occurred along much of the Darling River during the 1991-92 drought made national and international media. It graphically demonstrated that low flows are a key factor in the occurrence of blooms. This is because they result in lower water velocities and less flow turbulence.

Studies undertaken for several locations along the Darling (Mitrovic S et al 2003) have allowed estimates to be made of the flow velocity below which algae blooms may occur. This critical velocity was converted to a critical flow rate for a number of river sites for this report. The periods when flows would have been below the critical flow rate for 5 days or more between October and March were then identified and used to produce the data detailed on Map 7 in the Atlas. It was assumed that blooms were only likely during the warmer months of the year.

This data indicates the role of greater frequency of very low flows on the Darling and role of regulation (and reduced very low summer flows) on regulated rivers. Caution needs to be exercised with the low flow figures at the Bourke location. These numbers are unlikely to be representative of the current low flow regime due to over estimation of Bogan low flows

2.7 Future Risks

Thus far in the report, the discussion has focussed on surface water resource and how they have changed as a result of development. This next section is a discussion on what scope exists for further reductions in surface water. Whether or not such a reduction occurs will depend upon what actions are taken and as such these factors "**risks"** rather than forgone conclusions. Before discussing potential risk factors, it is necessary to outline the current water management arrangements in both Queensland and New South Wales.

2.7.1 Current Water Extraction Policies

2.7.1.1 Murray-Darling Basin Cap on extractions

An audit of water use in the Murray-Darling Basin was carried out for the Murray Darling Basin Ministerial Council in 1995. It concluded that growth in water extractions had seriously depleted river flows in the Murray-Darling Basin, and that, unless management rules changed, diversions would continue to increase. The response of the Council was that states should set limits (termed a "cap") on water extractions.

New South Wales agreed to set the limit for each of its valleys at the extractions that would occur under June 1994 levels of development. Victoria and South Australia agreed to also adopt this for their cap limits.

A different approach was taken for Queensland. The Council agreed to caps for Queensland extractions being set following completion of the Water Management Planning processes for each of its Murray-Darling river systems.

Within the New South Wales portion of the Basin, the Cap is managed in accordance with "Schedule F" of the Murray Darling Basin Agreement. Annual audits of extractions are carried out, and a running total of annual cap credits and debits is kept. If the running total reaches a debit for a valley that exceeds the amount prescribed in Schedule F, the state government must report on why the cap has been exceeded and the actions it will take to return extractions to Cap levels. QLD has indicated that they will be proposing a different approach.

2.7.1.2 New South Wales Water Sharing Plans

NSW water sharing plans:

- establish long-term extraction limits,
- specify how to determine whether extractions limits are being exceeded,
- set rules for reducing the amount of water that licence holders can take if it is found the limit is being exceeded,
- set environment flow rules that may include specific flow targets, allocations of water for the environment or limits on the extraction of water during periods of high flow.

Water sharing plans covering water allocation and extractions for the Gwydir, Namoi, and Macquarie regulated rivers and some of the Darling Basin's unregulated streams commenced in July 2004. "Macro" water sharing plans for the remaining unregulated streams are now under development. The plans are reviewed after 10 years.

The extraction limits set in the NSW regulated river plans were said to be 5% to 10% below those permitted under Cap rules. The extraction limit for unregulated rivers is based on the "estimated annual extraction of water over the period from July 1993 to July 1999. There is, however, some doubt about whether the estimates accurately reflect actual extractions (see section 2.7.2.3 for further discussion).

The regulated river water sharing plans only set specific rules for extraction of water from those river channels that have been "declared …. to be regulated rivers". However, the plans do require inclusion of "floodplain harvesting extractions estimated to have been taken for use in conjunction with extractions authorised from this water source" when assessing the " long-term extraction limit and auditing compliance with it". The issue of floodplain harvesting extractions (included in the Queensland term overland flow take) is further discussed in section 2.7.2.1.

2.7.1.3 Queensland Water Management Plans

Queensland has a two tier planning regime involving Water Resource Plans (which set the strategic rules for water management in a catchment) and Resource Operation Plans (which set the operational rules).

The Water Resource Plans set a number of high level management objectives such as:

- Management objectives for the catchment;
- Environmental flow objectives;
- Water allocation security objectives;

- Identification of volumes of water for future development;
- Long term flow targets at various locations in the plan area (set as percentages of natural flow);
- Limitations on additional diversions of water in the catchment;
- Control of overland flow works;
- Conversion of licences into volumetric, tradable allocations;
- Specific environmental provisions to protect environmental assets;
- Water sharing rules; and
- Provisions for changes to the plan in the future.

Water resource plans are implemented through the development of a resource operations plan. This plan contains the operational rules which will implement the strategic provisions in the water resource plan.

Queensland enacted Water Resource Plans for the Border Rivers, Moonie, Nebine, Warrego and Paroo valleys in 2003, and for the Condamine-Balonne in 2004. The Plans are in effect for ten years at which point they are reviewed.

Resource Operation Plans set out the rules and management arrangements intended to meet the objectives and requirements set out in the Water Resource Plan for the area. For example, they can set out flow conditions applying to the extraction of "unsupplemented" water (extractions from natural high flows), and provide for the inclusion in overland flow licences of limits on storage volumes, and rates and quantities of water extractions.

Resource Operations Plans for the Warrego, Paroo, Nebine, and Moonie catchments were gazetted in January 2006. It is expected that resource operations plans for the Border Rivers and the Condamine and Balonne will be gazetted in late 2007

All plans, other than the Condamine-Balonne Plan, allow for the granting of water entitlements to take water that is currently "unallocated" (see Table 11).

Table 11 – Unallocated volumes in Queensland Water Resource Plans.

Plan	Border R	Moonie	Paroo	Warrego	Nebine	**Total**
Unallocated water volume *(Megalitres per annum)*	5,000	1,200	100	8,100	1,100	**15,500**

2.7.2 Growth in Surface Water use

Although there is a cap in place, there appears to be scope for further reductions in surface water flows in the Darling Basin. This reduction can potentially be caused by a number of factors.

2.7.2.1 Floodplain Harvesting

Floodplain harvesting involves the capture and storage of water that overflows from river channels during periods of flood. It may occur by pumping of water into storages, or by water flowing through natural or artificial channels into on farm water storages. In Queensland, it is termed "overland flow take".

Both New South Wales and Queensland plans also do not allow increases in floodplain harvesting diversions. Queensland plans go further by also including rainfall harvesting in this definition. Despite the existence of plans in both states, there still appears to be some opportunity for further growth in the capture of overland flows and runoff from rainfall. However, initiatives are underway in both states to attempt to monitor these forms of water use.

The New South Wales water sharing plans for the Macquarie, Namoi and Gwydir regulated river systems say that floodplain harvesting extractions must be included in assessments of compliance with extraction limits. The NSW Department of Natural Resources is also attempting to develop a comprehensive policy with respect to the licensing of existing works, consideration of new works and management of extractions. However, the policy has yet to be finalised and put into practice. To date no action has been taken to monitor extractions or to prevent construction of works facilitating additional capture of floodplain flows.

In Queensland, additional floodplain harvesting works are embargoed, with any proposed alterations to existing works triggering an approval process that requires licencing, volumetric limits and metering of usage.

An attempt has been made to include floodplain harvesting in most NSW computer models, but without comprehensive data on the infrastructure and the volumes actually being taken, there must be considerable doubt about the accuracy of these assessments.

Likewise QLD computer models also include estimates of floodplain harvesting volumes. Queensland has attempted to more accurately quantify floodplain harvesting volumes through ground truthing with respect to works and levels at which harvesting occurs. However, some uncertainty about floodplain harvesting volumes still remains.

Queensland applied moratoriums on the construction of new overland flow works during 2000 and 2001. These were replaced by provisions in the water resource plan which stated that no new overland flow works which would result in an increase in the average volume of take may be constructed (no existing works modified). The resource operations plans provide for the licencing of overland flow works to ensure that there is no additional take of water. Licencing of overland flow works will occur if it is likely that any changes to either the works of licences that use the same storage may result in an increase in take. Licences for overland flow will be issued in the Lower Balonne as mandated by the finalised WRP.

Queensland has reported on floodplain harvesting volumes in its annual Cap reports to the Murray Darling Basin Commission. A study by Bewsher (2006) indicates that these estimates are likely to have some inaccuracies as they are based on estimates.. It is understood, however, that Queensland will meter floodplain diversion wherever a licence is required, that is where there are new works.

2.7.2.2 Hillside Dams

The New South Wales “harvestable rights” policy allows farmers to construct dams on hillsides and small gullies (defined as first and second order streams) without a licences, providing the total volume of such dams on a property is less than that the “Maximum Harvestable Right Dam Capacity” for that region and farm size. The dam capacity limit for each region is set at a dam size per hectare of property that is believed to permit the capture of 10% of property runoff. The captured water may be used for irrigation or commercial purposes as well as for stock and domestic purposes.

The limits to dam size do not apply to properties in the Western Division. This is said to be because runoff is low and generally does not reach rivers and because the amounts intercepted will not affect natural resources.

There has been no reliable assessment of the long-term increases in hillside dams that may occur under the harvestable rights policy or the impact it could have on river flows in the Basin.

All new hillside dams in NSW that fall outside of the harvestable rights policy require unregulated river access licences, and water cannot be taken from them without a works approval. Embargoes apply to the issue of new access licences for most purposes in the NSW portion of the Basin, so in most cases a runoff harvesting entitlement could only be obtained by purchase of an existing access entitlement.

The policy applying to overland flow work on floodplains also applies to hillside dams and their “overland flow take” in Queensland is the same as that applying to the taking of overland flows from floodplains (see section 2.7.2.1). The lack of reliable data on hillside dams volumes and use of water from them creates significant uncertainty regarding the impact they are currently having on water use in the Basin and monitoring whether this is increasing.

Table 5 and Table 6 indicate that the effect of dams could be significant, and that the total average annual volume of use and evaporation from hillside dams could be close to 1000 Gigalitres. This is about 20% of the total volume of water extractions and water storage evaporations for the Basin.

2.7.2.3 Plan Diversion Limits.

The diversions limits New South Wales is applying to water extractions from their major regulated river systems are based on those possible with the water use infrastructure and access licences in place in 1999/2000 and the management rules applied by each plan. In all cases this is said to allow no growth in extractions, with plan rules actually reducing extractions from these systems to levels lower than are required under the Murray Darling Basin Cap (see section 2.7.1.1).

With the exception of the Barwon Darling, the water sharing plans for unregulated rivers in New South Wales set a long-term limit on total extractions. This limit is equal to the assessed average annual diversions in the “management unit” between 1993 and 1999 “specified in conditions attached to or included in” licences in place when the Plans were enacted. Metering of usage in these unregulated tributaries is yet to occur.

The volumes attached to each unregulated licence was the total of the average volume assumed to have been used on areas reported as having been cropped plus a volume for areas authorised for irrigation but not cropped over the 1993 to 1999 period. The method for assessing the volume used on areas reported as having been cropped assumed that crops were always fully watered, and that the flows necessary to achieve this were always available. This was not the case for most rivers in the Basin, with the result that the assessed volumes are likely to have been well above actual usage. There were also other assumptions made about cropping practices that may have resulted in inflated assessments of crop water requirements.

It appears that New South Wales is adopting the same approach in the macro plans that will soon be finalised for the remaining unregulated rivers in the Basin.

The result of this is that the volume of long-term extraction permitted by NSW unregulated stream plans is probably substantially greater than that currently occurring. The total volume of licences on unregulated streams in the NSW section of the catchment is 262 Gigalitres.

In the case of the unregulated Barwon-Darling Cap limits have been set at the individual licence level in the form of a continuous account.

Queensland establishes extraction limits in its plans in a slightly different manner to New South Wales. Queensland's plans do not explicitly specify the volume of the extraction limit, but use a variety flow objectives and requirements with respect to licensing and allocation management to articulate limits. Presently, in some plans the level of current usage is below these extraction limits, and there is consequently some scope for further increases in surface water use. The actual extent of this increase is unknown. However, advice from Queensland agency staff indicates that the scope for increase is limited and small. It should be noted that the impacts of this increased in usage with respect to surface water pumped diversions has already been incorporated into the Queensland modelling results and the analysis presented in this report.

2.7.2.4 Rainfall Harvesting

Rainfall harvesting in this report means the collection of rainfall generated runoff from areas developed for irrigation cropping. Currently no restrictions are placed on how much water can be collected this way in New South Wales. In Queensland it would appear that water generated by rainfall on areas developed for irrigation cropping is classified as overland flow, and that the rules applying to rainfall harvesting are those applying to overland flow take (see 2.7.2.1).

The volumes included in Table 5 in section 2.4.1 are computer model estimates. These show that volumes being taken by rainfall harvesting could be substantial. Unfortunately, no data has been collected on farms to verify that the model results are reasonable reflections of the actual volumes currently being taken, or if the practice is growing.

Collection of this water may be having little effect on river flows, as it is possible that much of the runoff would not have occurred but for the land use changes associated with irrigation. However, there has been no reliable assessment of the effect, if any, that rainfall harvesting is having on runoff to rivers.

Even if this is the case, rainfall harvesting is a factor that needs to be taken into account when assessing the long-term volumes being taken from rivers or by floodplain harvesting. Failure to assess the impact of the practice on river flows, monitor its scale, and accurately represent it in computer models adds to the difficulty of assessing compliance with Cap and the limits or objectives set by NSW and Queensland water management plans.

2.7.2.5 Measurement of Use

A critical factor in assessing the impact of extractions on flows and restraining water extractions to desired levels is good information about the water extractions that are occurring. There are two reasons for concern about current measurement practices in the Basin.

The first is that there is no monitoring of several important forms of use. This has already been referred to in relation to floodplain harvesting, hillside dams, and rainfall harvesting. However, there are also gaps in measurement of extractions from rivers, notably in relation to extractions from unregulated rivers.

A second concern relates to the accuracy of metering. Recent reports prepared for the Murray Darling Basin Commission have shown that, in many cases water actual extractions are substantially greater than those being recorded by meters (SMEC 2006).

2.7.3 Groundwater Impacts

Many groundwater systems are recharged by seepage of water from rivers and many aquifers discharge water into rivers. This recharge and discharge may be occurring at different locations or at the same location at different times. During times of low or no rainfall, the only natural inflow to rivers is water that is coming from aquifer systems.

Pumping of groundwater may increase river losses to aquifers and/or decrease the volume of water a river receives from an aquifer. There are a variety of factors that affect the extent to which pumping will affect river flows, how long it will take the effect to be felt, and the effect this will have on river flows and the supply to water surface water users along the river. These include the distance the groundwater pumping is from the river, when pumping is occurring, how much water is being taken, the hydraulic characteristics of the aquifer and the degree of connection to the river.

Groundwater pumping from many aquifers in the Basin has increased significantly in recent years and is continuing to increase. Data provided by NSW Department of Natural Resources for a soon to be completed MDBC study on groundwater-surface water interactions indicates that the loss of river flows associated with current pumping rates from NSW aquifers is about 74,000 Megalitres per annum, and that pumping increases over the next 50 years will cause losses to rise to 191,000 Megalitres per year.

Much of the impact of past pumping has yet to be felt by way of reduced river flows, and very little of the effect of pumping is present in the data used to calculate current river inflows and losses for the computer modelling used in this report. A more extensive discussion of the connected aquifers issue appears in section 4.

2.7.4 Climate Change

The NSW Department of Natural Resources and Queensland Department of Natural Resources and Water have carried out assessments of the potential impacts of climate change upon streamflows and water extractions for the Macquarie, Namoi/Peel, Gwydir, Border Rivers, and Condamine-Balonne systems. These were based on CSIRO projections of future changes to rainfall and evaporation. The CSIRO projections spanned a range of possible outcomes. This range in projections is caused by uncertainties about future carbon-dioxide emission levels and other factors.

Unfortunately, the streamflow and water use assessment results (see Table 12) are not directly comparable as they did not all use the same climate change projections. Nevertheless, they do demonstrate that climate change is likely to result in significant reduction in streamflows, and a somewhat lesser reduction in water extractions within the next 25 years. They also show that this is likely to affect all rivers in the Basin and that reductions in flows into the Darling of the order of 20% are possible.

Table 12 – Percentage changes for 2030 climate scenarios.

Valley	**Change in flows/extractions**			
	Minimum change climate scenario	Mid range climate scenario	Dry climate scenario	Other
Gwydir Valley (93/94)				
Copeton Inflows		-13%	-20%	
Mean Wetland Inflows		-10%	-19%	
Water extractions		*-6%*	*-10%*	
Border Rivers (99/00)				
Pindari Inflows		-8%	-17%	
Mean EOS @ Mungindi		-9%	-19%	
Water extractions		*+1%*	*-1%*	
Macquarie (93/94)				
Burrendong Inflows				-24%
Macquarie River @ Carinda				-35%
Water extractions				*-20%*
Namoi Peel (99/00)				
Keepit Dam Inflows		-3%	-19%	
Namoi River @ Walgett		-2%	-24%	
Water extractions		*0%*	*-7%*	
Condamine Balonne (99/00)				
Beardmore Dam Inflows	-4%		-12%	
GS 422204A Whyenbah	-5%		-13%	
Water extractions	*-3%*			

3 GROUNDWATER

3.1 Groundwater Geology and Occurrence

The Darling Basin is underlain by a complex assemblage of rocks that can be divided into a number of major geological units, some of these extending far beyond the edge of the river basin itself, and formed across geologic time. These essentially sedimentary systems have in places been deformed by the action of heat and pressure, and show evidence of previous and subsequent volcanic activity. Most importantly for groundwater occurrence, much of this geological structure has more recently been blanketed by comparatively thin layers of sediments deposited geological time by the action of rivers and wind. These deposits are relatively extensive in the broader flat country, and are deepest in the broad alluvial valleys. Their occurrence is somewhat restricted in the highlands areas.

Ife & Skelt (2004) have characterised the Darling Basin as comprised of four main aquifer types (see Figure 10 and Figure 11).

- Alluvial sediment deposits in the Darling River Drainage Basin which are generally unconsolidated porous aquifers (where the sediment particles are uncemented);
- Layers within the Great Artesian Basin which are generally consolidated (cemented) porous aquifers;
- Fractured rock aquifers in the highlands of the Central West; Barwon and Barrier regions, and in Queensland; and
- The Queensland Basalts.

Figure 10 - Northern Darling Basin

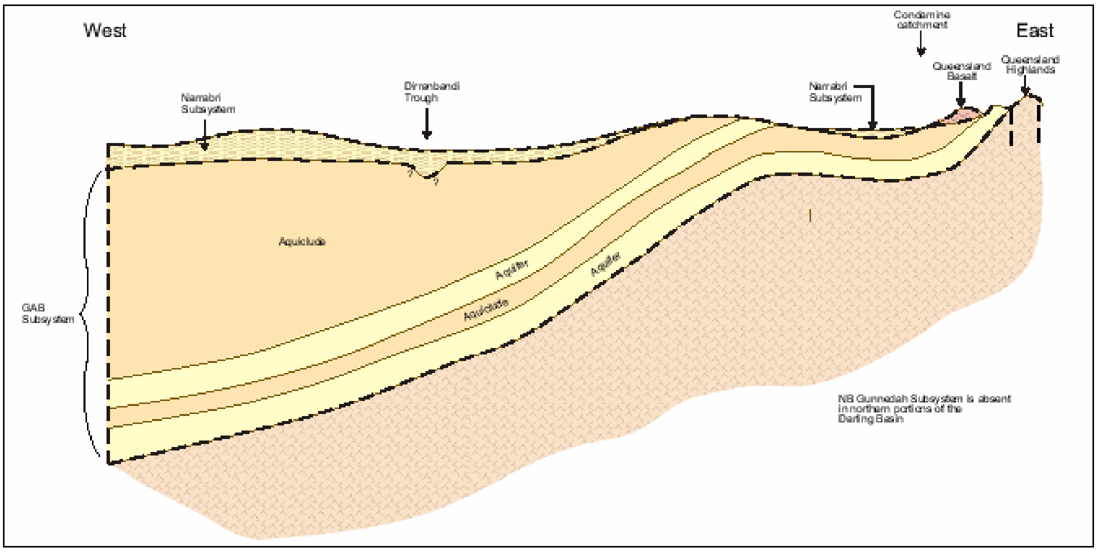
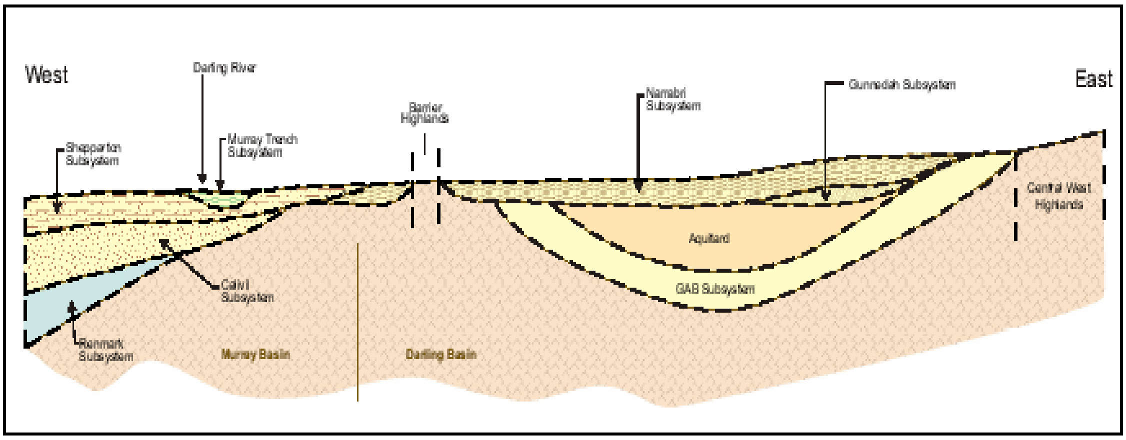


Figure 11 - Southern Darling Basin



The alluvial sediments of the Darling River Drainage Basin are less well known than those of the Murray Geological Basin. These alluvial deposits are the major resource aquifers in the Darling River Drainage Basin in NSW and are associated with the major river valleys in NSW and Queensland – the Macquarie/Bogan, Castlereagh, Namoi, Gwydir, Condamine, and the Border Rivers. In most cases, the thicker accumulations of alluvium are characterised by a deep coarse-grained unit (referred to as the Gunnedah subsystem) overlain by the more extensive, finer-grained layer referred to as the Narrabri Subsystem. The extent of the Gunnedah formation is not well known, but is believed to be restricted to the NSW valleys and the Border Rivers, and is generally thickest towards the east, thinning out towards the west. The more extensive Narrabri system extends over most of the basin, although west of the major eastern tributaries good quality water from the Narrabri formation can only be found in very narrow bands close to the rivers.

The Great Artesian Basin (GAB) of central and southern Queensland and northern NSW is a complex array of layers that form a large groundwater system that underlies the Darling Basin. Within the Darling Basin, the GAB consists of the Clarence-Morton sub-basin in the East, the Surat sub-basin in the central area, and the Euromanga sub-basin in the west. These sub-basins are hydraulically connected. The bulk of groundwater in the GAB flows in a northerly or westerly direction towards central Australia.

The Highland rocks outcrop around the perimeter of the Basin, where groundwater occurs in fractured rock, granite, and basalt aquifers. There are also minor upstream alluvial deposits that represent small but locally important sources of groundwater.

The Queensland Basalts are a series of volcanic flows hundreds of meters thick, extending north-west and south-east of Toowoomba.

The salient features of the subsystems described above are shown in Table 13.

Table 13 – Groundwater System Characteristics

	Gunnedah	Narrabri	GAB	Highlands			Qld Basalts
				Basalts	*Other fractured rocks*	*Upland alluvium*	
Aquifer material	Sands and gravels	Clay, sands, gravels, silts	Porous sandstone	Fractured Basalt	Fractured rocks	Sands, gravels, clays, silts	Fractured Basalts
Yield	High	Low-high	High	Low - moderate	Low	Low - Moderate	Low-moderate
Dominant Recharge sources	Narrabri formation leakage	Rainfall, river & irrigation losses, floods	Rainfall on outcropping areas mainly in east	Rainfall, local streams	Rainfall	Rainfall, local streams	Rainfall, local streams
Discharge areas (other than surrounding aquifers and evapotranspir-ation)	Unknown. Possibly surface seeps, westerly rivers (Barwon?)	Rivers	Mound springs, South Australia	Local streams	Local streams, land surface at break of slope	Local streams, beak of slope	Local streams
Flow path	Regional (long)	Local to regional	Extremely long	Local	Local (up to 30km)	Local (<5km)	Local
Water quality	Good nearer recharge areas, deteriorates down flow path.		Good in recharge areas, non-irrgation quality only down flow path.	Good	Poor to fair	Good to very poor	Good

3.2 Management Framework and Policies

The salient features of the groundwater management regimes in NSW and Queensland are shown in Table 14.

Table 14 – Groundwater Management Frameworks

	NSW	Qld
Managing agency	Department of Natural Resources	Department of Natural Resources and Water
Relevant Act	Water Management Act 2000 Water Act 1912	Water Act 2000 Integrated Planning Act 1997
Approval required for bores?	All bores	All bores excluding for stock and domestic purposes
Approval required for groundwater extraction?	All except for domestic and stock extraction	All except for domestic and stock extraction
Management units	GMAs – whole basin covered	GMAs – 31 (including 6 GAB areas)
Management plans in place?	End 2006 - Lower Gwydir, Upper Namoi, Lower Namoi, Lower Macquarie. Between 2007 and 2009 – entire NSW portion of Basin.	One formal water resource plan under the Act for the GAB, 9 other non-statutory management plans By end 2007 – Border Rivers
Use metered?	Required for all non-domestic and stock use. Compliance with requirement >80%, and close to 100% in management plan areas.	No, except Condamine GMAs, the Upper Hodgson Creek basalt and the Oakey Creek Management Area. Intent to require metering of all non-stock and domestic extraction in all GMAs.

The main unit for groundwater management in the Basin is the Groundwater Management Area (GMA). These are shown in Map 8. In GMAs where the Gunnedah system is overlain by the Narrabri system, (the Gwydir, Namoi and Macquarie systems in NSW), the aquifers are treated as a single unit for management purposes.

Note that all NSW portions of the basin have been assigned a GMA, and an extraction limit, that will be administered in accordance with the provisions of a water management plan (water sharing plan) by the end of 2007.

Queensland groundwater managers report that the only area in the Queensland portion of the Darling Basin with potential for groundwater development from a quality and quantity perspective is the eastern margin. This area contains all the GMAs except for the GAB units. The practice in Queensland has been to initially assign a yield figure to each GMA based on geology and estimated recharge, and allocate to that limit in the first instance. As the systems develops, the yield figures are refined. If the systems shows signs of stress prior to reaching the allocation limit, it is closed to further allocation by way of administrative holds or moratoriums. Unfortunately, some systems, such as the Condamine GMAs, were already over-developed when the whole area was licensed, giving rise to the current mismatch between entitlements and extraction limits.

Queensland reports that the only other areas in the Basin where groundwater could be accessed at the moment are the far western alluvials associated with the Paroo, Warrego and Maranoa, where preliminary drilling indicates low yield and variable quality.

3.3 Extraction Limits and Sustainable Yields

State and Territory jurisdictions have agreed to the following definition of "sustainable yield":

> *"The groundwater extraction regime, measured over a specified planning timeframe, that allows acceptable levels of stress and protects dependent economic, social, and environmental values."*

Extraction limits (sustainable yields) for the major NSW and Queensland GMAs in the Darling Basin are shown in Map 8, and further detailed in Tables 15 and 16. Numbers for the large fold belt and porous rock areas in NSW (with the exception of the GAB), the GAB alluvium, and the unincorporated areas of Queensland are not included in the map. Extraction limits assigned to these are extremely large. It is unlikely, however, that this water will ever be extracted. Water quality is generally poor, and yields are poor. They are suitable for domestic and stock supplies at best. Indeed, specifying such large extraction limits would seem somewhat misleading, implying that the water is there to be taken. These extraction limits associated with these areas have, however, been included in Table 15 and Table 16.

New South Wales

In NSW, the average annual extraction limit of a GMA is set as a proportion of 'recharge' to the system. The recharge is determined via various means, ranging from relatively crude estimates of rainfall infiltration to the system, to more complex computer modelling of system inputs, including from rainfall, inflows from other aquifers, floods, the river and irrigation losses. Models are calibrated against historical monitoring bore and groundwater extraction data.

In theory, the proportion of recharge that represents the extraction limit for a GMA is determined taking into account the "risks" posed to environmental values connected to groundwater from groundwater extraction. This theory is only applied in practice where the implementation of such an approach will not have any significant impact on the exercise of current groundwater extraction rights. However, in systems where a reduction in rights will be required to implement the approach, the allowable extraction tends to approach 100% of recharge. This is particularly the case in the Namoi groundwater systems.

The NSW groundwater sharing plan extraction limit determinations are discounted for salinity as this planning process was predominantly concerned with fresh water. This means that salt affected groundwater supplies were not included in the calculation of the extraction limit. The Macro planning process does not discount for salinity however as many aquifers have brackish/ salty water. They reflect groundwater 'availability' in quantity terms only, with the use to which the water can be put being considered a separately managed issue.

The NSW water sharing plans apply extraction restrictions in local areas (i.e. at a smaller scale than the GMA or zone) in response to local water level draw downs seen as "unacceptable", or if local extraction is causing an "unacceptable" deterioration in groundwater quality. They also impose conditions on bore licences or approvals regarding the distance of extraction bores from rivers, other dependent ecosystems, and other extractive uses.

The combination of the *extraction limits* and the *local impact management* measures give rise to the *sustainable yields* for NSW GMAs, consistent with the national definition.

Queensland

Ife and Skelt (2004) have described the Queensland approach to extraction limits, or sustainable yield as follows. "The groundwater yields that are used for management purposes in the Queensland portion of the Darling basin vary in the method in which they have been calculated, depending on the importance of the resource and the data available for analysis. Some yield estimates are still based on data analysis and water balance while many of the smaller alluvial systems have been analysed using fairly simple computer modelling techniques. Only the main Condamine GMA and the Border Rivers area have been subject to detailed modelling exercises. At this stage, none of the yield figures to which the systems are managed could be considered a "sustainable yield" in the true sense of the national definition. All current yields have been determined based on supplying water over a long term period with water available for the environment where possible, but have not been subject to major community input at this stage."

Ife and Skelt (2004) have also referred to the determination by Queensland groundwater managers of "failure" criteria. "The failure criteria vary in each GMA, but usually related to failure of supply, affect on base flow or other groundwater dependent ecosystem, or inducing water quality deterioration. An average yield figure that causes a low (usually under 10%) risk of failure is then determined", and established as the extraction limit or sustainable yield.

Table 15 – Groundwater entitlements, extraction limits and use (QLD)

Queensland					
GMU key	GMU name	Groundwater allocation/ entitlement (ML/a)	Extraction limit (ML/a)	Groundwater use 2004/05 (ML/a)[a]	New Entitlements Permitted?
Q53	Myall / Moola Creek North Alluvium	2341	3500	2500	N
Q54	Myall Creek Alluvium	1891	5300	1500	N
Q55	Lower Oakey Creek Alluvium	6125	6500	6000	N
Q56	Oakey Creek Management Area	9663	7000	5406	N
Q57	Condamine CGMA SA 1	3560	1440	4190	N
Q58	Condamine CGMA SA 2	11010	2490	8157	N
Q59	Condamine CGMA SA 3	50780	14810	32670	N
Q60	Condamine CGMA SA 4	4150	1930	3288	N
Q61	Condamine CGMA SA 5	1308	1500	970	N
Q62	Condamine River d/s of CGMA	4513	3500	1500	N
Q63	Condamine River Alluvium (Killarny to Murry Bridge)	2061	455	2000	N
Q64	Condamine River Alluvium (Murry Bridge to Cunningham)	4637	3014	4300	N
Q65	Condamine River Alluvium (Cunningham to Ellangowan)	8080	5855	6750	N
Q66	Glengallen Creek Alluvium	7308	4490	7800	N
Q67	Dalrymple Creek Alluvium	6082	3953	3600	N
Q68	King's Creek Alluvium	1780	4230	1850	N
Q69	Swan Creek Alluvium	1365	900	1200	N
Q71	St. George Alluvium	10028	18000	4500	N
Q73	Border Rivers Alluvium	14601	15000	6552	N
	Subtotal alluvial	**151283**	**103867**	**108827**	
Q70	Nobby Basalts	3004	2400	2800	N
Q52a	Toowoomba North Basalt [b]	9341	15000	9000	N
Q52b	Toowoomba South Basalt [c]	26116	35000	24000	N
Q52c	Warwick Area Basalt	8740	9600	6500	N
Q51	Upper Hodgson Creek Basalt	5700	7500	2500	N
Q52	Toowoomba City Basalt	6268	6500	3800	N
	Subtotal basalts	**59169**	**76000**	**48600**	
Q78	GAB Barcaldine	44170	36310	??	N
Q80	GAB Eastern Recharge B	37140	32450	??	N
Q82	GAB Eastern Recharge C	17950	15690	??	N
Q94	GAB Central Qld	28000	16680	??	N
Q95	GAB Warrego Qld	59400	48960	??	N
Q96	GAB Surat Qld	96720	71960	??	N
	Subtotal GAB	**283380**	**222050**	**??**	
Q106	UA New England fold belt	45422	532522		Y
	Total Qld	**539254**	**934499**	**257427[d]**	

Table 16 – Groundwater entitlements, extraction limits and use (NSW)

New South Wales					
GMU key	**GMU name**	**Groundwater allocation/ entitlements (ML/a)**	**Extraction limit (ML/a)**	**Groundwater use 2004/05 (ML/a)**	**New Entitlement s Permitted?**
N1	Lower Namoi Alluvium	108983 [e]	86000	85900	N
N3	Lower Gwydir Alluvium	45451 [f]	32300	36200	N
N4	Upper Namoi Alluvium	156422 [g]	122100	100000	N
N5	Peel Valley Alluvium	n/a	n/a	9000	N
N8	Lower Macquarie Alluvium	71016 h	69293	54890	N
N9	Upper Macquarie Alluvium	31290	28700	13892	N
N10	Cudgegong Valley Alluvium	12684	7800	1149	N
N19	Collaburragundry-Talbragar	5692	7000	n/a	N
N20	Bell Valley Alluvium	4364	7000	n/a	N
N22	Border Rivers Alluvium	13800	15000	6100	N
N23	Miscellaneous Alluvium of	12177	3600	7700	N
N45	Lower Darling Alluvium	942	1500	48	N
N46	Upper Darling Alluvium	150	21802	422	Y
N66	Castlereagh Alluvium	1500	1200	59	Y
	Subtotal alluvial	**464471**	**403295**	**315360**	
N63	GAB Alluvial	n/a	370936	1192	Y
	Subtotal alluvial + GAB	**464471 + GAB**	**774231**	**316552**	
N601	Great Artesian Basin				
	Eastern Recharge	35980	11900	10000	?
	Southern Recharge	26540	29700	8200	?
	Surat	29115	75000 [i]	75000	N
	Central	911	7900 [i]	7900	N
	Warrego	1867	22400 [i]	22400	N
	Subtotal GAB	**94413**	**146900**	**123500**	
N801	Orange Basalt	8925	16140	669	N
N803	Inverell Basalt	3211	26300	2600	Y
N813	Gulargambone Tertiary	1800	11500	130	Y
N814	Liverpool Ranges Basalt	4549	78789	2500	Y
N819	Peel Valley Fractured Rock	25714	78400	16300	Y
	Subtotal basalts /	**44199**	**211129**	**22199**	
N805	New England Fold Belt [j]	51581	1332022	15200	Y
N811	Lachlan Fold Belt [j]	73519	1057599	n/a	Y
N817	Kanmantoo Fold Belt [j]	0	121373	5100	Y
N818	Adelaide Fold Belt [j]	7	59079	221	Y
N604	Gunnedah Basin	26200	213000	14800	Y
N608	Oxley Basin	13500	86100	8700	N
	Subtotal sedimentary	**164807**	**2869173**	**44021**	
	Total	**767890** [k]	**4001433** [l]	**506272** [m]	

Notes for Tables 15 & 16

a	The Qld use figures, except for the metered systems of Condamine, Oakey Creek, and Upper Hodgson Creek and Border Rivers GMAs are estimates only
b	Underlain by Toowoomba North Sandstones
c	Underlain by Toowoomba South Sandstones
d	Plus unmeasured
e	Includes 22983 of supplementary access at start of plan, which will be reduced to zero over 10 years
f	Includes 13151 of supplementary access at start of plan, which will be reduced to zero over 10 years
g	Includes 34322 of supplementary access at start of plan, which will be reduced to zero over 10 years
h	Includes 2399 of supplementary access at start of plan, which will be reduced to zero over 10 years
i	Minus 100% cap and pipe savings to 1999, and minus 70% cap and pipe savings post 1999
j	Includes areas outside of the Darling Basin
k	Plus GAB alluvial, Peel alluvium
l	Plus Peel alluvium
m	Plus Lachlan fold belt, Collaburragundry-Talbragar, Bell, GAB eastern recharge

3.4 Current Entitlements and Use

Groundwater entitlements and use for NSW and Queensland GMAs in the Darling Basin are detailed in Tables 15 and 16. Note that 'use' figures for the GAB, other than for the sub-artesian intake bed areas, include total discharge from free flowing bores. Tables 15 and 16 also indicate whether or not new entitlements can still be granted in each GMA.

In almost all the Basin GMAs, the major use of groundwater is for irrigation. The major exception to this rule is in the non-intake areas of the GAB, where the groundwater quality makes it unsuitable for irrigation. Here, the water provided by the GAB is often the only source of water for remote communities and stock watering. Other exceptions include the Toowoomba City Basalts, parts of the Condamine GMA, and the Castlereagh alluvium, where a large proportion of the groundwater use is for urban centres.

Although the volumes of groundwater extracted for domestic and stock use are relatively small, a large number of towns and villages in the Basin are dependent on it. DNR&M (2003) report that approximately 80% of the rural community in the Queensland portion of the Basin relies on groundwater for all or part of their domestic requirements, and about 90% of stock watering requirements are met from groundwater.

New South Wales

Current water sharing plans in NSW require a matching of total entitlements in the systems to the average annual extraction limits by the end of the 10 year plan period. No decision has been made as to wether this will be the case for remaining plans. With respect to future In systems such as the Upper and Lower Namoi, the Lower Gwydir and Lower Macquarie, where pre-plan entitlements exceed the extraction limits, entitlements will be slowly reduced over the first planning period. At plan's end, NSW GMAs will be run as 'high security' systems, whereby, barring any need for local impact management, licence holders should be able to extract their full entitlement each year.

Map 8, and Table 16 show that in many NSW GMAs within the Darling Basin, current entitlements exceed the extraction limit, but that in all GMAs except the Lower Gwydir and the Miscellaneous Alluvium of the Barwon Region, 2004/05 use remained below the extraction limit. There are two issues that should be noted. Firstly, single year use numbers are not representative of average use, and they do not show trends in use. It would be fair to say, perhaps with the exception of the Namoi systems, groundwater use has been growing over the past decade, and this trend is likely to continue in GMAs where current use is below the extraction limits. Secondly, the total use figure quoted for GMAs that have been subdivided into zones (or separate water sources) do not adequately represent the over-use that is occurring in some zones. This over-use is being masked in the numbers by under-use in other zones. This is particularly the case in the Upper Namoi GMA.

Queensland

In all the Queensland GMAs, administrative holds have been placed on the issuing of further entitlements or allocations, pending more detailed investigations and/or the development of water resource plans. Areas such as the GAB may be opened up to new allocations once this process has been completed.

Map 8 and Table 15 show entitlements in many of the Queensland GMAs exceeding the determined extraction limits, particularly in the Condamine. Of the 25 GMAs, use in 11 exceeded the extraction limit during 2004/05. Queensland may consider reducing the volumes specified on licences in these areas as part of a formal water resource planning process. To manage extractions to within these limits, the current approach is to announce the available groundwater as a proportion of licence volumes. In contrast to NSW, in the long term, unless licence volumes are reduced, Qld licence holders in over-allocated systems will not be able to access their full licence volume each year. The amount they will be able to extract will depend on the behaviour of the system, and on the use of other entitlement holders in the GMA.

3.5 Current Impacts

All groundwater pumping will have an impact. The water is coming from somewhere, be it the rainfall, the river, floods, other groundwater sources etc, and is going to somewhere – discharging into rivers, lakes, wetlands or other surface seeps, other groundwater areas, or as evapotranspiration. The impacts may be felt within short time frames of 1-5 years, or may take hundreds of years or more to manifest. In its natural state, a groundwater system is said to be in equilibrium, wherein on average, discharge is equivalent to recharge. If pumping occurs, the total discharge (natural plus pumped) is increased, and the water (or pressure) level drops. In systems that are connected to rivers, the recharge from the river will increase in response to this level or pressure drop, and in most systems, the natural discharge will decrease. When the increased recharge and decreased natural discharge are equivalent to the pumping, the system is said to have reached a new equilibrium.

According to groundwater theory, this is said to represent a sustainable level of pumping. That is, the level of pumping that can occur without additional long-term water level declines. If the intensity of pumping is too great, water levels will continue to decline. This approach is generally the basis for calculation of extraction limits in GMAs across the basin.

In practice, however, groundwater is not distributed evenly across a GMA, nor is the pumping, and recharge is episodic in nature. In addition, in some locations, pumping of groundwater can draw in saltier water from surrounding aquifers or formations, so pulling down the water levels in these locations can be a problem. Where the groundwater 'stored' in an aquifer is far greater than the average annual extraction limit, this storage can buffer the variability in recharge associated with climate variability. However, in a system where the storage is relatively small, it is unlikely that the 'average annual' extraction limit could be taken each year without significant water level , and possibly water level, issues arising. Therefore, even though pumping from a GMA may look sustainable from an overall allocation perspective, there may be areas for concern on a more local scale.

Finally, groundwater does not exist in isolation from surface water. As discussed, groundwater extractions can increase river 'losses', and decrease the discharge to rivers, lakes, and wetlands. Conversely, the management of surface water flows can impact on the recharge to groundwater sources. These surface water/groundwater interactions are important when considering the overall hydrology of the Darling Basin. What may be considered "sustainable" from a groundwater supply perspective, may not be considered sustainable in terms of the impacts that these levels of extraction are having on surface flows and other dependent ecosystems, and on surface water access rights. Surface water/groundwater interactions have only recently, over the last 10 years, been recognised as an issue for policy and management. Research on, and quantification of, the interactions are in their infancy. Given these factors, surface water/groundwater interactions are being considered in a separate section of this report (see Section 4). The following discussion of current impacts of pumping on groundwater supply should not, therefore, be considered the only impacts on Darling Basin hydrology relating to groundwater.

3.5.1 Groundwater supply

Table 15 and Table 16 show that, with the exception of most of the Condamine GMAs, and some of the Upper Condamine tributary GMAs in Queensland, and possibly the Peel valley alluvium, and the Miscellaneous Alluvium of the Barwon region in NSW, current groundwater use in the Darling Basin GMAs is at or below the calculated extraction limit for most GMAs. These gross numbers, however, do not necessarily reflect local problems that may be occurring from uneven resource distribution across an area, uneven distribution of pumping, uneven recharge over time, and water quality declines resulting from migration of poorer quality water into the aquifers.

Gunnedah and Narrabri alluvial subsystems

The alluvial deposits within the Border Rivers area are relatively thin and narrow, with quite small storages. Long-term maintenance of withdrawals depends heavily on a continuous stream flow and consequential stream losses. On the Queensland side of the Border Rivers system, the shallower Narrabri alluvium responds to the river level changes and remains full most of the time. However it is apparent that recharge from the Narrabri to the deeper Gunnedah aquifer is limited. Recharge is not sufficient at a local scale to stop downward trends in areas of more intensive pumping from this aquifer.

In NSW, there is insufficient information available to make firm conclusions about the status of these aquifers. It is clear, however, that pumping impacts have been substantial and that there is at least a possibility that groundwater abstraction rates are beyond the long-term capacity of the aquifer in some areas.

The use of water from the Narrabri formation in the Condamine Groundwater Management Areas exceeds the sustainable yield and has done so for many years. Although the system has a large storage to recharge ratio, over time the storage will be depleted. The 30% reduction in water allocations means current use is unlikely to increase very much. However, it is likely that under current use, as the storage is drawn down further, poor quality water from the alluvial fringes could be drawn into the area of main use.

The groundwater levels from representative bores in many of the Upper Condamine tributaries are showing the effects of groundwater use and many have a falling trend. While sustainable yield figures for these areas are not very precise, the falling water levels in management areas where use exceeds the sustainable yield indicate unsustainable resource use from a long-term supply perspective. The falling water levels have also been exacerbated by less than average rainfall, and therefore recharge.

Analysis of water level changes in the Gwydir between 1990 and 2000 indicated a general decline in levels around Moree where pumping is concentrated, suggesting a depletion of the resource. However, it appears that, in general, this aquifer is in equilibrium, and that outside the concentrated groundwater pumping area the water level is essentially steady. Within the pumping area there is indications that stable conditions are being reached, with a new equilibrium established.

Water level changes between 1990 and 2000 in the Namoi suggest that there has been a general decline in the resource over that time, although the degree of change is variable and in some areas, pressures have actually increased. Large areas of the Gunnedah subsystem have been subject to high rate groundwater pumping, and there are indications that, in some cases at least, the withdrawal rate has exceeded the recharge capacity of the system. In some of the more intensively pumped areas, this situation is continuing, especially in the Upper Namoi, where there is also some evidence of water quality declines associated with pumping. In some areas of the Lower Namoi, there appears to have been a flattening of the downward trend of the mid 1990s and the aquifer system now appears to be in a new equilibrium condition. This may in part be a result of the reduction in very high level pumping undertaken in the mid 1990s.

In the Macquarie, Bogan, and Castlereagh systems, there has historically been a very low level of groundwater extraction, with surface water taken preferentially where this is available. Water levels have in the past exhibited a rising trend associated with land clearing and increased recharge. Over the past five to ten years, however, groundwater extractions have been increasing, and water level trends are reversing in some areas. Flanked by poor quality water, water quality appears to be a limit on resource use in these areas.

The Narrabri formation is also associated with other, more westerly rivers in NSW, including the Darling itself. In these areas, the water quality is generally poor, except in very narrow band close to rivers. Resource potential is low, and potential to induce lateral movement of poor quality water is high. Current extraction remains very low.

Very little is known about groundwater in the Warrego-Paroo and Western areas due to the scarcity of bores. The groundwater of the Narrabri subsystem in this area tends to be generally too saline to constitute a significant resource.

The groundwater in the Narrabri subsystem over much of the Maranoa-Balonne area is saline with the exception of the St George area where it is utilised for irrigation of crops including cotton. The St George Alluvium Management Area applies to this resource.

A geological structure known as the Dirranbandi Trough has been identified to the south-west of St George, however its extent has not been defined. It is known that a similar south-west trending feature is located near Wilcannia and this may be a continuation of this structure. Further work is needed to better define and understand this geological feature, but it may provide an additional source of water for irrigation.

Great Artesian Basin

Early development led to large bores supplying many properties, with water distributed via channels or bore drains. The bores were allowed to flow uncontrolled into pools that fed these bore drains. This has lead to a loss of pressure head of over 60m in some areas over the last 100 years. Although there is still a large volume of water available, some bores that previously flowed freely now need to be pumped. There has also been an impact on the natural ecosystems around many mound springs that have ceased to flow, or flow at a lesser rate.

Loss of GAB pressure is being addressed through a program of capping the headworks of free flowing bores and piping water to watering points. So far, about 1300 bores have been brought under control, with less than 400 uncontrolled bores remaining. While significant savings have been made, flows from the remaining uncontrolled bores still amount to more than 50,000ML per year. The hydrographs for many of the observation bores in the GAB indicate there has been some pressure recovery in the system over the past 10 years, which appears to be attributable to the impacts of the capping and piping program.

Highland subsystems

Generally, the Highlands are dominated by the fractured rocks of the Lachlan and New England fold belts, where, due to poorer water quality, current extraction levels are very low. There are a number of small GMAs in the NSW Highlands where groundwater supply is an issue. Most are in areas of upland alluvium in the Central West Region, such as the Bell and Cudgegong rivers, and in small basalt flows in the Barwon and Central West. Usage and allocation in these areas appear to be well within the assigned extraction limits. The exception to this is the Miscellaneous Alluvium of the Barwon region, which is both over-allocated and over-used. The consequence of over-extraction of upland alluvial groundwater is that water that is more saline will be drawn in laterally and from below resulting in degradation of the resource.

There is little groundwater information available for the Barrier Highlands area, and there are no monitoring records that would provide a time series of groundwater levels. Groundwater resources are extremely limited, with all use being associated with stock and domestic supply. Groundwater salinity is the main control on resource use.

Queensland basalts

Water levels in the basalts generally respond relatively quickly to rainfall and local river recharge. Groundwater use and natural depletion cause levels to fall in dry times, but groundwater levels appear to recover with subsequent recharge. The rate at which the levels fall is obviously increased by pumping. Water quality in the basalts is generally good, and on the limited data, there does not appear to be any deterioration of quality.

3.6 Future Risks

3.6.1 Growth in Groundwater use

Very simplistically, future risks to groundwater supply are a function of the following:

- Whether or not current entitlements are within the determined extraction limits. Presuming the estimated overall extraction limits are not grossly exaggerated, maintaining extractions within these will ensure long term supply of groundwater from an overall system perspective;
- Whether or not adequate arrangements are in place to reduce or maintain either entitlements or use to within these extraction limits;
- Whether or not adequate arrangements are in place to manage unacceptable local water level impacts associated with uneven distribution of resource occurrence and/or pumping, and;
- Whether or not adequate arrangements are in place to manage unacceptable local water quality impacts associated with inducing poor quality water into fresh aquifers by pumping.

NSW appears to be taking significant steps to manage the over-allocation and over-use of groundwater resources in it portion of the Darling Basin. Plans are, or will soon be, in place to reduce or limit both entitlements and extraction to within defined limits in all parts of the basin. There is also a framework within these statutory plans to manage any more local impacts of pumping on water levels and water quality. On paper, therefore, future risks to groundwater supply associated with over extraction are being managed. However, there remain the following concerns with respect to NSW groundwater supply management:

- There is limited water level monitoring in many areas outside major aquifers. While overall the systems may remain sustainable from a supply perspective, the managers' ability to detect, and subsequently manage, local water level declines in these areas is questionable.
- There is little or no water quality monitoring in any of the system to determine whether there are quality declines associated with pumping. This is of particular concern in high pumping areas such as the Upper Namoi, and increasingly in the Macquarie system. The risk of water quality declines and the resultant impacts on uses requiring high quality water is real, albeit unquantifiable.
- NSW groundwater managers have little experience in local impact management. Approaches to defining 'unacceptable' impacts, and determining the restrictions on pumping that should be imposed to mitigate these are still being developed. This will take some time, and resources should be applied to accelerate this effort.

The concerns expressed above in relation to NSW apply equally to groundwater supply management in Queensland. The administrative hold on further entitlements in all Queensland GMAs is an important tool to allow managers some breathing space to better define sustainable extraction limits before further entitlements are issued. In many systems, this will keep entitlements below current sustainable yield estimates. There are 13 GMAs (excluding the GAB GMAs) that are currently over-allocated by 64GL in total. Of these, in 11, use currently exceeds the extraction limit by a total of 38GL. The current impacts discussed in section 3.5 are, in part, a function of this 38GL over-use. In theory then, use can increase by a further 26GL above the extraction limits. However, the 30% announced allocation reduction negotiated with licence holders in the CGMA 3 (Q59) would limit this potential additional growth above sustainable yield to about 11GL. Under current management arrangements, therefore, in total use could grow from 38GL above the estimated sustainable limits to 49GL above. Under this scenario, water levels are likely to continue to decline in already stressed systems in the Condamine.

3.6.2 Recharge Change

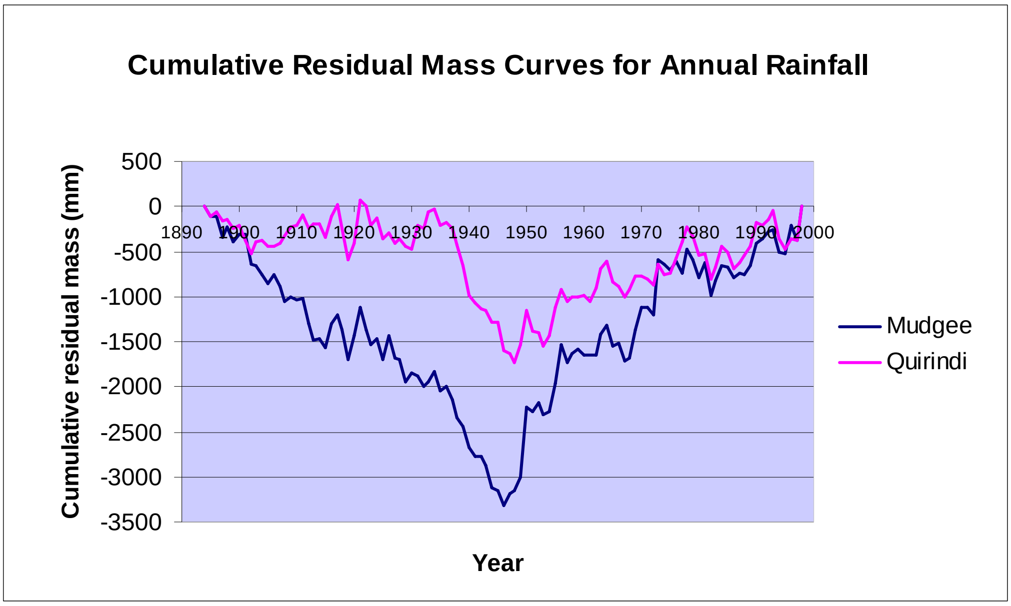
There appears to be little commentary on the potential impacts of long-term climate variability and climate change on groundwater resources in the Basin. It is possible that groundwater recharge could be affected in the following ways:

- Rainfall could decrease, either as a result of climate change, or long-term climate variability. Recharge would decrease, and this would be an issue in all systems, but particularly those where recharge is rainfall dominated - the basalts, and highland areas, including the upland alluvial systems. The annual residual rainfall mass curve for Mudgee and Quirindi are show below in Figure 12. These show the first half of last century being drier than the second. Average rainfall from 1895 to 1946 in Mudgee was, on average, 64mm (or 10%) less than the average over the entire period 1895 to 1998. In contrast the period from 1947 to 1998 was, on average, 10% wetter than the average. Cumulatively, rainfall in the first 51-year period was 3m less rainfall in more recent 51-year period.
- The frequency of flood events could decrease. This would particularly affect the major alluvial systems where flood events contribute significantly to estimated recharge values and therefore extraction limits.
- There is some suggestion that, although the dry times may be drier, and the frequency of small flood events may diminish, flooding may be more intensive. These more intensive flood events may in fact increase the recharge to groundwater.
- Flood control works on floodplain overlying major aquifers may increase or decrease flood recharge to groundwater. What happens will vary from system to system, and depending on the nature and pattern of flood works. A 1991 study by Ross *et al*. found, contrary to expectation, that flood control works in the Lower Namoi valley enhanced recharge to the shallow aquifer.
- Irrigation practices may become more efficient. In some of the modelled groundwater systems such as the Namoi, irrigation losses are factored into recharge calculations. A decrease in these losses may occur over time. This is not as significant an issue in the Darling as it is in the Murray system where large irrigation accessions represent a significant proportion of groundwater recharge.

- Off-river surface water impoundments may increase recharge. At this stage, losses from such storages are not included in groundwater recharge figures.

It is impossible to quantify the risks to groundwater recharge outlined above. It is likely, however, that reduced recharge from lower rainfall accompanied by higher evaporative losses associated with climate change scenarios, or even a movement to the drier conditions experience in the first half of the 20th century will more than offset any recharge increases arising from other factors.

Figure 12 – Cumulative Residual Mass Curves for Mudgee & Quirindi



4 CONNECTION BETWEEN SURFACE WATER AND GROUNDWATER

4.1 Introduction

Surface water/groundwater connections have been briefly referred to in sections 2.7.3 and 3.5. The understanding of these connections is still evolving, and a conceptual framework for their consideration and consequent management is yet to be agreed. Previous definitions and classifications have focussed on the "connectivity" of river reaches. REM (2006) has suggested a more logical approach to take would be to base any classification, and therefore management, on connectivity by aquifer systems, rather than by the immediately adjacent river reach. This recommendation is supported.

4.2 Processes

This discussion starts from the simple premise that all groundwater is coming "from somewhere" and is going "to somewhere". It then looks at where it is coming from and going to, and makes some qualitative assessment of the impact of groundwater pumping on these processes.

There are 4 ways in which water can enter (recharge) and aquifer: by infiltration of rainfall; by seepage of water through the beds and banks of rivers; by inflow from other aquifers, and; by seepage of floodwaters or other water on the floodplain, such as natural or man-made lakes, and irrigation water. The extent to which each of these components contribute to groundwater recharge varies from system to system. The impact of pumping on each of these is discussed below.

- Groundwater extraction is unlikely to have much of an impact on rainfall infiltration. The exception to this may be if unconfined aquifers would, under natural conditions, have been "full", and subsequent rainfall was "rejected", flowing instead back to rivers or other surface water expressions. If the water levels in these aquifers are drawn down by water extractions, at least some of this rainfall that under natural conditions would have been rejected may be "accepted" by the aquifer, thus reducing the flows to surface waters.
- Extraction of groundwater will increase river losses if the aquifer is in direct connection with the river, and the water is flowing from the river to the aquifer (a losing stream). "A connected stream is one where there is a zone of continuous saturation between the river and the aquifer. Where the stream and aquifer are separated by an unsaturated zone, the connectivity is termed disconnected", (REM, 2006).

  The extent to which river losses may increase will depend on the level of pumping, and its distance from the river, and therefore the increase in hydraulic gradient from the river to the aquifer. It will also depend on the characteristics of the bed and banks of the river, and of the aquifer, which limit inflows to varying extents. The time taken for the impacts to manifest may range from fairly immediate to a hundred years or more. Where the aquifer and the river are disconnected, water may still flow from the river to the aquifer, but increased groundwater pumping will not increase the rate at which this occurs.
- Groundwater extraction may increase the recharge from adjacent aquifers by increasing (or reversing) the hydraulic gradient.

- The impact of extraction of groundwater on infiltration of floodplain waters will be similar to that on rainfall recharge. Extractions will have no impact except where underlying aquifers are unconfined and would, under natural conditions, reject further inflows. The rate at which infiltration occurs will also be constrained by soil and aquifer characteristics.

Under natural conditions, there are 3 ways in which water can flow from an aquifer: by discharge to surface water expressions, including rivers, lakes, springs, wetlands or other depressions; as evapotranspiration, particularly through deep rooted trees, and; as seepage to other aquifers. Again, the discharge processes vary from aquifer to aquifer. The impact of pumping on each of these is discussed below.

- Extraction of groundwater will decrease discharge to rivers or other surface water environments such as springs, lakes, and wetlands where this is occurring under natural conditions. That is, where the surface system and aquifer are connected and the pressure in the aquifer is higher than the river (a gaining stream). The extent to which discharge to a river will decrease will depend on the level of pumping, its distance from the river, and therefore the decrease in hydraulic gradient from the aquifer to the river. The time taken for the impacts to manifest may range from days to hundreds or even thousands of years.
- Generally, both short term drawdowns during irrigation periods, and more long-term water level declines caused by groundwater extraction will reduce groundwater discharge via evapotranspiration. As water levels are lowered, plants are less able to access the groundwater. Pumping may be from a deeper aquifer, and the extent to which this pumping will impact on the water table aquifer, and therefore evapotranspiration will vary from system to system.
- Groundwater extraction in an "up-gradient" aquifer is likely to impact reduce flows to any "down-gradient" aquifer, as the hydraulic gradient is reduced. The extent of this impact and the time it takes to occur will depend on the scale of pumping, and its distance from the downstream aquifer.

4.3 New South Wales and Queensland assessments

The processes discussed above are very complex, and vary from aquifer to aquifer, from location to location within an aquifer, and even from time to time at a given location. For example, parts of the Darling River are "losing" to connected alluvial aquifers during periods of high flow, and "gaining" during low flow times. Quantifying these connections is, therefore, extremely difficult. Nonetheless, as part of an MDBC study undertaken by consultants REM, jurisdictions have been asked to:

- Make a professional judgement as to whether the aquifers in each GMA are "connected" or "disconnected" from the rivers in that GMA
- Estimate the "degree of connectivity"
- Estimate the impact of groundwater extraction on stream flow above natural, both in terms of increased recharge and decreased discharge, and
- Estimate the time lag between change in groundwater extraction and the full impact on the stream flow.

Data provided by NSW indicates a high level of connectivity (>80%) between the up-valley alluvial systems and rivers such as the Cudgegong and Peel, with less connectivity in the broader alluvial valleys such as the Namoi, Gwydir, and Lower Macquarie (around 20%). The basalts and fractured rock systems were all estimated to have a degree of connectivity of around 30%. In total in the NSW Darling Basin, the impact of current levels of groundwater extraction on surface water flows over and above natural was estimated at about 75 Gigalitres per annum. This figure increased to about 190 Gigalitres per annum for projected groundwater use in 2055. Map 9 shows the difference between current groundwater extraction, and 2050/55 projections, together with the 'degree of connectivity' reported by the States. This gives a broad indication of the risk posed to the rivers from increased groundwater extraction.

Three points can be made regarding the above numbers:

- It is likely that the full impact of current level of use has not yet been felt in the rivers. While lag times in the highly connected systems are 1-10 years, in the more heavily pumped systems of the Namoi, Gwydir, and Macquarie, lag times of 10-50 years have been estimated.

- Estimated impacts are those 'within' the GMA. The impacts of groundwater extraction (as either increased river losses or decreased discharge to rivers) outside of the GMA appear not to have been considered.

- The extent to which reductions in discharge to rivers, wetland or springs was included in the estimates is unclear.

Data provided by Queensland indicates that, with the exception of the Border Rivers, Queensland GMAs have very little or no connection to the surface water within the GMAs. This assessment seems at odds with previous studies undertaken on behalf of the MDBC (Ife and Skelt, 2004), suggesting that the Queensland basalts both recharge from, and discharge to the local streams. Likewise, the report indicated that the Condamine GMAs and Upper Condamine tributaries are recharged from the rivers. Queensland DNR&M (pers comm.) has suggested that these aquifers are now essentially "disconnected". They acknowledge that, while this may not have been the case under natural conditions, this is currently the situation, and therefore argue that further pumping will not result in additional losses from the rivers. Analysis of streamflow records indicate that most of these rivers have some flow in them at least 50% of the time. This suggests that that there is indeed a groundwater baseflow contribution. This is support by SKM (2002), who estimated that groundwater contributed in the order of 10% of annual flow in these rivers.

It is clear that different approaches to the issue of connectivity and impacts on stream flows are being taken by different jurisdictions. The previous recommendation to the MDBC (REM 2006) that an agreed definition of connectivity should be developed and applied to all GMAs is supported. Further the recommendation that the definition should "deal with issues such as timeframes for impacts, and recognise that impacts to streamflow can occur through induced recharge and captured discharge" should be pursued.

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