Cooperative Research Centre for Freshwater Ecology
Technical Report February 2000

Review of the Operation of the Cap

Ecological Sustainability of Rivers of the Murray-Darling Basin

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The Cooperative Research Centre for Freshwater Ecology aims to improve the health of Australia's rivers, lakes and wetlands.

The Cooperative Research Centre for Freshwater Ecology is a collaborative venture between:

- ACTEW Corporation
- CSIRO Land and Water
- Department of Land and Water Conservation, NSW
- Department of Natural Resources, Queensland
- Department of Natural Resources and Environment, Victoria
- Environment ACT
- Environment Protection Authority, NSW
- Environment Protection Authority, Victoria
- Goulburn-Murray Rural Water Authority
- Griffith University
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- Lower Murray Water
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- Murray-Darling Basin Commission
- Murray-Darling Freshwater Research Centre
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Executive Summary

The Ministerial Council introduced the Cap on diversions from the Murray Darling Basin river system in June 1995, which in 1997 was confirmed as a permanent Cap. Two primary objectives for implementing the Cap were:

- the need to maintain and, where appropriate, improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance the riverine environment; and,
- to achieve sustainable consumptive use by developing and managing Basin water resources to meet ecological, commercial and social needs.

With the introduction of the Cap, the Ministerial Council undertook to review its operation in the year 2000. The Ecological Sustainability of the Rivers component of the Review was undertaken by the Cooperative Research Centre for Freshwater Ecology, with input from submissions received from partner governments, the Community Advisory Committee and directly from stakeholders.

The main conclusions of the Review are as follows:

- Sustainability in the Murray-Darling Basin should be defined as *the indefinite preservation* of:
  - a functional and diverse ecosystem which, as well as meeting aesthetic and ethical requirements, provides a natural resource suitable for (all) human uses and production; and
  - a socio-economic system capable of using the natural resource productively to the maximum good of the current and future communities.

- The development of the Basin's water resources, and in particular the reduced flows associated with these developments, has had a major impact on the riverine ecosystem. Impacts related to reduced flows include;
  - reduced areas of wetlands;
  - degradation of floodplain forests;
  - less diverse and reduced populations of native plants and animals;
  - exacerbation of problems of salinity, pest species, eutrophication and blue-green algal blooms; and
  - alteration of the shape of the Basin's rivers.

- Because of water resource development, the Basin ecosystem is moving to a new and different state. This transition will require many decades to complete – with the full impacts of the current level of abstraction yet to be realised.

- The Cap is set at a level of diversions that contributed to the current degradation of the riverine environment, and while the Cap is an essential step in slowing on-going decline, there should be no expectation that the Cap, at its current level, will improve the riverine environment.

- However, without the Cap it is most probable that the health of the Basin's river system would be significantly poorer, as extractions approached the Full Development Scenario level.

- Determining an appropriate level for the Cap requires science to identify ecological impacts of the current level of diversions and describe the long-term consequences of these impacts on sustainability. It is the role of the community, using this understanding, to strike the balance between the economic benefits and ecological costs of diversions. The level of the Cap needs to reflect this balance. However, the ecosystem itself will decide if the level of diversions is sustainable.

- For the main part, the environmental benefits of the Cap, and hence its contribution to sustainability of the system, will depend on the skill with which the environment's allocation is managed. Provision of effective environmental flows are constrained by a lack of ecological knowledge, limitations of infrastructure, state boundaries, the wish to protect floodplain developments and timing and volume constraints imposed by the need to deliver water for consumptive use.

- Indications of continued decline in river health suggest that current land and water management practise will require that the Cap allow significantly less extraction if the Cap alone is expected to achieve environmental sustainability.

- Increasing the level of diversions in upstream rivers will further exacerbate environmental degradation downstream. These effects must be recognised when determining the level of the Cap in upstream jurisdictions.

- The Cap has contributed (or will when fully implemented) to the sustainability of the river system by:
  - Restricting further diversions in all rivers, regardless of their current level of water resource development, thus protecting all riverine environments to the benefit of the whole Basin;
  - Protecting important high flow events – through limitations on access to off-allocation that have been introduced to ensure Cap compliance;
  - Providing an incentive for more accountable water resource management, including conversion to volumetric allocations; and
  - In conjunction with other water reforms, provided a framework for water trading to develop.

- The Cap's contribution to ecological sustainability would be enhanced by:
  - Reducing transmission losses across the Basin;
  - Returning all government funded water savings to the environment;
  - More efficient management of the environments allocation;
  - Basin-wide adoption of diversions models for evaluating compliance;
  - Rapid development of Computer Simulation Models to replace Demand Models for determining the Cap;
  - Defining the Cap so as to protect the proportion allocated to the environment from the effects of reduced catchment water yield;
  - Adopting the principle that all water in excess of the Cap is considered the environment's entitlement; and,
  - Integrating management of groundwater and surface water.

- There is a need for an annual Ecological Audit of the Basin's river system. An Ecological Audit would assess the Basin-wide coordination, effectiveness and ecological outcomes of environmental flow management undertaken by the State's and the ACT. The Ecological Audit would also comment on the health of the Basin's river system by reporting the condition of a number of performance sites across the Basin.

In terms of the specific questions raised in the project brief, the responses are:

1. ***Collate and assess relevant scientific and policy reports and submissions of the partner Governments and the CAC addressing the ecological sustainability of the river system of the Basin.***

   A considerable body of scientific and management literature indicates that the health of the Murray-Darling Basin's river system has declined as a result of water abstraction, and that this decline is likely to continue as the full effects of past management practise occur. Scientific evidence indicates that further extractions from the river system are not ecologically sustainable, and that the existing level of extraction may not be sustainable. Much of this information is synthesised in the book, "Rivers as Ecological Systems - the Murray-Darling Basin". Relevant reports include the Stressed Rivers Assessments, Water Allocation Management Planning Reports, Scientific Panel Reports for the Murray, Barwon-Darling and the River Murray Barrages, and the NSW Wales Rivers Survey.

Submissions to the Review were received from the partner governments to the Murray-Darling Basin Initiative, The Community Advisory Committee of the Murray-Darling Basin Ministerial Council (CAC), industry groups and directly from other stakeholders throughout the Basin. A number of issues relating to the ecological sustainability of the Basin's rivers emerged from the submissions including:

- no consistent definition of ecological sustainability;
- widespread support for a Cap to protect the ecological health of the river system;
- disagreement over existing levels of environmental degradation and its causes;
- difficulties in striking the balance between environmental impact and economic benefit;
- insufficient scientific input into setting and evaluating the Cap;
- no agreement on a sustainable level for the Cap;
- greater accountability for management of environmental allocations;
- the Cap alone will not ensure sustainability – other water management policies will be required;
- the Cap needs to be supported by an integrated approach to catchment management;
- confusion between impacts of the Cap and other water reforms; and
- confusion about what the Cap is intended to achieve.

2. *Address the impact of the operation of the Cap in achieving its objectives to ensure ecological sustainability of the Murray-Darling Basin river system by examining the following questions:*

2.1. How Should Sustainability be defined for the purposes of the Cap?

The Cap aims to make increases in production sustainable by fostering *development*, through more efficient use of diversions, without allowing *growth* in diversions.

Production will only be sustained if both the ecosystem and the socio-economic system are sustained in the long-term. Recognising that sustaining the ecosystem that maintains the resource is the key component to the future of the Murray-Darling Basin, sustainability should be defined as the indefinite preservation of:

- a functional and diverse ecosystem which, as well as meeting aesthetic and ethical requirements, provides a natural resource suitable for (all) human uses and production; and
- a socio-economic system capable of using the natural resource productively to the maximum good of the current and future communities.

In terms of its operation, the Cap must seek to apportion water between the riverine ecosystem and consumptive human uses such as to:

- reserve sufficient water to maintain the ecosystem in line with ESD principles; and
- preserve a supply of water suitable for human use.

Leaving aside the socio-economic component, sustainability should address three fundamental ecological values: biodiversity, ecosystem function and ecosystem integrity. The appropriate spatial scale for assessing the Cap's contribution to sutainability is basin-wide and over a temporal scale of decades.

The long-term decline in the Basin's natural capital (soil and water resources) indicates that we are failing the test of intergenerational equity, a fundamental tenet of sustainability.

2.2. What does science tell us about the suitability of the level at which the Cap is set?

Determining an appropriate level for the Cap is a three-stage process – science addresses the first two stages:

- The effects of the current level of diversions on the ecology of the river system have to be determined,
- The long-term consequences of these ecological effects have to be clearly understood, and
- With this understanding, the community has to make an assessment of the benefits and costs of diversions to determine an appropriate level for the Cap.

Current levels of water abstraction are having a significant impact on the ecological sustainability of the Basin's river system. Throughout the Basin, Scientific Panel Assessments, Stressed Rivers Assessments and state water management planning reports have documented environmental impacts associated with reduced flows. These impacts include reduced areas of wetlands, less diverse plant and animal populations, and reduced populations of native fish, birds, macroinvertebrates and aquatic and floodplain plants. Reduced flows will continue to exacerbate problems of salinity, pest species, eutrophication and blue-green algal blooms. Reduced flows are altering the shape of the major rivers. In summary, reduced flows are a major cause of reduced river health in the Murray-Darling Basin. However, the full impacts of the current level of abstraction and other changes to the Basin's land and water resources are yet to be realised. The various ecological and geomorphic responses to the altered conditions that have been imposed will require many decades to complete.

Assessing the suitability at which the Cap is set is complicated by the long-term natural variability in stream-flow of the Basin's river system and the long time-period over which changes occur. Also, there are few pre-Cap data against which to assess the environmental impact of the Cap. The focus should be on determining whether the current (capped) levels of diversions will conserve ecosystem function, integrity and biodiversity. This will require the continued development of ecological tools and techniques for assessing whether this has been achieved.

It is clear from submissions to the Review that there is community disquiet over the state of the Basin's rivers. There is a strong desire to see an improvement in river health. It is also clear that further abstractions, anywhere in the basin, will decrease the health of the river ecosystem.

2.3. What aspects of the operation of the Cap constrain or support the sustainability of the river system?

The Cap contributes to the sustainability of the Murray-Darling Basin river system by protecting end-of-system flows through limiting the growth in diversions, regardless of a river's current level of diversions. This protects the few remaining relatively undeveloped rivers from exploitation. The Cap has protected ecologically important medium and high flow events through limitations on access to off-allocation that have been introduced to ensure Cap compliance. In conjunction with other water reforms, the Cap has provided incentive for conversion to volumetric allocations and provided a framework for water trading to develop.

Reducing transmission losses on water diverted to agriculture would enhance the Cap's contribution to sustainability of the Murray-Darling Basin river system. Information supplied by the Commission indicates that basin-wide at least 25% of diverted water is lost in transmission. Evidence from rehabilitation of South Australian irrigation schemes indicates much of this water can be reclaimed. At the Basin-scale river health will be improved by increasing the environment's share of water. Water saved from government-funded programs to reduce transmission losses should be removed from the Cap and be allocated to the environment. Water currently outside of the Cap (in-stream and environment's share) should not be traded into consumptive use.

The volume of water needed to achieve sustainability will depend upon the provision of effective environmental flows. The delivery of these is constrained by a lack of ecological knowledge, limitations of infrastructure, the wish to protect floodplain developments, state boundaries and timing and volume constraints imposed by the need to satisfy consumptive users.

Diversion models provide a more robust method of supporting the Cap than end-of-valley flow regimes, which have clear technical problems with accurate measurement. Climate adjustment of diversions in the southern parts of the Basin ensures that a greater proportion of total stream-flow is diverted in dry years. Over time, the Cap should be defined so that it both limits diversions and guarantees a minimum proportion of stream-flow for the environment.

3. ***At a Basin scale, assess the potential hazards and level of risk to the health of the riverine environment (including algal blooms and salinity), and comment on the role of the Cap in containing these hazards and reducing the level of risk to riverine health.***

Export of salt from dryland sources to the aquatic environment is a major threat to water quality in the Basin and will impact on both water users and the riverine environment. Additional diversions from the Basin's rivers will increase the salinity of the remainder of the river downstream. The availability of dilution flows, the volume of which is protected by the Cap, will be an increasingly important constraint on salinity management in the future.

Warm, slow moving, nutrient rich waters promote the development of blue-green algal blooms. Increasing flow can dissipate existing blooms. Further diversions from the Basin's rivers will increase the likelihood of conditions favouring the development of blooms. Also, increased diversions will reduce the capacity to provide flushing flows for diluting nutrient or dissipating developing blooms. The introduction of the Cap has not led to a reduced frequency and intensity of blue-green algal blooms however, it is likely that without the Cap, the frequency and intensity of blue-green algal blooms would be greater than it currently is.

Predicted long-term changes in climate and land use in the catchment will significantly reduce catchment water yield, and consequently the volume of water in the Basin's rivers. This will have the effect of increasing the long-term proportion of stream-flow diverted from the Basin's rivers. Reductions in water yield from a catchment disproportionately impact on the environment's share.

4. *Using two river valleys as the basis for case studies, assess the impact of the Cap to the sustainability of these valleys.*

4.1. Lower Murray

Regulation has significantly reduced the annual flow to the Lower Murray and the variability of mid-range flows so that the present regime is dominated by low flows with occasional high flows. As regulation has increased there have been declines in the range and abundance of many species of native plants and animals, including fish, crayfish, turtles, frogs, birds and mammals. In their place, species like carp and willows predominate.

Modelling of the effects of *Full Development Scenario* have shown that the Cap has protected against further reductions in short-term variations in flow and the magnitude, duration and frequency of floods. Expansion to *Full Development Scenario* would exacerbate the loss of habitat diversity, reduce the frequency and duration of exchanges between the channel and the floodplain and change the metabolic functioning of the Lower Murray aquatic system.

Due to the variability of the system, and the long lag times between the imposition of a stress and the ecological response, it is not possible to say whether the Cap has halted the decline in the integrity of the Lower Murray. It is possible to say that if the Cap had not been imposed, the move toward a *Full Development Scenario* would have resulted in further dramatic declines in the condition of the river. This decline would have affected areas such as the Coorong and Lake Victoria far more severely than other ecological components.

4.2. Condamine Balonne

Large-scale intensive irrigation and flow regulation began relatively recently in the Condamine Balonne system. Diversions in the late 1990's from the Condamine Balonne system were nearly double the diversions reported in the 1995 Water Audit.
Flow regulation now has a significant impact on the hydrology of the river, which has impacted on the fish and macroinvertebrate fauna.

Further development in the Condamine Balonne catchment is likely to have a dramatic impact on ecological functions and eventually the sustainability of the river system downstream of Bourke. There is a serious risk that a Cap implemented in the Condamine Balonne (based on the WAMP) will fail to recognise the relative importance and potential impact of water resource development in this sub catchment on the ecological sustainability of the entire Basin.

CONTENTS

1 Introduction

The Cooperative Research Centre for Freshwater Ecology was appointed to undertake the Review of the Cap – Ecological Sustainability of Rivers. This review forms part of a wider review of the operation of the Cap and how it can be refined to better meet the needs of the Murray-Darling Basin community, which is being undertaken by the Murray-Darling Basin Ministerial Council.

The Cap on diversions in the Murray-Darling Basin was introduced in response to the Water Audit, which indicated that:

- the river system was showing signs of stress;
- there was no certainty that the current riverine environment is sustainable with the current regime;
- increased growth in diversions would reduce security to existing irrigators; and
- there was no margin of safety for any further changes that will have an adverse impact on water quality (eg, the emerging problems of dryland salinity)

From the Cap's inception, ecological sustainability has been identified as one of the primary objectives of the Cap. In their November 1996 report, “Setting the Cap” the Independent Audit Group (IAG) made the following recommendations in regard to the objectives and definition of the Cap:

> *The IAG recommends that the Ministerial Council confirm its previous statement of aims adopted by the IAG as the primary objectives of the decision to implement the Cap, namely:*
>
> - *to maintain and where appropriate, improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance the riverine environment; and*
> - *to achieve sustainable consumptive use by developing and managing Basin water resources to meet ecological, commercial and social needs.*

This review proposes a definition of sustainability as it refers to water resource development in the Murray-Darling Basin. The Review collates the work done to date on assessing the ecological sustainability of the Basin’s river system both at a large scale and by way of two case studies, the Lower Murray and the Condamine Balonne. In the specific context of the operation of the Cap, the contribution of the Cap to the ecological sustainability of the Basin is assessed. This Review considers the role of the Cap in relation to the emerging hazards of salinity, blue-green algae and changing water yield from the Basin's catchments. Suggestions for refining the Cap to improve its contribution to salinity are made.

Submissions to the Review received from the partner governments to the Murray-Darling Basin Initiative, The Community Advisory Committee of the Murray-Darling Basin Ministerial Council (CAC), industry groups and directly from other stakeholders throughout the Basin were used as reference material for this review.

2 Terms of Reference

The Murray-Darling Basin Commission provided the following terms of reference for the Five Year Review of the Operation of the Cap:

> To review the operation of the Cap (and, importantly, not the Cap itself) and provide suggestions for the more effective future operation of the Cap through obtaining independent assessments (involving the Independent Audit Group and partner Governments to the Initiative as appropriate) in each of the following areas:
>
> ***Ecological Sustainability of Rivers***
>
> *Through addressing the impact of the operation of the Cap in achieving its objectives to ensure ecological sustainability of the Murray-Darling Basin river system.*

Main Tasks:

1. Collate and assess relevant scientific and policy reports and submissions of the partner Governments and the CAC addressing the ecological sustainability of the river system of the Basin.
   Such reports include but are not limited to:
   - "Long Term Water Management in NSW – Moving Towards a Sustainable Future for the Murray-Darling Basin";
   - Ecological Flow Handbook;
   - River Murray Scientific Panel Report;
   - Queensland WAMP reports;
   - NSW environmental objectives documentation.

2. Address the impact of the operation of the Cap in achieving its objectives to ensure ecological sustainability of the Murray-Darling Basin river system by examining the following questions:
   (i) How should sustainability be defined for the purposes of the Cap?
   (ii) what does the science tell us about the suitability of the level at which the Cap is set?
   (iii) what aspects of the operation of the Cap constrain or support the sustainability of the river system?

3. At a Basin scale assess the potential hazards and level of risk to the health of the riverine environment (including algal blooms and salinity) and comment on the role of the Cap in containing these hazards and reducing the level of risk to riverine health.

4. Using two river valleys as the basis for case studies, assess the impact of the Cap to the sustainability of these valleys.

3 Ecological Sustainability of the Basin's River System

Collate and assess relevant scientific and policy reports and submissions of the partner Governments and the CAC addressing the ecological sustainability of the river system of the Basin.

The Murray-Darling Basin Commission describes the Cap on diversions *as "the single most significant water resources initiative in the Basin since the establishment of the Murray-Darling Basin Ministerial Council in 1985*" (Blackmore, 1999). Government and community submissions to the Review support the need for a Cap with many arguing strongly that the Cap is crucial to the long-term health of the Basin's rivers. The evidence for the need for a Cap was initially detailed in the Audit of Water Use in the Murray-Darling Basin (Water Audit, MDBMC 1995). By calculating existing usage and modelling future demand, the Water Audit indicated that any further increase in the extraction of water from the river system in the Basin would erode the security of supply of existing diverters, and cause a continued decline in the health of the river system. A considerable body of scientific evidence from studies in the Murray-Darling Basin and elsewhere supports the view that the health of the Murray-Darling river system has declined as a result of water extraction, and is likely to continue to do so. This Review argues that the Cap has been critical to the maintenance of river health in the Murray-Darling Basin.

3.1 Overview of Scientific support for the Cap.

The Cap was implemented to restrict further growth in diversions with the view to prevent further decline in the environment. It is appropriate then, to ask:

- what is the evidence that the Basin's riverine environment was declining;
- is the Basin's riverine environment continuing to decline; and if so,
- is water extraction to blame?

There is a considerable body of scientific and management literature focussed on the river system of the Basin. This information has been synthesised in several books. By describing how the Basin's rivers function, the book "Rivers as Ecological Systems – the Murray-Darling Basin" aims to improve the information base upon which natural resource management decisions are made. In writing the book, over a 1000 books, papers and reports relevant to understanding riverine ecology in the Murray-Darling Basin were accessed (Young, 2000). Several other recently published books also advance our understanding of how the rivers of the Basin function including, "A free flowing River: the Ecology of the Paroo River" (Kingsford, 1999), "Australian Freshwater Ecology – Processes and Management" (Boulton and Brock, 1999), and "Wetlands in a dry land: Understanding for Management" (Williams ed. 1998). Books and brochures such as "Living on the Floodplains" (Mussared, 1997), "Sustainable Rivers: The Cap and Environmental Flows" (Whittington and Hillman, 1999) and "Murray Darling Basin Resources" (Crabb, 1997) synthesise relevant science and management knowledge for the broader community.

Water Quality is arguably the greatest indicator of a river health to the Basin community. Salinity trends in the River Murray at Morgan have been increasing for more than 80 years – the increase in salinity experienced since the late 1970's mainly due to saline drainage water return associated with the growth in irrigation diversions during this period (MDBC 1999b). While the Salinity and Drainage Strategy implemented in 1988 has successfully halted the increase in salinity, this halt is only temporary (MDBC 1999b). It is anticipated that salinity at Morgan will continue to rise for the next 100 years (MDBC 1999b, MDBMC, 1999) as dryland catchments continue to leak salt to the rivers (Walker et al, 1999).

Eutrophication, the process of nutrient enrichment of water bodies by nitrogen and phosphorus, is a major water quality problem facing the Murray-Darling Basin. The concentrations of nitrogen and phosphorus influence the growth of algae and along with flow, turbidity and climate, influence the type of algae present (eg. Oliver and Ganf 1999). It is generally considered that eutrophication of the Basin's rivers is increasing as loads of nitrogen and phosphorus increase. However, in most cases long term data have not been collected to demonstrate this (SoE, 1996). In recent years there has been an increase in the reporting of blue-green algal blooms (BGA Task Force, 1992). In the Basin's rivers, blue-green algal blooms generally develop during periods of low flows (Hotzel et al 1994, Webster et al. 1997, Oliver et al 1998). Extractions of water from the rivers have increased periods of low to no flow. While an increased awareness of the issues associated with blue-green algal problems will have contributed to their increased reporting, it is also likely that increased nutrient loads and altered flow regimes are increasing the frequency and intensity of blue-green algal blooms (SoE, 1996, BGA Task Force, 1992).

There are many other indicators that the Basin's health is in decline. The New South Wales Rivers Survey (Harris and Gehrke 1997) clearly shows that rivers in the Murray region are seriously degraded. Carp dominate the Murray regions fish population – there are few native fish. The Darling Region is less regulated (Gehrke et al 1995) than the Murray region and this was reflected in the NSW Rivers Survey finding about ten times more native fish in the Darling region compared to the Murray region. However, the fish population of the Darling Region is also impacted by water resource development. For example, the fish population in the Culgoa River at Weilmoringle, NSW was assessed as poor in the Condamine-Balonne WAMP Environmental Flows Technical Report (QDNR 1999). This was associated with water extraction. Across the Basin, Gehrke et al (1995) found a significant trend of reduced native fish species diversity in increasingly regulated catchments.

In the Murray river system as a whole, arguably 15 - 16 species of native fish are threatened and five are vulnerable and in the lower Murray regional extinctions are well advanced for five species (Walker and Thoms 1993). Historical catches of callop and Murray cod from the River Murray in South Australia declined by an order of magnitude since the expansion in water resource development after 1950. The Murray now has the lowest commercial fish yield per square kilometre of floodplain of any of the world's major rivers, although historical catches were comparable (Walker and Thoms, 1993).

The distributions and numbers of other biota have also reduced, including crayfish, freshwater mussels and snails (Walker and Thoms 1993, Sheldon and Walker 1997). There have also been changes in the composition of biofilms, which are an important food resource for riverine biota (Burns and Walker 2000). Changes in the flow regime of rivers and wetlands have impacted more on some water birds than others. Waterfowl species such as ibis, egrets and waders have probably decreased in abundance, as they rely on wetting and drying cycles of wetlands for food supply and breeding habitat (Scott 1997), whereas others that rely on a permanent water supply may have increased in abundance (Scott 1997). The abundance and diversity of waterbirds in the Murray-Darling Basin is strongly dependant on the maintenance of suitable wetland habitat, which due to water resource development has declined significantly (MDBMC, 1998). For example, as the Macquarie Marshes have reduced in area by 40 to 50% the numbers of breeding colonial waterbirds (ibis, herons, egrets and spoonbills) in the Marshes have also reduced (Kingsford and Thomas 1995, Kingsford1998). Drying out of much of the Gwydir wetlands has significantly reduced foraging areas for feeding waterbirds (McCosker and Duggin, 1992) and this is likely to have impacted on their populations.

A consequence of water resource development has been the dramatic reduction in the size and frequency of flooding events throughout many of the Basin's rivers (eg. MDBMC 1995, Close 1990, Thoms et al 1996, MDBC 1998b etc). This has contributed to the drying out and eventual disappearance of a significant proportion of the Basin's wetlands (MDBMC 1998, See Table 3.5) and the degradation of much of the remaining wetlands (MDBMC 1998). Floodplain vegetation has also been negatively affected by changes in the flow regime (eg Partners et al 1990). Even relatively recent water resource development has resulted in reduced floodplain vegetation vigour in the lower Balonne (Simms et al 1999). The timing, frequency, duration, extent and depth of inundation all influence where which aquatic, riparian and wetland plants will grow (Brock 1998). Water resource development has dramatically altered these aspects of flow regime in much of the Basin, and consequently altered the distribution of aquatic, riparian and wetland vegetation.

The Basin's river system has degraded and is heading to a new and different state. There is considerable evidence that it has not reached that new state, and is unlikely to do so for decades, if not hundreds of years (Walker et al 1995, Young 2000). The time-scales for some ecological changes in riparian systems (Church 1995, Young 2000) and geomorphology (Walker and Thoms 1993, Walker et al 1995, Young 2000, Church 1995) are likely to be in the order of centuries. The effects seen now are the result of past levels of water extraction and the impacts of current and past catchment management will impose a progressively greater stress on the river system for many decades to come. For example, inputs of salt to the river system (and therefore salinity) will continue to rise Basin-wide for at least the next century (MDBMC 1999). In short, the riverine environment has degraded, and as a result of previous land and water management is likely to continue to degrade for many decades to come.

An assumption made to support the implementation of the Cap is that water extraction is a major contributor to the decline in ecosystem health. It is not possible to completely separate the effects of water extraction from other effects of water resource development, which include altering the timing and variability of flows, however it is clear that extraction is a major contributor to the decline. The Stressed Rivers Assessment undertaken in NSW (DLWC 1998) indicates that 49% of unregulated streams in the Basin in NSW exhibited a high degree of environmental stress. Water extraction was a major contributor to the environmental stress, with 32% of all unregulated streams exhibiting a high level of hydrological stress (DLWC 1998). It is often argued that Queensland's rivers are relatively under-developed, however, as a result of water abstraction, the flow regime below of the Lower Balonne has been assessed as poor (QDNR 1999). It is believed that flow changes resulting from water extractions for irrigation are the cause of the degraded fish and macroinvertebrate fauna in this region (QDNR 1999). Another example is the Barwon-Darling system where river regulation, resulting primarily from water extraction, has led to habitat degradation with reduced habitat availability and food sources for aquatic invertebrates (Thoms et al 1996).

Water extraction has reduced the frequency and magnitude of flood events in many of the Basin's rivers (MDBMC 1995). This has reduced the connectivity of the river with the floodplain. Connectivity is critical for maintaining ecosystem integrity and function (Junk et al 1989, Ward 1995, Ward and Stanford 1995). Altering the wetting and drying cycles of the floodplain changes the cycling of nutrients on the floodplain and between the floodplain and the river (Baldwin 1999, Baldwin and Mitchell 2000). Evidence from the Condamine Balonne indicates this can have major implications for downstream supply of carbon (Thoms and McGinness, in press, See also Condamine Balonne Case Study in this Report).

Reducing the flooding regime impacts on native fish and invertebrate populations. For some species of native fish (eg. Golden Perch, Silver Perch) increases in flow provide a cue to initiate migration, maturation and spawning, and flooding may open up important spawning and rearing habitat (Lake 1967, Harris and Gehrke 1994). For other species, despite the fact that they spawn independent of high flows, flooding indirectly benefits them through input of nutrients or food (Humphries et al 1999). Aquatic invertebrates in dryland ecosystems mediate many ecological processes in the channel and on the inundated floodplain (Boulton 1999). Most native invertebrates have opportunistic, flexible life histories that enable them to cope with the variable flow regime, indeed the spectrum of habitats provided by this variability promotes their survival. Maintenance of biodiversity requires a mosaic of both ephemeral and permanent wetlands (Hillman 1998, Hillman and Quinn 2000). Reducing the flooding regime reduces the available habitat for invertebrates and will lead to a loss of biodiversity (Boulton and Jenkins 1998, Boulton 1999).

This brief overview of scientific and management literature indicates that the Basin's riverine environment has degraded. It is also clear that reduced flows are a major cause of this decline. The Cap, by restricting further growth in diversions, is an important step in reducing further decline in the riverine environment.

3.2 Information directly addressing the Cap.

Most of the current literature directly addressing the Cap concentrates on issues of compliance and implementation – on gigalitres diverted (eg. Review of Cap Implementation reports for 97/98 and 98/99, (MDBMC 1999 & 2000) and the Water Audit Monitoring Reports for 94/95, 96/97 and 98/99 (MDBC 1998, 1999c & 1999d)). As audits of water diverted, the annual reports produced by the Commission and the Independent Audit Group are valuable. However, considering the widespread community interest and the importance of the Cap, there is little information in the public domain that discusses:

- the specifics of how the Cap is determined;
- ecological objectives of the Cap; and
- impacts of the Cap and other Water Reforms on the health of the river system.

A literature search using the Australian database *Streamline* (which attempts to include published material from a broad base including LWRRDC, MDBC and government publications) revealed eleven articles directly addressing the Cap (Appendix 4). Of these, about half mention the condition of the Basin's environment. Similar searches using *Biosis* and *Enviroline* showed nothing of relevance. The Review accepts that this does not constitute an exhaustive literature search and that other printed material directly addressing the Cap exists. These searches are indicative of the paucity of information regarding the role and value of the Cap in promoting ecological sustainability in the public domain.

The annual implementation reports of the Commission and IAG provide an important overview of water use across the Basin and should continue to be published annually. These reports however, are not intended to assess the Cap against any ecological (or social and economic) objectives. The value of the reports to the community would be significantly improved an assessment of the effect of the Cap on the ecological health of the Basin – from a whole-of-Basin perspective (as this review is intended to achieve).

An Ecological Audit administered in conjunction with the Independent Audit Group's Cap Implementation Reviews would achieve this. The Ecological Audit could be undertaken by an ecologist appointed to the Independent Audit Group, or by creating a separate Ecological Audit Group.

The Ecological Audit would comment on the Basin-wide implications, effectiveness and ecological outcomes of environmental flow management undertaken by the State's and the ACT. Environmental flows impact downstream jurisdictions therefore close coordination across State and territory boundaries is required and this should be assessed by the Ecological Audit. The Commission should facilitate interstate coordination.

The Ecological Audit would also comment on the condition of the Basin's river system. This could be achieved by identifying a number of representative river reaches in the Basin to be used as performance sites, much like Morgan has been used for reporting salinity trends within the Basin for many years. The choice of performance reaches could include areas of ecological significance, such as RAMSAR sites etc. Significant ecological events related to the flow regime would be highlighted, for example, successful bird breeding and fish recruitment. The environmental condition of these sites (measured using a variety of indices[1]) could be monitored annually by the States and the ACT and the results of this presented to the Ecological Audit. This will require the appointment of Environmental Resource Managers by the States and the ACT to be responsible for managing, monitoring and reporting on environmental flows and outcomes.

An Ecological Audit be undertaken on annual basis and the results be made available to the Basin community.

To prepare an annual environmental report card provides significant challenges, including:

- the completion of the flow models to calculate the climate-adjusted Cap targets for each river valley,
- the collection (or compilation), analysis and interpretation of environmental data,
- linking environmental data with hydrological data,
- communication of the environmental 'report card' to the Basin community.

While these are difficult challenges, it is clear is from a number of submissions to the Review the community expects this information be made available.

3.3 Overview of Submissions

Submissions addressing issues associated with the Ecological Sustainability of Rivers were received from:

- the partner governments to the Murray-Darling Basin Initiative (Commonwealth, New South Wales, South Australia, Queensland, Victoria and Australian Capital Territory);
- the Community Advisory Committee of the Murray-Darling Basin Ministerial Council (CAC)
- industry groups; and
- directly from other stakeholders throughout the Basin.

A summary of the submissions made by partner governments and the CAC is presented in Appendix 1. A full listing of submissions addressing Ecological Sustainability of Rivers by Basin stakeholders made directly to the Commission can be found in Appendix 2.

Submissions to the Review indicate a high level of community awareness and interest in the Cap and the effectiveness of its contribution to Basin sustainability. Several key points related to the ecological sustainability of rivers emerged from the submissions to the Review. These are:

[1] Tools for assessing 'river health' are improving with indices such as AUSRIVAS, the Index of Biological Integrity (IBI), and the Index of Stream Condition (ISC) currently available. Also, a method for detecting environmental effects of flow change (Integrated Monitoring of Environmental Flows, IMEF) is currently being developed by New South Wales Government Agencies which appears promising.

- no consistent definition of ecological sustainability;
- widespread support for protecting the ecological health of the river system with a Cap;
- disagreement over existing levels of environmental degradation and its causes;
- difficulties in striking the balance between environmental impact and economic benefit;
- insufficient scientific input into setting and evaluating the Cap;
- no agreement on a sustainable level for the Cap;
- greater accountability for management of environmental allocations;
- the Cap alone will not ensure sustainability – other water management policies will be required;
- the Cap needs to be supported by an integrated approach to management the catchment; and
- confusion between impacts of the Cap and other water reforms.

On these key points a range of views was expressed to the Review, which are discussed below. Issues in this section form the basis for discussions in following sections of the Review.

3.3.1 No consistent definition of ecological sustainability.

Sustainability is a term that means different things to different people. This is reflected in the submissions presented. While most submissions argue that the definition of sustainability has to balance both environmental and economic sustainability, there is no consensus as to where that balance lies. For example, the Twynam Group argues "*Financial viability of all stakeholders is an essential ingredient for the long-term ecological sustainability of rivers in the MDB*." The Murrumbidgee River Management Committee adopts a different view: "*Ecological sustainability is taken to mean the long-term maintenance of the ecological processes on which life depends*."

A number of non-government submissions indicate that to ensure intergenerational equity, sustainability to has to be defined over a time scale of generations not a few decades. This is supported by the submissions of the New South Wales Government and the Commonwealth, which indicated sustainability has to comply with the Principles of Ecologically Sustainable Development as set out in their respective Acts and Policies. These include:

- the Precautionary Principle,
- inter-generational Equity,
- conservation of biodiversity and ecological processes; and
- the improved valuation and pricing of environmental resources.

It is clear that a widely accepted definition of sustainability is fundamental to a better understanding of the outcomes expected from changed water management associated with the Cap.

The Review proposes a definition of sustainable as it refers to the establishment, operation, and performance review of the Cap as the indefinite preservation of:

- a functional and diverse ecosystem which, as well as meeting aesthetic and ethical requirements, provides a natural resource suitable for (all) human uses and production; and,
- a socio-economic system capable of using the natural resource productively to the maximum good of the current and future communities.

3.3.2 Widespread support for a Cap on diversions

Submissions from non-government stakeholders generally recognise that water abstraction in the Basin has negative impacts on the riverine environment, with most submissions supporting the need to have some controls on the levels of abstraction from the Basin's river system. For example, the Southern Riverina Irrigation Districts Council *"accepts the suggestion that continued river extractions would result in a decreased ecological health of our river system"*.

State Government and Commonwealth submissions provide unanimous support for the Cap. There is a recognition that the Cap, in isolation, will not result in a sustainable Basin. The South Australian Government submission argues "*the Cap does not effectively address ecological sustainability–although it has been effective in slowing the decline*." A similar argument is made by the New South Wales Government, "*While the Cap alone will not achieve ecological sustainability, it is fundamental to achieving the benefits targeted by the environmental flow rules and other water reform initiatives*". There is disagreement as to whether the Cap, as implemented, is the most appropriate resource management tool to provide resource security and environmental protection.

> The Cap is critical to the sustainability of the Basin, however in isolation, the Cap does not represent a sustainable level of water use.
>
> The Cap is set at a level of diversions that contributed to the current degradation of the riverine environment. The Cap was implemented with the aim of restricting growth in diversions with the view to stopping <u>further</u> decline in the riverine environment. There should be no expectation that the Cap, at its current level will <u>improve</u> the riverine environment.
>
> However, the Cap is an essential <u>first step</u> in providing sustainable water resource management.

3.3.3 Disagreement over existing levels of environmental degradation

There is considerable disagreement over the existing level of environmental degradation of the Basin's river system, and of the need to restrict further impacts. Inland Rivers Network argues that current environmental degradation in the rivers and wetlands of the Murray-Darling Basin clearly indicates that too much water is being extracted. Similarly, ACF argues "*river regulation and diversion of water resources represent the key threatening process for the ecology of the Murray Darling*". The North West Catchment Management Authority argues that "*The major problem is, that Cap or not, present diversions and practises threaten a salinity problem perhaps equal to the Aral Sea and certainly equal to the Nile."* However, not all submissions agree on the level of degradation of the riverine environment, for example the submission from the Shire of Brewarrina, *"the potential hazards and risk to the health of the riverine environment appear to have been grossly exaggerated in a number of aspects"*.

The South Australian Government submission argues that even with the Cap in place, "*significant degradation continues in major parts of the Basin*". However, submissions from the more northerly areas of the Basin often question the level of environmental degradation resulting from water abstraction, perhaps reflecting the relatively lower levels of abstraction in these valleys. This view is also reflected in the Queensland Government submission, which argues that the low level of abstraction in the Western Rivers of that State indicate, *" some scope for further development may be possible without causing any significant detrimental impacts to the overall health of the stream or the interests of downstream users*". A similar argument, that water resources are not heavily developed in their jurisdiction, is presented by the Australian Capital Territory "*The Cap must acknowledge that the ACT's water resources are* *significantly under developed* ….", and "….*the ACT approach to water resource management results in a sustainable system which includes provision for further utilisation*".

The evidence indicating many of the Basin's rivers are stressed, and that the current levels of abstraction are a major cause of this, is overwhelming (See Sections 3.1, 5.2, 5.3, 8 & 9). Evidence includes reductions in areas of wetlands and degradation of floodplain woodlands, changes in the shape of the river channels (including closing of the Murray Mouth), increasing salinity and eutrophication, declines in the range and abundance of many species of native plants and animals, including fish, crayfish, turtles, frogs, birds and mammals. In their place, species like carp and willows have become established.

Increased water abstraction anywhere in the Basin will increase this stress. The effects of increased diversions in relatively 'under developed' headwater streams will impact in downstream (and often interstate) rivers (See Section 9.4), most of which are already showing significant signs of stress. There are arguments, based on equity, for transferring allocations (diversions) into upstream jurisdictions, which are beyond the scope of this review. The important principle is that these transfers should be within the Cap and not increase total diversions within the Basin.

Community confidence in the Cap will be eroded unless there is a rapid Basin-wide implementation of the Cap.

3.3.4 Striking a balance between consumptive use and the environment

There is consensus that a balance needs to be struck between the damage caused to the riverine environment from water abstraction and the economic and social benefit derived from water use. There is disagreement as to where an equitable and sustainable balance lies, no doubt further complicated by environmental values being different between stakeholders. The submissions suggest that considerably more effort to inform stakeholders of the need for, and the aim of, water resource management initiatives is required.

The Murray Darling Association argues that there is a relatively poor understanding of the variability of the Australian climate and the relationship between the lack of rainfall and the availability of water resources for distribution within the Basin community. Unless the Basin community understands the physical constraints on the supply and delivery of irrigation water as well as the ecosystem's water requirements, it will be impossible to strike a universally accepted balance between abstraction and the environments water requirements.

A number of submissions to the Review call for increased transparency of scientific studies and greater communication of their results to Basin community. The Southern Riverina Irrigation Districts Council asks "…*have any studies been completed [that aim to determine the environmental outcomes of the Cap] and if there has, why has this knowledge not been imparted to the wider valley communities?*"

The community expects rigorous science to underpin water management decisions and that the anticipated outcomes from water management be expressed in quantifiable and understandable way. A number of submissions strongly argue that it is the responsibility of water resource managers to assess and disseminate the outcomes of water management.

Determining an appropriate level for the Cap requires science to identify ecological impacts of the current level of diversions and describe the long-term consequences of these impacts on sustainability. It is the role of the community, using this understanding, to strike the balance between the economic benefits and ecological costs of diversions. The level of the Cap needs to reflect this balance.

At present, the community does not have access to sufficient ecological information to make these complex decisions. However, there is community disquiet over the state of the Basin's rivers and there is a strong desire to see an improvement in river health. The challenge for science is to provide the ecological understanding needed by the community. The challenge for the Commission and other water resource managers is to ensure that this information is available to the community.

3.3.5 Insufficient scientific input into setting and evaluating the Cap.

Many non-government submissions argue that there is little baseline ecological data against which to assess the impact of the Cap on the environment. This view is typified by Murray Irrigation Limited, which *"is not confident there is sufficient scientific information available to evaluate the effectiveness of the MDBC Cap of achieving ecological sustainability on a valley by valley basis"*. This view is supported by the Commonwealth submission, which states, *"…long term baseline data on river health required to assess the effectivness of management strategies (including the Cap) on the riverine environment are limited or unavailable*".

Many non-government submissions are disappointed that, despite the lack of existing information, there appears little effort to collect the data required for measuring the effectiveness of the Cap in achieving positive ecological outcomes. The Commonwealth submission does point out however, a number of programs and policies currently in operation that aim to measure, albeit indirectly, the effectiveness of environmental allocations.

A number of non-government submissions argue that water allocation decisions have to be based on the best possible science, for example Berrigan Shires' submission states "*…efforts to improve sustainability should be based on objective data, not simple perceptions or notions*". Similarly, there is considerable concern that the hypothesis "less extraction is better for the environment" needs to be rigorously tested before it is applied. The Commonwealth submission acknowledges that "*the level that the Cap was set, however, was not based on scientific knowledge of ecological water requirements of the riverine environment*."

A number of submissions also note that it is too early in the life of the Cap to be assessing environmental outcomes of the Cap. This is exacerbated by the lack of baseline information, understanding of how the river system functions and the dry spell in the southern region of the Basin. For example, the West Corurgan Private Irrigation District submissions states, "*The time span between initial Cap implementation and today, coupled with the climatic resource constraints during this period do not, I believe, permit science to be in a position to accurately assess sustainability levels*."

On the other hand, there are submissions arguing that the Cap has failed because the Commission, and science generally, have not demonstrated any discernible environmental improvements resulting from the Cap.

While many hope the Cap represents a sustainable level of diversions, the level of the Cap was not chosen to be this. Rather, the Cap was set in response to the Water Audit which recognised that the levels of abstraction and the potential for their growth were leading to a long-term decline in riverine health and threatened security of supply for existing users.

There are some limited data available to assess the impact of the Cap on the ecological health of the Basin's rivers. However, the riverine ecosystem will require many decades to complete its various ecological and geomorphic responses to the altered conditions that have been imposed on it.

In most cases it will not be possible to separate the impacts on ecosystem health of the Cap from other water reforms and environmental flows.

The Commission has to regularly demonstrate both compliance with and effectiveness of the Cap. This can be achieved by providing an annual Environmental Audit for the Basin's river system in conjunction with the Water Audit Monitoring Reports.

3.3.6 Disagreement on a sustainable level for the Cap

Submissions to the review argue for and against changing the level of diversions allowable under the Cap. Arguments are presented for an increase, for maintaining the status quo, and for decreasing the level of diversions.

The Government submissions of Queensland and the Australian Capital Territory argue that in their jurisdiction, there is scope for a sustainable increase in diversions. Both submissions acknowledge that there would be downstream effects of increased diversions, however these would be small in *their* jurisdiction.

The Commonwealth submission argues that diversions are likely to be too high and will have to be reduced to achieve sustainability. "*As the knowledge of environmental flow requirements improves, the provision of environmental allocations is likely to require adjustment to the level of the Cap to remain consistent with the COAG water reform requirements*".

Current indications of continued decline in river health suggest that with current land and water management practises, the Cap does not reserve enough water for the environment.

Increasing the level of diversions in upstream rivers will further exacerbate environmental degradation downstream and these effects must be recognised when determining the level of the Cap in upstream jurisdictions.

3.3.7 Better management of environmental allocations

Submissions call for water allocated to the environment to be managed to achieve best environmental outcomes and, importantly, that this management and its outcomes be evident to the Basin community.

There is a need for a regular Ecological Audit of the Murray-Darling Basin river system. The Ecological Audit would report on the efficiency, coordination and ecological outcomes of environmental flows Basin-wide (See Section 3.2).

Improving the efficiency with which water is used to satisfy ecosystem requirements will require improved ecological knowledge. Water resource management requires a strategy for identifying knowledge gaps, seeking knowledge to fill those and for incorporating this knowledge into their operations.

The outcomes of water management should be available to all interested stakeholders. Principle 12 of the National Principles for the Provision of Water to Ecosystems is relevant here: All relevant environmental, social and economic stakeholders will be involved in water allocation planning and decision making on environmental water provisions.

3.3.8 The Cap alone will not ensure sustainability

Most submissions accept that in isolation the Cap is unlikely to significantly improve river health. However, the reasons for this are varied. Some non-government submissions indicate that much damage has already occurred, probably at lower levels of abstraction than at present. Their conclusion – that the level of the Cap is too high.

Many submissions argue that improved environmental flow rules will be required to support the Cap. For example, the New South Wales Murray Wetlands Working Group indicate that the Cap needs to be supported with an "*assessment of the environmental flow requirements of the rivers of the Basin and implementation of these actions to meet flow requirements…*". This is supported by the Governments of NSW and South Australia and by the Commonwealth. For example, the South Australian Government argues the need for "*a complete sustainable rivers program that would address flow regimes, timing and quality issues in addition to the volumetric rationale of the Cap*."

For the main part, the environmental benefits of the Cap, and hence its contribution to sustainability of the system, will depend on the skill with which the environments allocation is managed.

The amount of water required to achieve a sustainable ecosystem will depend on the efficiency with which water is used to satisfy ecosystem requirements.

3.3.9 Integrate river and catchment management.

It is widely acknowledged by the submissions that the Cap on diversions limits further extractions for consumptive use, but this alone will not guarantee the long-term maintenance of a healthy river system. Submissions indicate that not all river health issues are flow-related, and that there is an over-reliance on managing river-flow to achieve river-health objectives. *"The lack of any strategic plan to address the degradation of the upper catchments, with the attendant effects on water quality, is to be condemned. ….. Until there is an integrated approach to managing the entire catchment in an ecologically sustainable fashion, there will be no improvement in the riverine channel itself."* [Namoi Valley Water Users Association].

Concern is emerging about the impacts of changed land-use on catchment water yield and stream flow. This is highlighted in the Victorian Government submission, which indicates re-afforestation of Victoria's Northeast is likely to dramatically reduce water yield.

There is recognition of the physical connectedness of groundwater with surface water and how supply of one affects demand on the other. Victorian Government and the Commonwealth submissions call for the coordinated management of groundwater and surface water resources.

Integration of catchment and water management is required. A better understanding of long-term changes in catchment water-yield is critical for water allocation planning.

Groundwater and surface water are physically interconnected, and for some users alternate sources of water. The Cap does not assess the extent of conjunctive use of groundwater and surface water and the level and extent to which capping surface water leads to switching to groundwater use. It is critical that surface water and groundwater management is integrated if both resources are to be conserved.

3.3.10 Confusion between impacts of the Cap and other water reforms.

There is some understanding that the Cap is just one of a number of water management reforms introduced during the last 5 years, however the impacts of the Cap are regularly confused with other water reforms. Many non-government submissions indicate a need for considerably greater effort aimed at assessing the ecological impacts of the Cap and distinguishing these from the effects of other water reforms. The MIA Council of Horticultural Associations argues *"that a proper scientifically rigorous process be established so that each particular [water reform] initiative can be assessed in its own right, rather than as a combination of effects"*. The Commonwealth recognises the difficulty of this task, *"…differentiating between the impact of the Cap from other management strategies such as water trading, water pricing or allocation of environmental flows on river health may prove difficult*".

At the Basin-scale it will not be possible to differentiate between the ecological impact of the Cap and many other management strategies. The aim should be to assess the impact of river management as a whole and to educate the community as to why the Cap, in conjunction with other management initiatives, is critical to the sustainability of the Basin.

3.3.11 Confusion about what the Cap is expected to achieve

Submissions to the Review highlight a lack of understanding about the implementation of the Cap, but more importantly, they highlight a lack of understanding of the ecological, social and economic goals of the Cap. The goals of the Cap need to be clearly expressed and ecological targets set, against which the Cap can be assessed, otherwise there will be unrealistic expectations of the Cap. For example, some in the community expect the Cap to improve river health in the Basin and make consumptive use of water sustainable. While this is clearly an aim of the Commission, it is not a realistic objective of the Cap in isolation. This misunderstanding is not surprising. The Commission's often-stated primary objectives for implementing the Cap are[2]:

- *to maintain and where appropriate, improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance the riverine environment; and*

- *to achieve sustainable consumptive use by developing and managing Basin water resources to meet ecological, commercial and social needs.*

The message from these objectives is that implementation of the Cap will ensure sustainable water use in the Basin. In a bid to garner support for the Cap, which is undoubtedly a critical water resource issue, there is the clear danger of 'over-stating' its short-term benefits. If these benefits are not realised, for example if blue-green algae continue to bloom and carp dominate recreational fish catches, the Cap no matter how successfully implemented, will be viewed as failing.

[2] For example, Review of Cap implementation 1996/97 & 1997/98 MDBMC. Canberra.

4 Defining Sustainability

Address the impact of the operation of the Cap in achieving its objectives to ensure ecological sustainability of the Murray-Darling Basin river system by examining the question, "How Should Sustainability be defined for the purposes of the Cap?"

4.1 Introduction

Conservation of water is an urgent issue. It is true that water, *the compound* (H_2O), is a renewable resource, it is continuously cycled between the earth and the atmosphere via evaporation and rainfall, fairly independently of how well rivers and lakes are managed. However, the *water resource* is significantly more than H_2O. The *water resource* involves considerations of quality, timing and reliability. These are very susceptible to human activity, both directly through water resource development and pollution, and indirectly through damage to the complex ecosystems essential for maintaining the quality of the resource.

Sustainability has been a primary objective of the Cap since its inception. These objectives are expressed as:

- *"To maintain and were appropriate, improve existing flow regimes in the waterways of the Murray Darling Basin to protect and enhance the Riverine environment, and*

- *To achieve sustainable consumptive use by developing and managing Basin water resources to meet ecological, commercial, and social needs".*

Published discussions and submissions to this review revealed a variety of assumed meanings for the word sustainability. This is not surprising. Along with such terms as biodiversity and river health, sustainability is what Gaston (1996) refers to as a pseudo-cognate term. It describes a concept that is generally comprehended, but for which a shared definition is often elusive. This section does not attempt a universal definition of sustainability, but rather seeks to reach a shared interpretation as it refers to the establishment, operation, and Review of the Cap.

4.2 Some Background

In a global sense, Costanza & Daly (1992) describe ecosystem resources such as water, air and soil as Natural Capital. These resources can be renewable or non-renewable[3]. The other form of capital is Industrial Capital[4], which consists of Manufactured Capital such as physical enterprises and farm machinery, and Human Capital such as skills and knowledge. Production results from the combining of Natural and Industrial Capital (Fig. 4.1). As an example, irrigated farming combines skill and knowledge, the farm infrastructure, and natural resources such as soil, water, and nutrients to produce rural commodities. A system is sustainable when both Natural Capital and Industrial Capital are sustained in the long-term.

There are many pressures, including population growth and a desire for increased 'standards of living', which drive increased production. Production can only be increased by increasing the rate at which Natural Capital (such as water, soil, nutrient) is used and/or by increasing the input of Industrial Capital. The former increases the pressure on the ecosystem, which in the Murray-Darling Basin is already in decline. Increasing inputs of Industrial Capital require either

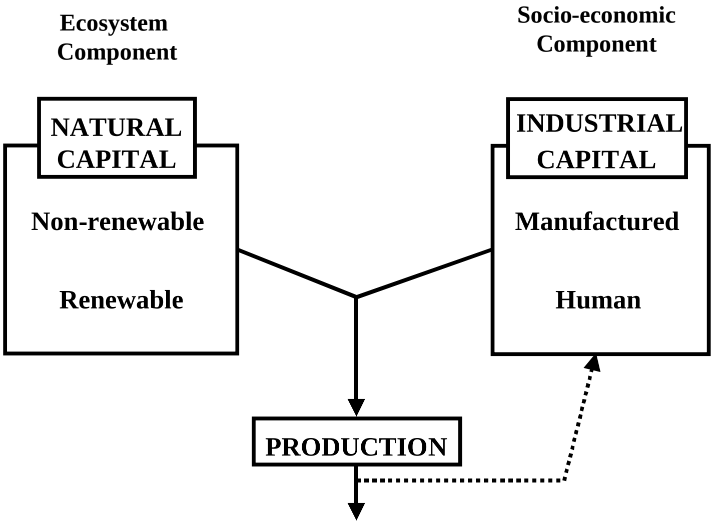
[3] As well as being used directly by the human community Natural Capital also supports 'ecosystem services'.
[4] This was initially described as Man-made Capital by Constanza and Daly (1992).

increased inputs of Manufactured Capital (machinery, irrigation infrastructure etc.) which can threaten economic viability, or increased inputs of Human Capital (skills, knowledge etc.).

From another angle, increases in production can be achieved either through *growth* and/or *development*. Growth is achieved by increasing the amount of Natural Capital used (i.e. more water, nutrient and soil). Development results from increases in the amount of Industrial Capital used, often Human Capital (skills, knowledge), without changing the use of Natural Capital.

The Cap aims to sustainably increase production by fostering *development*, through more efficient use of existing diversions, without allowing *growth* in diversions. This model of sustainability fits that proposed by the North-West Catchment Management Committee, *"sustainability must be defined in such a way that it does not restrict further development but prevents the further growth of diversions".*

Figure 4.1 Production results from combining Natural Capital and Industrial Capital. Production is not sustainable if either is depleted in the long term.



4.3 What is to be sustained?

One of the most divergent aspects of the submissions to the Review relates to assumptions about what the Cap is to sustain. For the most part sustainability is taken to refer to aspects of the riverine ecosystem such as biodiversity, the condition of the resource, or various aspects of the human use of the resource, such as farm economic viability.

Production will collapse if the drain on either Industrial Capital or Natural Capital becomes too great – if it is not sustainable. There is, however, a significant difference in the time scale of these responses. Response to depletion of Natural Capital, in this case the riverine ecosystem, is likely to be very much slower than the response to the depletion of Industrial Capital. It is also possible that increases in Human Capital (skill, technology) will maintain production and mask the decline in Natural Capital in the short to medium term. Some marine fisheries enterprises are a good example of this. Advances in tracking and catching technology can mask the decline in fish stocks. Fish catches remain constant until there are too few to catch fish (because their population collapsed), and then the fishery collapses. If current management initiatives, including the Cap, fail to halt the decline in the riverine ecosystem, then increases in Human Capital, such as efficiencies in water use and ability to manage declining water quality, will merely mask the progression towards collapse of both the ecosystem and the socio-economic system. If the ecosystem or socio-economic system collapses then a Cap of any size is unlikely to restore production or the ecosystem. As stated by the Lower Murray Catchment Committee, "the purpose of the Cap should be to *halt* decline".

Leaving aside the socio-economic component, which is considered in the Economic and Social Impacts Review, sustainability of the riverine ecosystem should address three fundamental ecological values:

- Biodiversity;
- Ecosystem function; and
- Ecosystem integrity.

4.3.1 Biodiversity

Diversity is the basis of adaptation. At the genetic level it provides the basis for selection of appropriate individuals in response to changing environmental pressures. At the community level it provides a suite of species which, collectively, has the capability of supporting ecological functions in the spectrum of conditions encountered in a variable environment such as the Murray-Darling Basin. The capacity of an ecosystem to rebound from unusual events is dependent on biodiversity.

The significance of sustaining biodiversity has received wide-ranging support. It is the subject of international agreements to which Australia is a signatory. The NSW EPA, as part of setting water quality and river flow objectives (EPA 1999) identified sustaining biodiversity as the highest environmental objective in a recent community survey.

Definition, description, and objective measurement of biodiversity has proved very difficult (Heywood 1995), but some of the metrics used to assess 'river health' may provide a means of assessing biodiversity relatively over time.

> We now have very few data on which to assess the effect of river management and, specifically, the operation of the Cap on biodiversity. This urgently needs redressing if managers are to be able to address national obligations or the wishes of the Basin community.

4.3.2 Ecosystem Function

With regard to the Murray-Darling Basin there are two aspects of ecosystem function which bear on sustainability; general ecosystem services and that component of the riverine ecosystem which maintains the utility of the water resource.

Globally the biosphere is a self-sustaining (though changing) system founded on solar energy. As part of the biosphere humans derive a number of benefits which are referred to collectively as Ecosystem Services. Clean water, pure air, soil formation and protection, foods, fuel, fibres, and naturally occurring drugs are examples of these benefits, as are aspects of the climate. If production in the Murray Darling Basin results in a reduction in ecosystem services it is important to include the value of those forgone benefits in assessing the sustainability (or cost-effectiveness) of that production.

The quality, and therefore the utility, of the water resource is maintained through the functioning of the riverine ecosystem, including the catchment. It is reasonable to assume that any diversion of water will have some effect on the ecosystem, and there is a point at which further diversion will result in its collapse[5]. Avoiding collapse of the ecosystem is an important function of the Cap. Attempting to sustain ecosystem function without addressing biodiversity and larger scale issues of ecological services and ecosystem integrity is a minimal response likely to be effective only in the short-term, at best.

4.3.3 Ecosystem Integrity

The third characteristic of ecological value is ecosystem integrity. Ecosystems that are quite different may support similar levels of ecosystem services and have similar biodiversity. However, these ecosystems might be quite different in terms of wider ecological values or from the human perspective. For example, low flow may facilitate a shift in algal community structure form one dominated by diatoms to one dominated by blue-green algae. In these two communities biodiversity and ecosystem function may remain unchanged, however ecosystem integrity has altered in a direction the community would perceive as bad. Another example is the shift from aquatic plant-dominated to algal-dominated waterbodies resulting from increased turbidity and/or eutrophication.

There are other aspects of ecosystem integrity, such as local depletion of endangered or highly valued organisms, which reflect ethical and aesthetic aspects of community values (perhaps reflecting a wish for intergenerational equity as well) which need to be accounted for in managing for sustainability.

4.4 Spatial and temporal dimensions.

4.4.1 Spatial scale.

The current debate regarding deficiencies in the Murray-Darling Basin and a requirement for environmental releases in the Snowy, exemplifies the importance of considering sustainability at appropriate scales. Although it may be necessary to identify sacrificed zones in the future management of the system, such decisions must be made as free as possible from political and interstate pressures.

The Cap is a basin-wide measure and needs to be operated at that scale for the good of the Basin is a whole.

At the smaller scale, management practices that depend on a program of retiring irrigation land and commencing new sites is of dubious sustainability.

4.4.2 Temporal scale.

The temporal scale is very important in measuring sustainability. Short term considerations of sustainability may overlook gradual degradation of the ecosystem if it is masked by development (increased use of technology etc.). Objectives for sustainability over a long-time scale are likely to be complicated by future changes (eg. meteorological change) outside the influence of river management. Where the objectives of sustainable management are expressed only in terms of production outcome, then assessments over short time scales can result in apparently sustainable production but at the expense of the ecosystem (rather than maintaining its function).

> Assessment of ecological sustainability has to be made over appropriate time-scales – which are often considerably longer than those used in conventional economic assessments of sustainability.

[5] There is no particular reason to assume that the relationship between abstraction and ecological damage is linear, however.

4.4.3 Inter-generational Equity

Considerations of time scale introduce the issue of intergenerational equity. Intergenerational equity is an important issue and is succinctly analysed in the ACF submission to the Review[6]. A productive system cannot be considered sustainable if either the Industrial Capital or the natural resources and ecosystem that supports it are handed on to the next generation in a worse condition than that in which they were received. This evokes the notion of resource stewardship and the obligations which that implies.

In the case of the Murray-Darling Basin there appears to be little disagreement that the Natural Capital are currently in worse condition than it was when the current generation undertook this stewardship.

We are currently failing the test of intergenerational equity.

4.4.4 Future technological advances

It is tempting to excuse robbing future generations for current gain on the assumption that future technological development will redress the imbalance. This is probably the last vestige of the confidence of the mid-20th-century (see eg. Water into Gold, Hill 1951), which recognised the dedication and ingenuity of 'pioneer generations' and the power of technological advancement at the time. The conclusion was drawn that human resourcefulness and science would lead to boundless production and development. We now recognise that bounds exist and importantly, we may be reaching or even exceeding these bounds. This change has come about partly from being confronted by issues such a salinity, but also by a growing understanding of the ecological systems which underpin our natural resources. We are now beginning to recognise that the functioning of these systems is governed by laws of nature which technology can scarcely influence – let alone override. In other words, until recently, production was limited by Industrial Capital, which technology was able to improve significantly. Increasingly, production is now limited by Natural Capital that is virtually beyond the influence of technology. The messages from this are:

- We cannot expect technological advances to compensate for our borrowing from future generations any longer; and,

[6] (ACF Submission to Review)

Inter-generational equity requires that the present generation ensures that future generations inherit an environment that maintains or improves current levels of welfare. It involves the following principles:

- ensuring a constant stock of natural capital* (*air, water quality, species and ecosystems, soil composition and structure, climate, and natural cycles such as carbon and hydrology);
- operating within biophysical limits to natural resource use, acknowledging that uncertainty and time irreversibility demand a precautionary approach;
- efficiency of resource use maximises benefits, and minimises costs to the future;
- resilience in natural systems and economic structures alike; and
- external balance in economic terms is important in minimising pressure to deplete natural capital.

- In terms of scientific advances, future benefits are likely to be gained by increasing our knowledge of ecological systems that underpin the water resource and thereby learning efficiencies in supplying the water required for its maintenance.

We have used up the credit gained by technology and can no longer depend on it to pay our debts to future generations.

4.5 Defining Sustainability for the purposes of the Cap

The discussion paper, 'Managing Natural Resources in Rural Australia for a Sustainable Future' (Gorrie and Wonder 1999) states that the outcomes of future management should be:

- *Healthy ecosystems and catchments in which the integrity of soils, water, flora, and fauna is maintained or enhanced whenever possible;*
- *Innovative and competitive industries that make use of natural resources within their capability, to generate wealth for social and economic well-being;and*

- *Self sustaining, proactive regional communities that are committed to the ecologically sustainable management of natural resources in the region.*

The discussion paper further indicates that this level of management should lead to ecologically sustainable development (ESD) for which they quote the National Strategy for Ecologically Sustainable Development definition:

> *Ecologically sustainable development is using, conserving, and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.*

The objectives of ESD are expressed as:

- *To enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations;*

- *To provide for equity within and between generations;*

- *To protect biological diversity and maintain essential ecological process and life-support systems.*

These descriptions incorporate the main aspects of sustainability and include issues such as production, quality of life, maintaining the ecosystem that maintains the resource, biodiversity, intra-and intergenerational equity. These are also the main issues raised in submissions to the review. However, mainly because of their global nature, they do not definitely answer questions such as:

- How long is long-term?
- How do we quantify sustainability against the background of extreme variability and unpredictability that characterises much of the Murray Darling Basin?

Costanza points out that measuring sustainability, including the measurement of success in adaptive management programs, is difficult because the achievement of sustainability, is by definition, at some point in the future.

The reference point for sustainability in the Murray Darling Basin is a sustained or increasing level of rural production achieved at an acceptable level of Industrial Capital (finance and ingenuity) at no cost to future generations. For production to be sustainable it must be achieved without:

- damaging or degrading the Natural Capital;
- contravening international biodiversity agreements; or
- resulting in unacceptable (to current of future communities) aesthetic damage.

The problem is how to strike a balance between water use for human and ecological uses. Failure to meet either requirement will result in collapse of the current system of production.

By limiting allocation for human use, the Cap, in effect, reserves a volume of water for ecosystem maintenance. The Cap does not prescribe how it is to be used. Currently, in many parts of the Basin, the community, with managers and other experts, are attempting to determine ways in which to deliver water to sustain the ecosystem – to provide environmental flows. This process will be continuously refined as additional ecological knowledge becomes available. However, it should be noted that it is the system itself – not the scientists, managers, or users - that will determine whether the quantity of water or its deployment is sufficient to sustain the ecosystem, and therefore sufficient to sustain production.

Production will only be sustained if both the ecosystem and the socio-economic system are sustained into the long-term. Collapse of production through failure of the socio-economic component is unlikely to harm the Murray-Darling Basin ecosystem. However, collapse of production through failure of the ecosystem will mean the collapse of the socio-economic component of the Murray-Darling Basin.

Recognising, then, that the ecosystem maintaining the resource is the key component to the future of the Murray-Darling Basin, sustainability should be defined as *the indefinite preservation* of:

- a functional and diverse ecosystem which, as well as meeting aesthetic and ethical requirements, provides a natural resource suitable for (all) human uses and production; and
- a socio-economic system capable of using the natural resource productively to the maximum good of the current and future communities.

In terms of its operation, the Cap must seek to apportion water between the riverine ecosystem and consumptive human uses such as to:

- reserve sufficient water to maintain the ecosystem in line with ESD principles; and
- preserve a supply of water suitable for human use.

It should be noted that the term 'preservation' is not meant to imply a static condition. Long-term rainfall patterns, climate change, changes in catchment management are all capable of producing significant changes to the amount of water available. Likewise socio-economic development will change production requirement (and, perhaps, ethical, aesthetic, and recreational views on the riverine ecosystem). This means that the Cap and any other means of sustaining the Murray Darling system, will need sufficient flexibility to achieve that goal whilst managing a changing resource.

4.6 Delivering a sustainable Cap

Flow management deals with a subset of factors required to sustain the riverine ecosystem. It does not take into account contaminants, alien species, or catchment management. It follows

that flow management can do little more than provide hydrological and other habitat requirements which, in the absence of limitation by other factors, will support a riverine ecosystem which, in turn, will sustain a given level of exploitation indefinitely.
The amount of water required to maintain an ecosystem will depend on the efficiency with which the water is used to satisfy the ecosystems requirements. Just as productivity of irrigated agriculture depends on the efficiency with which that water is used, not just the quantity provided – so too does the ecological benefit derived from the environments allocation. Efficient use depends on ecological knowledge.

Essentially, a sustainable Cap requires an amount of water which, when *used efficiently*, will result in the indefinite support of the riverine ecosystem to the level that, in turn, supports exploitation indefinitely. The following should be noted:

- this amount of water is essential but not always sufficient, in that factors other and hydrology suppress ecosystem performance. This means that maximum use of water can be sustained only if all environmental factors are effectively managed;
- this definition of sustainability is entirely human oriented. The community may choose larger environmental allocations to achieve conservation and aesthetic goals outside those relating solely to production.

As a means of insuring sustainability, the Cap is a blunt instrument. In effect, by limiting the level of abstraction, it preserves a quantity of water for the riverine ecosystem. It says nothing about the way in which this water is to be used. There are direct environmental benefits of the Cap. For example, the Cap prevents further increases in the return frequency of very low flows which, under natural circumstances, could be considered as drought. For the main part however, the environmental benefits of the Cap, and hence its contribution to the sustainability of the system, will be dependent on the way in which the remaining water is managed.

It is most likely that the Cap would need to allow significantly less diversions if it were expected to achieve environmental sustainability on its own. Fine-tuning of environmental flows, based on ecological knowledge not yet to hand, is the only means of achieving environmental sustainability with a Cap that preserves something approaching current exploitation rates. Current indications of continued decline in the riverine environment indicate that the Cap is necessary, but not sufficient, to ensure sustainability.

In the interim, we are faced with making decisions regarding the use of the water reserved by the Cap to maximise the 'health' of the riverine ecosystem. This requires an adaptive management approach, because, whilst it is necessary for the community with management and technical support to make decisions about the allocation of water to support the ecosystem, it is the system itself which will decide if that is sufficient.

What then is the connection between the Cap and the indefinite sustainability of the Murray Darling Basin as a functioning socio-economic and ecological system? Blackmore (1999) states that "The Cap is critical to the long-term health of the Basin's rivers and hence to all water users, now and in the future, and will be a permanent feature of water management in the Basin". Submissions to this review indicate widespread agreement with the significance and intent of the Cap.

As the Western Catchment Management Committee suggest "Sustainability needs to be defined in the first instance by determining a flow regime which relates to actual needs under present developed circumstances and not by assuming that flow patterns can be made to revert to those which existed prior to irrigation development." This describes clearly our present dilemma. It can be summarise as follows:

- We have some understanding of the human requirements for the water resource, the possible efficiencies (in water use and delivery), and their likely cost;
- There are generally accepted signs that the ecosystem which supports that resource is changing in the direction of functional breakdown in response to altered flow;
- In the absence of adequate ecological knowledge, the surest way to support the riverine ecosystems is to increase the amount of water remaining in the system and to aim at restoring pre-European flow patterns (the level of sophistication in the management of environment's share compares unfavourably with what is expected of other water users);
- Efficiency in producing ecological gains from environmental water allocations is dependant on increased knowledge of the relationship between ecological function and flow; and
- With current land and water management the quantity of water reserved by the Cap is probably insufficient to halt ecological decline. We can expect a worsening quality of the Basin's water resource. However, knowledge-based increases in efficiency of supplying environmental water will tend to redress this situation.

5 Is the Cap at a sustainable level?

Address the impact of the operation of the Cap in achieving its objectives to ensure ecological sustainability of the Murray-Darling Basin river system by examining the question, "what does science tell us about the suitability of the level at which the Cap is set?"

"*After years of extensive development of freshwater resources, particularly for agriculture, water demand management and water quality degradation have become important concerns*" (OECD, 1989).

Historically, the environment used every drop of water from rivers within the Murray-Darling Basin. Once water is diverted from the river system there is an impact on the environment. The challenge for scientists is to identify, measure and understand that impact of current and future water diversions. The challenge for the community is to decide how much of an impact is acceptable. The ecosystem itself will decide if the system is sustainable. Adaptive management is needed to reach a sustainable balance and to adjust that balance for future changes.

The environment today is not what existed in the past. The Basin is moving to a new and different state. Water chemistry, hydrology, geomorphology and biota of the Murray-Darling river system have changed dramatically since the period of rapid expansion in diversions and they will continue to change, with changing patterns of water usage and as sufficient time passes for the slow-changing impacts occur. To decide on an acceptable level of diversions the community requires knowledge about how the environment is likely to function now and in the future at different levels of diversions.

Determining the limit of acceptable change in the Basin's river systems is arguably the most complex decision confronting the community. This section of the Review describes what science presently understands to be the effects of diversions and other water resource development on the function and sustainability of the river system as well as what constrains this understanding.

5.1 Improving scientific knowledge

Historically, the fundamental objective of water management was to regulate rivers to:

- meet demands for water supply by creating sufficient storage to control seasonal and between-year variations in flows[7], and
- maximise consumptive use of the resource by minimising the amount 'lost' to the sea.

The emphasis is now changing toward allocating water to sustain natural ecosystems, to restore rivers degraded by over-abstraction or inappropriate regulation of the past, and to protect biodiversity for future generations (Petts 1996). The challenge for science is to provide the knowledge to achieve these aims in the most 'water efficient' manner.

In the five years since the Cap was introduced there has been considerable effort aimed at understanding the environmental water requirements of the Basin's rivers. Impetus for this

[7] Increases in storage capacity are still increasing in the Basin. Current storage capacity in the Basin is approximately 36,000 GL, more than 3 times the median flow to the ocean. Whilst most of the larger rivers are now regulated by large dams, storage capacity in the Basin continues to climb, with on-farm storage capacity continuing to grow at 2% each year (MDBC unpub. data).

understanding was provided by the adoption of the Council of Australian Governments' (COAG) Water Resource Policy. The aim of the Policy is to achieve an efficient and sustainable water industry in Australia. A major component of the policy is the provision of water for the environment. To guide water management, the National Principles for the Provision of Water for the Ecosystems were jointly developed in 1996 by the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Australian Resource Management Council of Australia and New Zealand (ARMCANZ). As signatories to the COAG Water Resources Policy and the National Principles for the Provision of Water for the Ecosystems, partner governments have committed to using the best science available in determining water regimes and to improving our knowledge of environmental water requirements[8].

5.2 Determining the impacts of diversions

There is considerable evidence that diversions from the Basin's river system have had a major impact on the riverine ecosystem. It was in response to these, and the declining security of supply to existing water users, that the Cap was introduced. However, many submissions to the Review express disappointment that there is no evidence that the Cap on diversions has improved river health. That the Cap has not led to signs of *improved* river health is to be fully expected. There are a number of reasons for this, including:

- the Cap was implemented to restrict growth in diversions with a view to *reduce* further degradation of the riverine environment – not to *improve* the riverine environment;
- limited data (and tools) are available to quantify changes in river health;
- lack of dedicated program to identify impact of diversions and Cap;
- a growth in diversions since the implementation of the Cap;
- impacts of water resource development (other than the volumetric issues dealt with by the Cap) and catchment management confound impacts of water abstraction;
- impacts of other Water Reforms (eg trading, environmental flows) make it harder to isolate the impact of Cap from other reforms;
- time-lags between changing the level of diversions, first detecting an impact and reaching a new stable state.

5.2.1 Failure to quantify the impact of the Cap

A clear message from the submissions to the Review is that science has *failed* to demonstrate the environmental impact of the Cap, quite apart from whether the Cap actually has had an impact. A question often asked is, "does science have the tools, knowledge and data to demonstrate the environmental impact of the Cap - even if there is one?"

Since the introduction of the Cap, there has been increased research activity to understand the hydrological, geomorphological and biological processes occurring within the rivers of the Basin. This research has been undertaken by a number of research institutions including the CRC's for Freshwater Ecology and Catchment Hydrology, CSIRO and research groups in a number of universities and State agencies.

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[8] Specifically principles 2 and 11 of the National Principles for the Provisions of Water for Ecosystems:
Principle 2….. Provision of water for ecosystems should be on the basis of the best scientific information available on the water regimes necessary to sustain the ecological values of water dependent ecosystems.
Principle 11…. Strategic and applied research to improve understanding of environmental water requirements is essential.

Encouraged by COAG's Water Resources Policy, the States and Territory have developed programs to determine current condition of their water resources and the environmental water requirements of their rivers. These programs include:

- Queensland Governments Water Allocation Management Plans and Water Management Plans;
- NSW Rivers Survey and aspects of the New South Wales Government's Water Reforms which includes the Integrated Monitoring of Environmental Flows (IMEF) and the Stressed Rivers Assessment;
- Victorian Government's Bulk Water Entitlement Process and development of Streamflow Management Plans and River Restoration Plans;
- South Australian Government's State Water Plan and Catchment Water Management Plans; and
- In the Australian Capital Territory the development of Environmental Flow Guidelines for the Water Resources Management Plan.

The Commonwealth has provided funding and policy support for the Basin's rivers through various programs including:

- National Strategy for Ecologically Sustainable Development;
- National Heritage Trust – particularly the following programs:
    - Murray-Darling 2001
    - National River Health Program
    - Waterwatch;
- National Strategy for Conservation of Australia's Biological Diversity;
- Wetlands Policy;
- National Water Quality Management Strategy (NWQMS); and
- MDBC Salinity and Drainage Strategy.

Funding has also been provided through the Commission's SI&E program and LWRRDC to develop tools to determine river health and to estimate environmental water requirements and determine environmental flows.

There has been considerable effort and resources focussed on understanding how the Basin's river system functions and to developing tools for assessing environmental condition and environmental water requirements. However, there are limited data available to quantify the impact of the Cap and there is no monitoring program designed to determine (either quantitatively or qualitatively) the environmental impact of the Cap. Statewide programs that could be used to determine the impact of the Cap are available. For example, Harris and Silveira (1999) provide a baseline Index of Biological Integrity (IBI) data against which to benchmark change in New South Wales rivers. The Integrated Monitoring of Environmental Flows (IMEF) program currently being developed for assessing the environmental benefits of water reforms in New South Wales will also be a valuable tool. In Queensland, ecological and geomorphological data collected for the WAMP's will be useful.

Other data and tools are available for assessing river-health in the Basin and could be used to assess the impact of the Cap. These are presented within a listing of ecosystem condition indicators likely to be influenced by alterations in the flow regime was recently developed by the CRC for Freshwater Ecology (Table 5.1). While a sub-set of these indicators would be a minimum requirement for assessing the impact of water diversions (and the impact of the Cap), there are limited data available for much of the Murray-Darling Basin. However, these indicators do provide a starting point for assessing river health.

Table 5. 1 Indicators of river health that may be used to assess the impact of the Cap. (adapted from Technical Review of Elements of the WAMP Process of the Queensland DNR. 2000. CRC for Freshwater Ecology. Canberra.)

Habitat variable	Description
Macroinvertebrates AUSRIVAS	The AUSRIVAS approach to sampling and analysis of macroinvertebrate communities provides a valuable index of river health. AUSRIVAS data are generally the most comprehensive data-set currently available on general river health The value of AUSRIVAS predictions relies on the quality and applicability of the reference sites and regional models. There are few valid reference sites in lowland rivers and so analysis will have to consider this limitation. The method has had little validation in lowland rivers, which are the main focus of the Cap.
AUSRIVAS habitat measures	As part of the NRHP and the FNARH various habitat measures were collected including assessments of: • riparian condition • bank stability • stock access to banks • depth of water over riffles Little use of these measures has been made in the past, but they do provide the basis for an index of habitat condition.
Index of Biotic Integrity (IBI), using fish communities	Metrics used in the fish-based Index of Biotic Integrity (IBI) include: • Number of native / alien species • Numbers of individual fish • Species richness • Trophic and habitat guilds • Condition of fish Fish stocking activity and the effect of barriers on fish passage may need to be considered. Difficulties with both AUSRIVAS and the IBI include the poor representation of reference condition and the spatial and temporal variability of faunal community structures.
River Cross-Sections	River cross section is sensitive to gross changes in the flow regime. Channel contraction has been identified as a significant effect of water abstraction.
Aquatic macrophytes	The presence / absence and the percentage cover of macrophytes can be strong indicators of flow regime, however more research is required to interpret macrophyte data.
Incidence of fish kills	Fish kills may be flow related and autopsy data plus flow records should indicate if this is the case. It may be difficult in some cases to know if fish kills are a response to environmental change or a density-dependent response to successful recruitment.

Fish Condition (lesions etc)	May be flow related, caused by crowding below barriers during migration, or sudden contraction of habitat through water diversion.
Water Quality • Turbidity • Dissolved oxygen • Temperature • Nutrients • Salinity	Turbidity is catchment specific and temporally variable with very high turbidities occurring naturally in most western rivers. Difficult to determine what are "good and bad" turbidity values. A reference-related predictive capability is required. Open water oxygen percent saturation may be a valuable indicator, however it is highly variable over short time scales (e.g day/night) Temperature data will indicate thermal pollution (such as chilling below a major impoundment or heating through loss of riparian vegetation) and the development of stratification, which is important for blue-green algal growth under low flow conditions.
Riparian vegetation	The extent and condition of riparian vegetation can be flow dependent. Structural changes in riparian vegetation and changes in vegetation condition do respond to the flow regime.
Landuse	Indices such as area of a particular land use upstream, human populations, road development, remnant native vegetation or percentage tree cover may explain some of the variation in river health. Landuse has also to account for quality of land management.

A number of programs have been undertaken across parts of the Murray-Darling Basin to determine environmental water requirements. Some data on ecological condition have been collected. However, without a long-term coordinated program to assess the impact of the Cap on the condition of the riverine environment it is unlikely that an environmental impact of the Cap can be unequivocally shown.

Rainfall and river flows are exceptionally variable in the Murray-Darling Basin. The complexity of measuring the ecological effects of maintaining current levels of diversions with the variability and the long time periods for change to occur makes it unlikely an impact could be quantified over a five year period. Especially since there are few pre-Cap data against which to assess change. The focus should be on conserving ecosystem function, and developing tools and techniques for assessing whether this has been achieved.

5.2.2 Why is the Cap set at its current level?

A clear message arising from the submissions to the review was that the *level* at which the Cap was set, rather than the *need* for a Cap, was not supported by rigorous science. The Cap was implemented in response to the Water Audit. The Audit showed diversions from the Basin's rivers were increasing significantly and would continue to rise unless water management arrangements were amended. The Audit concluded that current consumptive use of water was significantly impacting on the health of the Basin's rivers and increasing diversions would threaten the security of existing allocations.

The Water Audit (MDBMC 1995) listed a number of environmental impacts of consumptive water use on river health. The Water Audit argued that water diversions, by reducing flows, provided conditions that encourage the growth of blue-green algal blooms. These include the development of stratified 'stable' waters, which provide a suitable light climate for buoyant blue-green algae. The Water Audit argued that stratification increased anoxia in the bottom waters and sediments promoting the release of nutrients from the sediments. Also, less water in the rivers reduced the ability to flush blooms when they did form. The Water Audit recognised that reduced flows lead to increased salinity problems because as there is less water in the rivers and a constant or rising salt load, the salt concentration of the remaining water has to increase. The Water Audit recognised that floodplain health is dependent upon frequency of inundation. With fewer floods, the ecological functions performed by wetlands are compromised. For example, with less frequent flooding the Water Audit argues that there would be less nutrient captured and retained on the floodplain. As increased diversions reduce river flows, flooding is less frequent and the Water Audit details the considerable loss in areas of wetlands across the Basin attributable to lack of water. The Water Audit indicated that losses in wetland habitat have resulted in serious reductions in the numbers of the birds, fish, amphibians and insects that depended upon them. The changes in flow patterns in the Basin's rivers resulting from the collection, storage and distribution of water for consumptive use are detailed. The Water Audit indicated that reduced flows in the Basins rivers had decreased the frequency with which weirs drown out, further restricting the passage of fish. In summary, the Water Audit recognised that current and projected increases in diversions represented a clear danger to the riverine environment. It is important to remember that the environmental impacts documented by the Audit occurred prior to the introduction of the Cap and these problems were probably the result of water diversions below the *current*[9] level of abstraction allowed by the Cap.

In response to the issues raised by the Water Audit an interim Cap on diversions of water was introduced. This was confirmed as a permanent Cap in 1997. In 1995 the Cap was seen as an essential *first step* in establishing a management system to achieve healthy rivers. The level of the Cap reflected the levels of diversions at the time of the Water Audit – the climate-adjusted levels of diversion in the last full year of irrigation before its introduction. This is clear from its definition, "*The volume of water that would have been diverted under 1993/94 levels of development*…" The important point is that the Cap was introduced to stop further expansion of diversions. The Cap was not designed to represent a sustainable level of diversion.

> The Water Audit catalogued environmental impacts of water diversions, but importantly, did not attempt to determine a sustainable level of water abstraction required to rehabilitate the river. Therefore there is no *a priori* reason to expect that the Cap represents a sustainable level of water diversion or a level of diversion that will improve river health.

5.2.3 Diversions continue to increase

At best, the Cap would have restricted diversions from increasing beyond the climate-adjusted levels of 1993/94. This has clearly not happened. Diversions in the northern areas of the Basin have continued to increase and compliance in the mid-sections of the Basin is regularly questioned (eg. MDBC, 1999c,d). In the Southern section of the Basin, diversions in 1997/98, and again in 1998/99 for the River Murray have been constrained by the amount of water in storage, not the level at which the Cap was set[10].

[9] See section 5.2.5 for a discussion of time lags.
[10] See Section 6.6 for discussion about the suitability of the models used to determine the level of the Cap.

The Cap has constrained the growth in diversions in some of the Basin's river valleys, however in parts of the Basin the trend in diversions is still rising. Rising diversions, wherever they occur in the Basin, impact downstream.

While abstractions have continued to rise since the implementation of the Cap, it is not possible to determine whether at the Basin scale the Cap has been exceeded. There are two reasons for this. Computer simulation models required for determining Cap compliance throughout the Basin have not yet been developed. Currently only four of the 22 valleys (18%) have draft models submitted to the Commission. Also, the Cap level has yet to be determined for Australian Capital Territory and Queensland. Until the level of the Cap is determined for all jurisdictions and models are available to assess compliance it will not possible to determine if the Cap is exceeded.

5.2.4 Many factors influence river health

River and floodplain ecosystems are extremely complex, and we do not fully understand how they function. However, based on the best available scientific knowledge, models of river function for the Murray-Darling Basin are being developed. Our models will improve and adapt as more research is undertaken and completed. These models will allow the design of better ways to deliver water downstream – to protect or restore important ecological functions, as well as to provide downstream users with water.

The proportion of flows diverted is a major influence on river health across the Basin. Many factors affect river health and ultimately sustainability. Non-flow factors such as land use and management, introduction of alien species, and the loss of longitudinal and lateral connectivity resulting from the building of physical barriers such as weirs, dams and levees are critical. The way water is captured, stored and delivered also impacts on river health. These impacts on river health, and how water diversions affect them will be discussed.

5.2.4.1 Flow patterns

The flow regime is central to controlling the form and function of a river (Walker and Thoms 1993). The amount of water in a river is an essential component of the flow regime, but so too is the timing of flows. The salient feature of dryland rivers is flow variability (Walker et al 1995). Compared to many of the world's other major river systems, flow regimes of the large Murray-Darling Basin rivers are exceedingly variable. Two aspects of variability are important, the magnitude of the variations and the temporal pattern, or sequencing, of the variations (Young, 2000).

The magnitude of variations, the size of floods and droughts, is altered by the presence of dams. That was why storages were built in the first place – to reduce natural variability. This is clearly expressed by Blackmore (1989). "*In their unregulated state, the streams within the Murray-Darling Basin were unreliable, thus putting at risk any permanent development. They generally followed a yearly cycle of flows, which included winter and spring flooding, gradually receding until, between February and May, they were, in many years, reduced to trickles. …It was the need to overcome this massive variability and provide adequate flows in all years to sustain development that drove regulation of the rivers in the Basin*".

Water resource development has successfully reduced variability in streamflow. Currently, the storage capacity in the Basin is 36,000 GL – approximately three years of diversions from the Basin's river system. Storage capacity is more than 14 times the current median annual flow past the barrages in the Lower River Murray. However, large floods and drought-like flows are still a feature of the Murray-Darling Basin river system.

The temporal sequencing of flows has to be considered at a number of time scales, from daily to seasonal to interannual. The huge storage capacity existing in the Basin has led to a more stable water regime. There has been a massive reduction in the small to mid-sized floods below major storages in many of the Basins rivers. For example minor to medium floods (up to one in seven year exceedance level) entering the Coorong have been eliminated (Jensen *at al*, 1998). Releasing stored water for downstream use results in constant flows for sustained periods at times of the year that would naturally have lower and more variable flows. For example, rivers in the southern part of the Basin, such as the Murray, Goulburn, Campaspe and Murrumbidgee, naturally had high flows in winter and spring and low flows in summer and autumn. Releasing water for irrigation during summer months means that these rivers now have high flows during the naturally dry time of the year. Unseasonable high flows tend to flood wetlands at the wrong time of the year and do not allow natural wetting and drying cycles to occur. During summer and autumn high river flows in the south of the Basin severely reduce the chances of emergent aquatic plants establishing on the riverbed and banks. There are many ecological responses to reduced flow variability. These have been summarised by Young (2000) and presented in Table 5.2.

Flow regulation has generally led to a decrease in short-term flow variability, and has altered the seasonal flow patterns. In the south of the Basin, seasonal patterns are commonly reversed below the major dams, to supply irrigation water during the naturally low-flow summer period. In the north, summer rain dominates, and so regulation has enhanced rather than reversed the seasonal pattern. The impacts of reduced flow volumes on river health are difficult to isolate from those associated with changing the timing of flows and reducing the variability of the flow regime.

Table 5.2. The ecological responses to change in flow variability. (Reprinted from Young, W.J. (Ed) (2000) "Rivers as Ecological Systems – the Murray-Darling Basin”, in press.)

Flow hydraulics: • The variability of flow determines the variability of depth, velocity and shear stress. Decreases in flow variability lead to a reduction in the temporal variability of hydraulic conditions. Flow variability may change at the daily and, or seasonal scales. Changes in hydraulic patterns at both scales are important for instream habitat (see below). • The short-term flow variability associated with freshes and minor floods is important in determining the frequency of lateral connections with the riparian zone.
Sediment and nutrient transport: • The short-term flow variability associated with freshes (within channel high flows) and small floods is important in determining how often the river bed is disturbed. As well as influencing sediment transport, this flow variability determines the disturbance regime for bottom-dwelling (benthic) plants and animals. • The short-term flow variability of freshes and floods is also important in moving organic material from the riparian zone and backwaters into the main channel. • Bank slumping (see below) will lead to increases in the amount of sediment entering the channel, leading to local sedimentation and increases in turbidity. • Changes in the seasonal variability of flow will alter the seasonal pattern of material transport. These may alter important seasonal variations in habitat character. Clean gravels, for example, flushed of fine sediment, are required for the spawning of native fish such as Macquarie perch and Catfish. Changes to the seasonal patterns of flow may mean the required flushing does not occur. Changes in the seasonal pattern of nutrient availability may alter the seasonal patterns of instream production.
Channel forms:

• Reduction in the short-term variability of flows often leads to incision of channel banks. Over time, banks may erode sufficiently to cause bank slumping, thus further altering the cross section shape. • Generally, a reduction in short-term flow variability will reduce the complexity of the channel cross section, making it progressively more canal-like. This in turn will affect transport of material and nutrient processes, as the loss of river structures such as ‘benches’ and other zones of lower velocity, decreases the opportunity for material to be deposited and decomposed. • Channel benches are related to modal (the most frequent) flows. Where the modal flows change or flows become uniform, changes in cross-sectional shape will occur. Constant flows lead to simple rectangular cross-sectional (canal-like) channels. • Short-term flow variability provides a diversity of bedforms and substrate types on the river bed. Reductions in flow variability will alter these aspects of channel-bed character.
Riverine habitats: • Reductions in short-term flow variability lead to reductions in habitat diversity. Changes in flow hydraulics are particularly important over short periods of days to weeks. This temporal variability is an important characteristic of aquatic habitat. • The seasonal pattern of flows is an important feature of instream habitat. Changing the seasonal patterns of flow will alter the seasonal availability of habitats. As well as changing flow hydraulics, a change in seasonal pattern often changes the seasonal thermal regime of aquatic habitats. • Fish have differing hydraulic preferences for resting, feeding and spawning. The short-term and seasonal changes in flow determine the suitability of instream habitat for different fish species. During short periods of higher flow, for example, fish may seek refuge in backwaters or under banks. Changes in flow variability change the nature of the backwater habitats and change the strength of their connection with the main channel. • The soil moisture in the riparian zone depends on the water depth in the river. The habitat of deep-rooted riparian plants is characterised by the variability of flow depth. Changes in flow variability will alter the character of these habitats.
Riverine plants and animals: • The habitat changes associated with changes in flow variability will influence the plants and animals in the river system. Where flow variability is reduced, the reduction in habitat diversity is likely to lead to changes in both species composition as well as a reduction in species diversity. • Reduction in the frequency of depth changes is likely to alter the composition of riparian plant communities, while reduction in the frequency of bed disturbance is likely to lead to less diverse benthic fauna. • Changes in the seasonal pattern of flows may alter the levels of instream primary production. For example, irrigation release flows, may prevent suitable conditions for algal growth. Alterations to water temperature caused by changes to the seasonal flow pattern also cause changes in the levels of instream production. • Seasonal flow patterns provide cues for the reproductive behaviour of some animals higher up the food chain. For example, some species of native fish depend on freshes to trigger spawning. Seasonal flow patterns may also trigger non-spawning migratory behaviour in some fish species. In upland river sections, small freshes are often required to enable fish to pass natural barriers such as rock weirs. • Changes in the seasonal pattern of flows may alter the seasonal growth patterns of deep-rooted vegetation along the river bank. • Seasonal flow patterns also determine the breeding responses of some bottom-dwelling invertebrates, and hence are important for determining species composition. • Bank slumping leads to a reduction in littoral and riparian plants, but an increase in the recruitment of large woody debris to the river.

5.2.4.2 Connectivity

"Floodplain river ecosystems are among the plane'ts most valuable, and most abused, resources. In the unaltered state, they are dynamic in space and time, thereby constituting an environmental mosaic inhabited by lotic, lentic, semiaquatic, and terrrestrial species" (Ward 1995).

Rivers are characterised by longitudinal, lateral and vertical gradients of physical and chemical processes and biological communities (Petts 1996). There is an exchange of nutrients, matter and energy downstream (Vannote et al. 1980) and laterally between the river and the floodplain and between surface water and groundwater. These environments, upstream–downstream, in-channel and the floodplain are connected, sometimes intermittently, by water. The need to maintain this connectivity is an important feature of river management. Diverting water from the rivers reduces connectivity.

Ward and Stanford (1995) argue that resource managers should become 'conservators of ecological connectivity'.

Physical barriers, such as the construction of weirs and dams reduce longitudinal connectivity along a river as can water abstraction. Diversions increase the chance of a river ceasing to flow and forming a string of unconnected waterholes. Floodplains connect running waters with standing waters and terrestrial systems with aquatic systems. They are also areas where surface waters and ground waters are linked vertically (Ward, 1995). Water moving over the floodplain–floods, and the disturbance resulting from flooding provides the driving force to maintain the ecological connectivity and integrity of the floodplain ecosystem (Ward and Stanford 1995).

Reductions in connectivity reduce the ecological integrity of river systems. Building levees on the floodplain severs lateral connectivity. Connectivity is also reduced by major changes to the flow regime, such as reducing flood peaks, flood frequency and channel forming flows. Flow regime is influenced by both the amount of water diverted from the rivers and by how water is captured and delivered for downstream use. The Cap protects against further growth in diversions, but other contributors to lost connectivity also require management.

5.2.4.3 Water Quality

Together with the flow regime, land use determines the quantities of sediment and nutrients that move through the river system. Land management determines the amount of salt and nutrient in the soil, the susceptibility of this soil to erosion, and the likelihood of this soil reaching the river system. This in turn is an important determinant of in-stream water quality. Water quality has significant impacts on river health. The impacts of salinity and blue-green algae are discussed in Section 5.1.

Separating the effects on river health of the amount and delivery of water in the river from the effects of water quality is difficult because water quality is dependent on flow regime.

Releasing water from the base of large dams can significantly reduce the temperature of water downstream. This is a common problem with the large, bottom release dams throughout the Basin (Table 5.3).

Table 5. 3. Estimated length of rivers potentially affected by thermal pollution in inland New South Wales. From Blanch 1999.

River	Impoundment	Length potentially affected (km)
Murray	Hume Dam	300
Swampy Plains R and Murray River from Swampy Plain to Hume Dam	Khancoban and upstream Snowy Scheme impoundments	120
Tumut	Blowering Dam	60
Murrumbidgee	Burrinjuck Dam	400
Lachlan	Wyangala Dam	400
Belubula	Carcoar Dam	50
Macquarie	Burrendong Dam	400
Namoi	Keepit Dam	300
Peel	Chaffey Dam	90
Gwydir	Copeton Dam	300
Dumaresq	Glenlyon Dam (in Qld)	250

Cold water releases can have negative impacts on the fish, amphibians, aquatic insects and plants that live below them. In particular, as they are all cold-blooded organisms, cold water slows their growth and development and reduces their chances of successful reproduction. Unless water temperature in these sections of river is increased, sustainable populations of many native organisms will not re-establish.

5.2.4.4 Pest Species

The introduction of alien species, such as carp, has had a major effect on river health. Carp numbers have been correlated with the degree of river regulation. The NSW Rivers Survey (1997) found that carp were most abundant in rivers modified by the effects of dams and agriculture. The effects of alien species are extremely difficult to disentangle from the effects of poor river and catchment management. For example, carp feeding habits have been shown to prevent macrophyte regeneration and to cause water quality problems. This view is expressed by the Lachlan Shire Council, *"Yes, water quality has deteriorated, river health has deteriorated but only since the invasion of the carp. Yet the ratbag fringe who have infiltrated NCC and other "quangos" have been able to convince all and sundry that over use of water by greedy irrigators is the root of the problem."*

While carp do exacerbate long-standing river-health problems such as loss of water plants, blue-green algal blooms, bank erosion and poor water quality, they are only adding to and accelerating the effects of long-standing impacts associated with agriculture and water-resource development.

Constant river heights in weir pools, releases from dams and weirs, excessive pumping that accelerates bank instability, trampling of banks by cattle, clearing of riverside vegetation and catchment erosion all contribute to the problem. It is rarely possible to separate the ecological impacts of alien species from the impacts of catchment management and alterations in flow pattern and volume.

5.2.4.5 Conclusion

These examples demonstrate that river health is dependent upon many factors. However, the amount of water in the river system is a critical determinant of river health. Water quality, the influence of alien species, the lack of flow variability and longitudinal and lateral connectivity all influence river health and are dependent upon the amount of water diverted from the

Murray-Darling Basin river system. The impacts of these factors on river health are also modified, at least in part, by how the land and the remaining water in the Basin are managed. Determining a suitable level for the Cap depends upon how well the catchment and non-volume aspects of river regulation are managed. For example, if riparian and floodplain vegetation is being decimated by intensive cattle grazing, restoring flow volumes to 'natural' will not restore the floodplain and riparian vegetation. Similarly, reintroducing flows sufficient to re-instate small to medium sized floods will not increase river–floodplain connectivity if the floodplain is separated from the river by levee banks.

5.2.5 Time lags

Significant time lags occur between a change in the flow regime and when an environmental impact can first be detected. There are even longer time lags between a flow change and the development of a new equilibrium. These time lags represent a major difficulty in determining a sustainable level of diversions.

The time-scales for some ecological changes in riparian ecosystems resulting from flow reductions are likely to be in the order of centuries (Church 1995). For example, Young (2000[11]) indcates that Black Box (*Eucalyptus largiflorens*) requires a flood frequency of one in three to one in five years with a duration of two to four months to maintain populations. However, Black Box are quite drought hardy, and have survived on the Chowilla floodplain with considerably reduced flood frequency. Regeneration, however, occurs only after floods when seedlings can take advantage of the moist ground. The impacts of reduced flooding on long-lived species, such as Black Box, may not be apparent for hundreds of years. Time-scales of other riparian responses may be much shorter, with lags of seasons, years or decades before changes become evident.

The time-scales for morphological adjustments in river sectional geometry can be of the order of decades to centuries when flows are reduced (Church 1995). There have been significant changes in the channel profile of the lower reaches of the Murray River as a result of weir building and lower flows. These changes are still incomplete 60–70 years after weir construction and significant increases in diversion (Thoms and Walker 1993). Young (2000) summarises the expected time-scale for various changes to occur to a river in response changes in flow and sediment regime for upland and lowland river sections in the Murray-Darling Basin. This is reproduced in Table 5.4.

Table 5.4. Time scales of river channel change for upland and lowland river sections in response to natural or human-induced changes in flow or sediment regime. (Table 3.4 reprinted from Young, 2000).

Upland River Sections				**Lowland River Sections**			
	Years	*Decades*	*Centuries*		*Years*	*Decades*	*Centuries*
Wider	X			Wider		X	
Narrower			X	Narrower			X
Deeper	X			Deeper		X	
Shallower	X			Shallower	X		
Straighter		X		Straighter			X
More sinuous		X		More sinuous			X
Steeper		X		Steeper			X
Flatter		X		Flatter			X

[11] Example adapted from Young (2000) pg 139

Walker and Thoms (1993) argue the large temporal variability in the Lower Murray ecosystem suggests that we must view the river over a longer time frame than is necessary for rivers in regions with more stable climate. From an ecological perspective, time-scales of the order of a few hundred years are appropriate for the lower Murray ecosystem. Walker et al (1995) elegantly encapsulate the difficulties of managing low land rivers "*A big-river ecosystem is therefore 'a moving target', and we need to consider its trajectory more than its status at merely a few points in space and time*."

Recognising the long time-scales over which biological and physical changes occur re-enforces the need for a precautionary approach to be taken. Just as it may take decades or longer to see the full ecological impacts of water diversions, so too it is likely to take decades to see the full ecological impacts of improving flow regimes. This provides a suitable timeframe over which to assess the impacts of the Cap.

The ecological damage evident to the Water Audit in 1995 was the result of exploitation from a number of years before, when diversions were lower. It is essential to recognise that the effects of today's diversion levels may not be fully appreciated for decades to come.

5.3 Are current levels of diversions sustainable?

It is clear that to achieve sustainability for the Basin the level of the Cap will depend upon how well the river is managed. The more skilful river management is, the less impact abstractions will have.

Notwithstanding the difficulties of separating out the effects of reduced volumes from other hydrological and land management effects, and the problems of time lags there are a number of indicators that show clearly that with current management practises, current levels of abstractions are not sustainable.

5.3.1 Global perspective

Some 40% of the world's food comes from irrigated agriculture, however globally the productivity of irrigation is threatened by increasing diversions, over-pumping of groundwater and salination of the soil. For example, it is estimated that one in five hectares of irrigated land across the globe is damaged by salt (Postel 1999) The volume of water being diverted from many of the world's big rivers and their wetlands has resulted in serious ecological damage. The total area of wetlands in the world has been halved (Meyers 1997 cited in Cosgrove and Rijsberman 1999). China's Yellow River first ran dry in 1972. Since 1985, it has run dry for part of each year. In 1997, it failed to reach the sea during 226 days. Similarly, much of India's Ganges River is diverted before it reaches the Bay of Bengal. This seriously threatens the unique ecosystem of the Sunderband Wetlands in Bangladesh as the reduced flows have allowed a rapid advance of the saline front across the western portion of the delta. Flows in the Colorado River in south western United States rarely make it to the sea, which has decimated the Gulf of California's fishery. The World Commission on Water for the 21st Century cites the Nile River as having serious problems, as only 10% of its original flow reaches the sea. Consequently the Nile delta is rapidly shrinking. Under natural conditions subsidence in the Nile delta was compensated for by the continual re-supply of sediment from the Nile River. With the completion of the High Dam at Aswan most sediment now does not reach the delta, consequently it is subsiding and shrinking – the town of Borg-el-Borellos is now two kilometers out to sea (Postel, 1999). The character of the Indus delta that borders India and Pakistan is significantly changing as a result of flows to the sea have being reduced to 20% of the annual average flow. This has reduced the delta's extensive mangrove forests by nearly 250,000 hectares and a major prawn fishery the forests support is threatened (Pirot and Meynell 1988). The plight of the Aral Sea is one of the world's graphic environmental disasters. Increases in diversions from the Amu Darya and Syr Darya rivers to support irrigated cotton production between 1960 and 1980 reduced average flows to the Aral Sea to 13%, from 55,000 GL to 7,000 GL. This has resulted in dramatic reductions in biodiversity on the floodplains and deltas of the Amu Darya and Syr Darya rivers as 30,000 ha of wetland are now dry, and has resulted in a lowering of the Aral Sea by 17 metres (UNESCO, 2000). Other problems include the loss of large areas of deltas for agriculture through insufficient freshwater and salination of soils. There are also increased difficulties in providing good quality drinking water as salt concentrations rise. Long-term restoration of the Aral Sea's ecosystem would require that water withdrawals for irrigation be reduced to a fifth of the current level (FAO,1996). Complete restoration is now considered impossible. The goal of the Governments of Uzbekistan, Turkmenistan and Kazakhstan is not the restoration of the Aral Sea, *"..as that would mean curtailing irrigation which is socially and politically unimaginable*" but rather to stabilise the environment of the Aral Sea Basin, to rehabilitate the disaster zone around the sea and to improve the management of the international waters of Aral Sea Basin (UNESCO, 2000).

Around the world there is mounting evidence that high levels of diversions have major influences on rivers, the wetlands they support, and on the receiving waters – such as estuaries and oceans. The examples above are regularly cited as high profile, international examples of over abstraction and declining water quality. The sobering reality is that the proportion of abstraction from the Murray-Darling Basin prior to being capped was approaching the proportion of abstraction in these systems.

5.3.2 The Coorong

Under natural conditions, approximately one half the runoff that entered the Murray-Darling Basin river system flowed to the Coorong estuary. At the Cap level of diversions, the median annual flow at the barrages at the lower end of the River Murray is 2,540 GL/year. Therefore, in half of the years, 21% or less of the natural flow of the River Murray reach the Coorong estuary. Coupled with this reduction in median flows, the frequency of extended no-flow periods has increased from one in twenty years to one in two and minor to medium floods (up to one in seven year return frequency) have been eliminated (Jensen *et al.* 1998). The barrages, which separate the saline Coorong estuary from the fresh waters of the Murray, have reduced the estuary to 11% of its original area.

Reduced freshwater inflows are identified as the major ecological threat to the remaining Coorong estuary. River flow affects the physical and chemical properties of estuaries–the geomorpholgy, salinity, turbidity and nutrient levels such as nitrogen, phosphorus and carbon. These in turn influence the distribution and numbers of commercially important fish and crustaceans, as well as many other organisms. A reduction in freshwater flows below a certain system-specific level can completely alter the estuarine food web, turning it from highly productive system to one with a substantially reduced productivity (Livingston RJ *et al* 1997). Loneragan and Bunn (1999) provide a strong correlation between river discharge and production of coastal and marine fisheries in southern Queensland. They also show that the seasonal pattern of flow is equally important as the magnitude of flow. They conclude that river regulation is likely to have a dramatic effect on the production of coastal fisheries. In the Coorong commercial catches of Black Bream, Green Flounder and Mulloway have declined dramatically since significant river regulation. Pre-regulation catches of Mulloway were in the vicinity of 400-600 tonnes per annum, now they are between 40 and 80 tonnes per annum. Similarly, Black Bream catches have declined from a pre-regulation level of 100 tonnes per annum to less than 10 tonnes per annum.

Controlling diversions from the Murray-Darling Basin is seen as a key issue for the sustainability of the Coorong and Lakes Albert and Alexanderina. For example, closure of the Murray mouth is related to the reduced median flows in the River Murray. Lower flows will mean the mouth is more frequently blocked.

The management aim recommended by Jensen et al. (1998) for the Lower Lakes, the remnant Coorong Estuary, the mouth channel and the off-shore zone is to *increase* the flows from the barrages (Jensen at al 1998). This will require a Basin-wide review of water allocation to decrease the current level of diversions. However, the current Cap is a fundamental tool for ensuring that flows reaching the lower Murray are not reduced further.

5.3.3 Terminal Wetlands

Nearly all of the Basin's major rivers have a large terminal wetland complex in the open floodplain section (Young 2000). These terminal wetlands include the RAMSAR listed Macquarie Marshes, Lake Albacutya, Lower Gwydir Wetlands and the Narran Lakes and other major wetlands of significance including the Great Cumbung Swamp and the Paroo Overflow. Terminal wetlands occur where flows spread out over the floodplain producing large shallow areas of inundation. Under low and medium flow conditions most of this water either evaporates or seeps into the soil. Very little flows out of the wetland. Outflows are only significant during large floods. The international significance of the Basin's terminal wetlands are recognised by their listing as Wetlands of International Importance.

Outflows from terminal wetlands are generally low to zero in all but the wettest years. Low outflows have been used in the past to argue that rivers flowing into terminal wetlands should be considered outside of the Cap. For example, the Lachlan Shire Council states, "*The former Director General of "Water", Peter Millington publicly stated the Murray Darling Cap "should not apply to the Lachlan River because for all practical purposes it does not have any effect on the health of the Murray Darling system, positive or negative*". Similarly, the Twynam Group argues, *"The Lachlan River should be excluded from the MDB Cap as it does not contribute flows to it, emptying into the Great Cumbung Swamp which only connects with the Murrumbidgee in the largest of floods"*. However, this is not widely held view across the Basin with most submissions recognising that these rivers are an integral part of the Basin's river system and need to be managed accordingly. For example, Lachlan Valley Water recognises the Cap, but questions the appropriateness of its level.

Terminal wetlands are of considerable ecological significance to the Murray-Darling Basin and are seriously threatened by water diversions. Connectivity between rivers like the Paroo, the Lachlan and the Macquarie with the rest of the Basin is critical for maintaining their genetic diversity. As genetic diversity declines the resilience of the ecosystem in these rivers also declines, reducing the ecosystem's ability to adapt to long-term flow change (which ironically includes river regulation) or recover from short-term disturbance, such as drought.

Migration of fish and other aquatic animals requires floodwaters to connect between upstream and downstream of the terminal wetlands. During floods, discharge from the terminal wetlands provides significant water downstream. This water carries with it energy to fuel downstream foodwebs, in the form of organic carbon (See Section 9 – Condamine-Balonne Case Study). The large terminal wetlands of the Basin support massive colonies of migratory birds. There also clear groundwater connections between the upstream rivers and the rest of the Basin.

Across New South Wales, an estimated 50% of wetlands have been lost since river regulation commenced (NSW State of the Environment Report, 1997). The decline in area of wetland has been more dramatic in some regions of the Basin. Examples are presented in Table 5.5

(reprinted from "Floodplain and Wetlands Management Strategy for the Murray Darling Basin" MDBMC 1998). In most cases, reduced flow is the primary reason for reductions in their area. The impacts of changing water regime has been identified as the highest priority issue for the National Wetlands R&D Program. Changes in flow regimes have been listed as seriously threatening the conservation of each of the following Murray-Darling Basin RAMSAR Sites:

- Riverland
- Macquarie Marshes
- The Coorong, Lakes Alexanderina and Albert
- Lake Albacutya
- Barmah Forest
- Kerang Wetlands
- Gunbower Forest
- Hattah -Kulkyne Lakes
- Lower Gwydir Wetlands
- Narran Lakes

These sites, having been nominated as Wetlands of International Importance or RAMSAR Sites, have special ecological character, and often have unique qualities. Australia has an international obligation under the Convention to ensure the special ecological values of these sites are maintained or improved.

Table 5.5 Reductions in areas of wetlands across the Basin. These reductions are primarily the result reduced flows to them. Table from MDBMC 1998.

State	***River***	***Floodplain Wetland Type***	***Original Area of Wetland***	***Current area of wetland***	***% reduction in wetland type***	***Source of Information***
Victoria	State-wide	Shallow Freshwater marsh	33 531 hectares	9814 hectares	71 %	Norman and Corrick 1988
Victoria	State-wide	Shallow Freshwater marsh	2131 individual wetlands	988 individual wetlands	54%	Norman and Corrick 1988
Victoria	State-wide	Deep freshwater marsh	109 315 hectares	30 226 hectares	72%	Norman and Corrick 1988
New South Wales	Gwydir River–Gingham Watercourse	Couch meadow wetland	13500 hectares	1000 hectares	92%	McCosker and Duggin 1993
New South Wales	Macquarie River	Intermittently flooded floodplains including 40000 hectares of perennial marsh	190000 hectares uncleared	95000 hectares uncleared	50%	
New South Wales	Gwydir River	Water couch wetland	7500 hectares	5000 hectares	33%	Kyte 1994
New South Wales	Murrumbidgee River –between Wagga Wagga and Hay Weir	Open water ephemeral wetlands	100% of wetlands intermittently flooded	69% of wetlands intermittently flooded	31%	Thornton and Briggs 1994
New South Wales	Murrumbidgee River –between Wagga Wagga and Hay Weir	Red gum wetland	Healthy river red gums	570 hectares killed by permanent inundation	Unknown	Thornton and Briggs 1994
New South Wales	Lachlan River and Murrumbidgee River Confluence–lowbidgee Wetlands	Red gum, black box and lignum vegetation	110000 hectares	90 000hectares	18%	DWR 1994
New South Wales, Victoria, South Australia	River Murray–between Hume Dam and Wellington (SA)	Intermittently flooded wetlands	105715 hectares	68715 hectares (37000 hectares are now permanently inundated)	35%	Pressey 1986

Victoria	River Murray–Barmah Forest	Moira grass wetland	45,000 hectares	1,500 hectares	55%	Chesterfield et al 1986 Ward et al 1992
Queensland	Condamine-Balonne River, Warrego River, Culgoa River, Border Rivers	Intermittently flooded wetlands	Undeveloped, unregulated river systems	Regulated river systems–flow diversions–increased on-farm water storages	Unknown	Wettin et al 1994.

5.3.3.1 Macquarie Marshes

As a result of water diversions and flow management practices since the construction of the Burrendong Dam in 1967 the RAMSAR-listed Macquarie Marshes have reduced in area by 40 to 50% (Kingsford and Thomas 1995). Numbers of breeding colonial waterbirds (ibis, herons, egrets and spoonbills) have also declined. However, the Marshes still represent good examples of inland reedswamps and floodplain wetland. The Macquarie wetlands provide drought refuge when wetland areas in other parts of the Basin are dry.

The management response for the Macquarie Marshes has been the introduction of an environmental water allocation for the Marshes. Up to 125,000 ML per annum from Burrendong Dam, called a wildlife allocation is now allocated to the Macquarie. In the flow range 500-4,500 ML/d, the wildlife allocation is released *transparently* to match inflows as closely as possible. Also, all tributary flows and unused storage is directed to the Macquarie Marshes during a waterbird breeding event (Blanch 1999).

5.3.3.2 Gwydir River Wetlands

The Lower Gwydir Wetlands are significant because their flooding is not always synchronous with flooding in other nearby wetlands such as the Macquarie Marshes and therefore the wetlands are likely to provide an important drought refuge for the basins waterbird populations. The Gwydir River wetlands have decreased in area by 75% over the last 20 years (NSW SoE, 1997) with plant communities requiring frequent flooding reduced to less than 5% of their original extent (QDNR, 1999). This has resulted from diversions, used primarily for cotton irrigation, reducing flows to the core areas of the Gwydir River wetlands by 70% (QDNR, 1999). Keyte (cited in QDNR, 1999) argues that the Gwydir Wetlands are undergoing a transition from intermittent wetlands to terrestrial ecosystems as a result of the current water regime. There are documented declines in the 'health' of macroinvertebrate communities, fish and waterbird populations (QDNR, 1999).

In response to the degradation of the wetlands, there is now an annual allocation of 25,000 ML from Copeton Dam. However, it is estimated that 75,000 ML is required to adequately flood the Gwydir Rivers terminal wetlands. The annual allocation from Copeton Dam has been used in the each of the last four years to extend flooding in the Gingham wetlands to ensure successful bird breeding in the wetlands. There is also a 50:50 sharing of off-allocation water between consumptive users and the wetlands (when flows at Yarraman >1, 000 ML/d). A minimum flow of 500 ML day^{-1} is allocated the Gingham and Lower Gwydir wetlands (Blanch 1999).

5.3.3.3 Narran Lakes

The RAMSAR-listed Narran Lakes are terminal wetlands on the Narran River at the lower end of the Condamine-Balonne River system. They remain in relatively natural condition, though this is threatened by water resource development and provide drought refuge for many birds. The Lakes are in New South Wales, however most of the upstream catchment is in Queensland. Flooding in the lakes must persist for a minimum of four months for successful ibis breeding to occur. Modelling undertaken for the Condamine-Balonne Water Allocation Management Plan (QDNR, 1999) clearly indicates that bird populations do not commence breeding until the lakes fill to 95% capacity. Field observations indicate that young birds resulting from this nesting are abandoned and die if water levels drop below 86% storage capacity. Diversions upstream have reduced filling events in the Narran Lakes above 85% by approximately half. Consequently, bird breeding events are only initiated half as often as they would have occurred under natural conditions. The Narran Lakes System has been assessed by the Condamine-Balonne Technical Advisory Panel to be in a fair to poor ecological condition (QDNR, 1999). Disappointingly, diversions in the Condamine-Balonne continue to grow (MDBC, 1999d). A Cap on diversions, at the current levels of diversions, will be the first step in sustaining the Narran Lakes, as an internationally recognised RAMSAR site.

The area of wetland in the Basin has greatly declined as a result of diversions, principally for irrigated agriculture. Most of the documented decline in wetland area occurred at levels of abstraction lower than the level permitted under the current level of the Cap. The Cap is a critical first step in protecting what remains of the Basin's terminal wetlands. However, it has become obvious that for many terminal wetlands the protection offered by the *current* level of the Cap is insufficient, and more water will have to be returned to them. There is a danger that by focussing environmental allocations primarily upon large wetlands those important ecological processes that are sustained by the cumulative expanse of smaller wetlands will be lost. Similarly, important in-stream ecological processes may be lost.

5.3.4 Stressed Rivers

The COAG Water Resources Policy requires that the States identify over-allocated and stressed rivers, and that they be given priority in implementing a better balance between consumptive use of water and the environment[12].

The New South Wales government undertook a stressed river classification for the States unregulated rivers (DLWC, 1998). The Stressed Rivers Assessment procedure involved determining hydrological and environmental stress separately. An index of hydrological stress was derived by proportioning water extraction to the 80th percentile flow (50th percentile in some ephemeral streams). Environmental stress was determined using any simple biological, chemical and geomorphological indicators of stream health that were available. The results of the Stressed Rivers Assessment for New South Wales streams in the Murray-Darling Basin indicate that under existing conditions 85% of unregulated streams exhibit at least a medium environmental stress with 49.6% of streams exhibiting a high degree of environmental stress. Environmental stress reflects problems caused by water abstraction, land management and pollution. Water extraction was a major contributor to the environmental stress, with 32% of all unregulated streams exhibiting a high level of hydrological stress (greater than 70% of 80th percentile flow extracted) and a further 24% had a moderate level of hydrological stress (between 40 and 60% of 80th percentile flow extracted) (DLWC 1998). The high proportion of streams hydrologically and environmentally stressed is a result of past and current levels of diversions. This is a level of diversions permitted under the *current* level of the Cap. Hydrological stress on New South Wales unregulated rivers is currently being addressed by River Management Committees across the state. A function of these committees is to recommend rules that will result in a flow regime that meets identified river health and water quality objectives. These flow rules can affect both the timing and volume of diversions.

To achieve the desired environmental objectives for many of Basin's New South Wales unregulated rivers the River Management Committees will have to reduce the current levels of diversions.

Existing licences for diversions are considerably higher than current diversions in many New South Wales unregulated streams. The hydrological classification was also calculated assuming full water licence development. For example, it is estimated that in the Billabong Creek – which is considered hydrologically stressed (DLWC, 1999), only 30% of licences are currently used. Activation of the remaining 70% would see a great increase in hydrological

[12] COAG Water Resources Policy. Part 4(d) …..In cases where river systems have been over allocated, or are deemed stressed, arrangements will be instituted and substantial progress made by 1998 to provide better balance in water resource use including appropriate allocations to the environment in order to enhance/restore the health of river systems.

stress (in most years there would not be enough flow to supply this level of abstraction). Under full licence development, the proportion of streams having a high level of hydrological stress increases from 32.5% to 52 % and the number of low hydrological stress streams reduces from 43.7% to 25.8%.

The Cap is a key protective measure for unregulated streams.

The assessment of stress for Queenslands rivers is currently being undertaken as part of the Water Allocation Management Plan (WAMP) and the Water Management Plan (WMP) process. In general, the basin's rivers in Queensland have lower diversions than in the southern parts of the Basin. Also, the problems of seasonal inversion of flows do not occur to the same extent as the peak period for water use coincides with peak water use in these summer rainfall rivers. However, the Technical Advisory Panel Reports to the Condamine-Balonne WAMP and the Border Rivers WAMP[13] have identified major changes to the flow regimes in both river systems resulting from irrigation diversions.

In the Border Rivers major increases in diversions have occurred since the capacity of Pindari Dam was increased from 37 GL to 312 GL in the early 1990's. Ecological data collected between 1996 and 1999 indicates that the Border Rivers are currently in relatively good ecological condition. However, increases in diversions have occurred very recently, and during a four-year period of above average flows in this river valley. As discussed in Section 3.2.5 it is still much too early to assess the ecological outcomes of these diversions.

The Condamine-Balonne river valley has undergone considerable water resource development in the last ten years, significantly altering the hydrology of the river system. The flow regime of the Upper and Lower Condamine and the Upper Balonne has been assessed as fair to good, while the Lower Balonne has a generally poor flow regime – the result of diversions directly from the channel and from floodplain harvesting. Changes in the flow regime have resulted in the ecosystem of the Lower Balonne to be assessed as poor. River health indices using macroinvertebrates (AUSRIVAS) and fish community condition scores were used for this assessment.

The Cap is currently being determined for the Basin's river system in Queensland – based on the outcomes of the WMP and WAMP process. What is clear, is that the *current* levels of diversions in Queensland have impacted on the flow regime, and the effects of these diversions on river health are now becoming evident. It will take decades or longer for the full impact of these diversions to occur (see section 3.2.5).

5.3.5 New South Wales Rivers Survey

All regulated rivers in New South Wales have been identified as stressed (DLWC, 1998). This was supported by the New South Wales Rivers Survey (1997). The survey undertaken over two years sampled 80 sites four times across New South Wales. The survey concluded that rivers sustain a large proportion of New South Wales total biodiversity, however biodiversity in the State's degraded riverine ecosystems was rapidly being lost. Evidence is especially clear in the Murray region (which includes the Lachlan and Murrumbidgee systems), particularly in rivers regulated for water supply. An Index of Biotic Integrity was developed to measure the health of rivers at large scales using fish-community attributes (Harris and Silveira, 1999). This index has shown that the Murray region's rivers are in a degraded condition compared to other regions and river types. The primary recommendation from the Rivers Survey *"…is to accept that our riverine heritage in New South Wales is in a*

[13] Border Rivers WAMP being undertaken jointly between New South Wales and Queensland Governments.

generally degraded condition and in urgent need of restoration. River biota is reflecting problems of river habitats: aquatic biodiversity is rapidly being lost; productivity of natural resources is seriously declining, especially recreational and commercial fisheries; and the values and supply of the basic resource, fresh water, have been damaged. Restoration of river-ecosystem components is needed, especially flow regimes, thermal regimes and river catchments, particularly in the riparian zones. There is an urgent need to control carp and to restore fish passage at barriers such as dams and weirs.'

Gehrke et al. (1995) have shown fish species diversity (as indicated by Shannon's *H'*) to be inversely proportional to the amount of river regulation (as estimated by Annual Proportion of Flow Deviation) in the Murray-Darling Basin. Diversity was highest in the Paroo followed by the Darling, Murrumbidgee and then the Murray.

5.3.6 Expert Panels

The Expert Panel Assessment was developed to be a widely applicable and inexpensive method for determining environmental water requirements of a river (Swales and Harris 1995 - cited in Arthington 1998). The assessment involves assembling a group of scientists with expert knowledge of the system to make an interdisciplinary 'best judgement' of the flow needs of a river. The Scientific Panel Assessment Method is a more sophisticated development of this approach. The difference being that "…*key ecosystem and hydrological features and their interactions are used for the basis for assessment, rather than visual assessment and interpretation of a trial flow change*.." (Arthington 1998). Scientific panel assessment reports have been undertaken for the Barwon-Darling River (Thoms et al 1996), the River Murray - Dartmouth to Wellington and the Lower Darling River (MDBC 1998b) and the River Murray Barrages (Jensen et al 1998). The major aim of these studies was to identify key environmental flow requirements of these rivers and identify flow changes to improve their environmental condition.

5.3.6.1 River Murray

The River Murray Scientific Panel found that water resource development has imposed a stable water regime in the Murray River – currently there is less variability over daily, seasonal and inter-annual scales than under natural conditions. Significantly, this loss of variability and other water resource development has resulted in long term, detrimental ecological changes in the River Murray. Flow management activities that threaten ecosystem health include: constant flow for sustained periods, unseasonal flow patterns, increased minimum flow, decreased frequency of flooding periods, reduced duration of individual floods, rapid rates of rise or fall and the development of weir pools.

The report made a number of recommendations to improve the flow regime, some of which will require a reduction in water available for diversions. Changes in flow regime likely to result in a reduction in water available for diversions include:

- reinstating a flooding frequency of no less than 50% of what it was under natural conditions with a duration of flooding as close as possible to natural;
- introducing greater flow variability into the River Murray by allowing a passing flow through major storages during June to September, as they fill; and
- not allowing base flows to drop below 8000 ML per day through weir pools on the Lower Murray for periods of greater than two weeks between November and April.

To be able to undertake the Scientific Panel's recommendations for the River Murray it is likely that current diversions will have to decrease. Until appropriate scenarios are modelled the amount of water required to fulfil these recommendations is unknown. However, the Scientific panel recommendations indicate that the level of the Cap does not provide sufficient water for the environment's share.

5.3.6.2 Barwon-Darling River

The Scientific Assessment of Environmental Flows for the Barwon-Darling River (1996) found that abstractions have had a significant impact on flows in the Barwon-Darling River. Under the 1994/95 levels of development, diversions above Menindee were equivalent to approximately 60% of the natural average flow at Menindee. These diversions for irrigation have changed the size, duration and frequency of flows. About 8% of the diversions upstream of Menindee occur in the Barwon-Darling system (Table 5.6).

Table 5.6 Diversions upstream of Menindee in 1997/98. (MDBC, 1999d).

	System	***Diversion (GL)***
Queensland	Condamine-Balonne	545
	Border Rivers	177
	Macintyre Brook	9
	Moonie	8
	Warrego	2
	Paroo	0
New South Wales	Border Rivers	206
	Gwydir	535
	Namoi/Peel	260
	Macquarie/Castlereagh/Bogan	435
Total Upstream of Barwon-Darling		2177
	Barwon-Darling	186

The majority of diversions occur in the headwaters upstream of the Barwon-Darling system (see Table 3.6), reinforcing the principle that diversions have to be managed at the river basin scale. Management of diversions from one system always impacts downstream. This is clearly recognised by Darling River Food and Fibre (DRFF) "*It becomes clear that the Darling River inherits many of its problems from upstream [of the Barwon-Darling river valley]. This must be realised and accepted when we seek solutions*" (DRFF, 1998). Just as diversions upstream of the Barwon-Darling Valley impact the Darling River, diversions within the Barwon-Darling valley impact downstream in the River Murray.

River regulation upstream of Menindee has led to habitat degradation in the Barwon-Darling system. In-channel habitat availability and accessibility of important food sources have also declined throughout the Barwon-Darling because of changes in the flow regime. The Scientific Assessment Panel proposed the following management principle for the valley, *"It must be recognised that the Barwon-Darling riverine ecosystem is in a state of deterioration and changes in water management are required if its condition is to be improved.*"

The Barwon-Darling Scientific Panel recommended a number of changes to flow management of the Barwon-Darling and its tributaries. These included an immediate moratorium on additional diversions or the transfer of licences upstream. It was recommended that diversion of water for irrigation cease during low flow periods – when flows fall below the 80th percentile. DRFF supports the recommendation to protect low flows of less than 1000ML/day from diversion (DRFF, 1999).

Implementation of the Cap at 1993/94 levels of development would satisfy the recommendation for an immediate moratorium on additional diversions. However, many of the upstream tributaries to the Barwon-Darling are yet to have a Cap implemented and large scale increases in diversions continue in some of these valleys (MDBC, 1999d). At present, the Cap does not protect the Barwon-Darling riverine ecosystem from growth in abstractions.

5.3.7 The Paroo – An unregulated river

Currently there are no significant water diversions from the Paroo River in Western Queensland, however this may change as a Cap has not yet been determined for this river valley (MDBC, 1999d). The Paroo River and its wetlands contain exceptional genetic, species and ecosystem diversity and it makes an irreplaceable contribution to the biodiversity and environmental values of the Murray-Darling Basin (Watts, 1999). The development of irrigated agriculture is recognised as the single greatest threat to this ecosystem (Kingsford, 1999). The potential impacts of water extraction and associated activities on three levels of biodiversity in the Paroo River are described in Table 5.7 (reprinted from Watts, 1999).

The Cap plays a critical role in protecting the few remaining unregulated river systems in the Basin.

Table 5.7 Potential impacts of water extraction and associated activities on three levels of biodiversity in the Paroo River (reprinted from Watts, 1999).

Level of diversity	Potential Impacts of Water Abstraction
Genetic	Changed flows may fragment populations into smaller breeding groups, resulting in inbreeding and loss of genetic diversity. Presence of pesticides or insecticides may reduce the viability of local populations, resulting in fragmentation and subsequent loss of genetic diversity.
Species	Fragmentation of populations, loss of water quality or reduced floods may remove cues that stimulate breeding, thus preventing breeding from occurring and ultimately resulting in local loss of species. Fragmentation of populations, loss of water quality or reduced floods may prevent the successful completion of breeding, ultimately resulting in local loss of species. Seed banks may become inviable if the length of time between floods is increased, resulting in loss of plant species. Competition through increased numbers of alien species may result in loss of native species. Presence of pesticides or insecticides may prevent successful breeding from occurring, resulting in loss of species.

Ecosystem	Changed flood regime will result in loss of habitat diversity. Loss of species diversity will result in loss of diversity of aquatic communities. Changed flow regimes and community structure will result in changed ecological processes and loss of ecosystem diversity.

5.4 Summary

Determining an appropriate level for the Cap is a three-stage process:

- The effects of the current level of diversions on the ecology of the river system have to be determined,
- The long-term consequences of these ecological effects have to be clearly understood, and
- With this understanding the community has to make an assessment of the benefits and costs of diversions to determine an appropriate level for the Cap.

While it is obvious that current levels of water abstraction are having a significant impact, the full impacts of that abstraction and other changes to the Basin's land and water resources are yet to be realised. The Basin is moving to a new and different state. The riverine ecosystem will require many decades to complete its various ecological and geomorphic responses to the altered conditions that have been imposed on it.

Water resource development in the Basin has had a major impact on the riverine ecosystem. Throughout the Basin, Scientific Panel Assessments, Stressed Rivers Assessments and state water management planning reports have all documented impacts of reduced flows. These impacts include reduced areas of wetlands, less diverse plant and animal populations, and reduced populations of native fish, birds and aquatic plants. Reduced flows will continue to exacerbate problems of salinity, pest species, eutrophication and blue-green algal blooms. Reduced flows are altering the shape of the major rivers. In summary, reduced flows are a major cause of reduced river health in the Murray-Darling Basin.

It is clear from submissions to the Review that there is community disquiet over the state of the Basin's rivers. There is a strong desire to see an improvement in river health. It is also clear that further abstractions, anywhere in the basin, will decrease the health of the river ecosystem.

6 Making the Cap work

Address the impact of the operation of the Cap in achieving its objectives to ensure ecological sustainability of the Murray-Darling Basin river system by examining the question, "what aspects of the operation of the Cap constrain or support the sustainability of the river system?"

6.1 Introduction

The Cap contributes to the sustainability of the Murray-Darling Basin river system by protecting end-of-system flows by limiting growth in diversions. Some aspects of the operation of the Cap enhance its contribution to sustainability, but there is scope for improving the operation of the Cap. This discussion is limited to comments about areas where science indicates that the operation of the Cap might be improved to maximise the Cap's contribution to ecological sustainability. These include:

- increasing efficiency of delivery of diversions;
- returning all government funded water savings to the environment;
- more efficient management of the environments allocation;
- basin-wide adoption of diversions models for evaluating compliance;
- rapid development of Computer Simulation Models to replace Demand Models for determining the Cap;
- redefining the Cap to protect the proportion allocated to the environment in dry years;
- adopting the principle that all water in excess of the Cap is considered the environment's entitlement;
- improving community confidence in the Cap by:
  - Improving compliance with the Cap,
  - Implementing a Cap in all valleys,
  - Not allowing special conditions for some valleys,
  - Demonstrating the environmental benefits of the Cap,
  - Reducing the confusion between the Cap and other water reforms; and
- integrating management of groundwater and surface water.

Many aspects of the Cap support the sustainability of the river system. The operation of the Cap has (or would if fully implemented):

- restricted further diversions in all rivers, regardless of their current level of water resource development, protecting riverine environments of high conservation value (eg the Paroo River) to the benefit of the whole Basin;
- protected important high flow events by limiting access to off-allocation;
- in conjunction with other water reforms, provided a framework for water trading to develop; and,
- provided incentive for conversion to volumetric allocations.

6.2 Efficient delivery of diversions.

It has been conservatively estimated that across the Basin that 14% of all water diverted is lost between the river channel and delivery to the farm gate (Whittington and Hillman, 1999). However, more recent estimates of distribution losses in Victoria and South Australia indicate that distribution losses could be significantly higher than this (MDBC, unpublished data). Distribution losses averaged over 5 years across Victoria represented 24% of all water diverted, which for Victoria represented 992 GL in 1997/98 (Table 6.1). This loss is the result of seepage and leakage from irrigation canals and from evaporation. It also includes under-reporting of Dethridge wheels, theft, and diverted water that outfalls back to the river[14]. Losses in individual valleys are considerably higher, for example the average loss from the Wimmera-Mallee between 1994/95 and 1998/99 was 55%.

Assuming the losses in transmission of irrigation water in Victoria are similar to transmission losses for irrigation in the remainder of the Basin then transmission losses for the 1997/8 water year were about 2,500 GL Basin-wide. To put this figure into context, it represents about 16 years allocation to metropolitan Adelaide, it is more than three times the current level of diversions in Queensland and it is equivalent to the total annual diversions from the Murrumbidgee River (MDBC, 1999d).

Table 6.1. Total diversions and transmission losses between 1994/95 and 1998/99 for Victorian rivers in the Murray-Darling Basin. Transmission losses include seepage, leakage, evaporation, under-reporting of Dethridge wheels and theft. (MDBC, unpublished data).

River	Losses (GL) 1994/95 - 1998/99	Use (total diversions from River) (GL) 1994/95 - 1998/99	Percentage Loss 1994/95 - 1998/99
Kiewa	0	48	0%
Ovens	0	130	0%
Goulburn/Broken	1,554	6,395	24%
Campaspe	333	1,812	18%
Loddon	569	2,208	26%
Wimmera Mallee	498	906	55%
Murray	2,010	9,123	22%
Total	**4,962**	**20,621**	**24%**

Experience with rehabilitation of irrigation scheme distribution networks in South Australia has shown that rehabilitation can recover most of the water lost during transmission. Commission data indicates that prior to rehabilitation, South Australian Government owned irrigation schemes along the Lower Murray operated at an average efficiency of 64% – 36% of diverted water was lost during transmission – however rehabilitated schemes operated at an average efficiency of 93% (MDBC, unpublished data) (Fig. 4.1). Irrigation schemes need regular maintenance to remain efficient. The efficiency of rehabilitated schemes along the Lower Murray appears to decline over time (MDBC, unpublished data) indicating that vigilance in infrastructure maintenance is required.

NSW department of Land and Water Conservation and Murrumbidgee Irrigation commissioned a study (SKM 1995) to review the system losses for the Murrumbidgee Irrigation Area. Between 1977/78 and 1994/95 diversions to the Murrumbidgee Irrigation Area and Districts averaged 1,163 GL, representing 10.2% of the current Basin-wide Cap target diversions. Over the 18 year period an average of 928 GL/year was accounted for at the

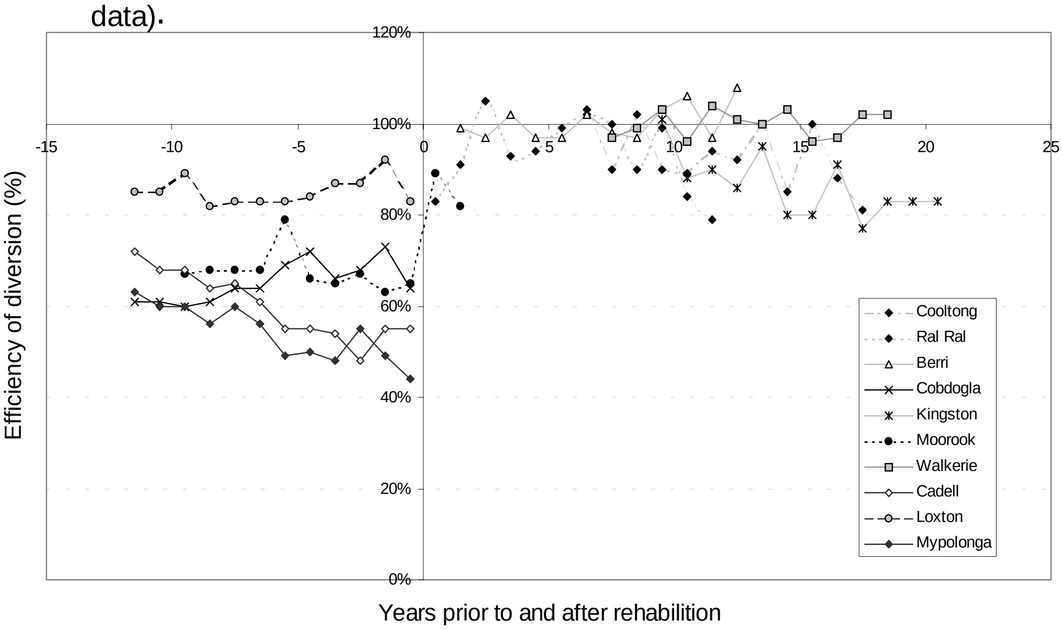
[14] Outfalls back to the river may account for up to 5% of the total water diverted from the river.

farm gate. This represents an average annual loss of 20%. Losses in individual years ranged between 15% and 31%. The report identifies that water is lost to:

- Evaporation, seepage and leaks — 8% of diversions
- System Storage — 3% of diversions
- Measurement error on diversions — ± 10% of diversions
- Measurement error on deliveries — ± 14% of diversions

About half of the system losses in the MIA are actually used by irrigators – however, this water is not accounted for. The report concluded that significant improvements in system efficiency are possible within the MIA Irrigation area with improved management and measurement of diversions.

Figure 6.1 Diversion efficiency before and after rehabilition of South Australian Government Irrigation Schemes (MDBC, Unpublished data).



Approximately 95% of water diverted from the Basin's river system is used for irrigated agriculture. Adoption of best management practices in irrigation will increase productive use of water, reducing the problems such as salinity and nutrient pollution of the river system and may reduce demand pressure on the environment's allocation. Reviewing irrigation farming practices is beyond the scope of this review, but there is little doubt that in many irrigation sectors and districts, significant on-farm savings can be made. For example, it is estimated that some 12.5% of water applied to irrigated pasture runs off as waste water (SKM, 1995). Adoption of more sophisticated irrigation techniques can eliminate this loss.

High diversion losses reflect the historically low value placed on water. With the acceptance that water is a finite resource (and facilitated by the introduction of water reforms) the potential value of transmission losses are now being realised.

Reducing transmission losses and improving on-farm water use efficiency will increase the production per unit of water diverted from the river system and will increase sustainability of the Basin.

6.3 Return government funded water savings to the environment

Under current cost sharing agreements, the ownership of water savings rests with the owner of the entitlements from which savings were made. This Review has shown that current levels of diversions have resulted in considerable degradation of the riverine environment, and will continue to do so. It is important that as water savings are made, regardless of the owner of the entitlement, that consideration is given to returning some or all to the environment.

Returning water saved through government funded rehabilitation of irrigation schemes to the environment is a high priority. This remains as one of the few avenues available for improving river health without reducing current levels of consumption. The Commonwealth submission supports this argument, "*The ownership of water savings from system losses rests with the government/s who paid for the water saving measures. These savings were generated through public investments, therefore it is appropriate that it should result in some level of public benefits including returning water for the environment*".

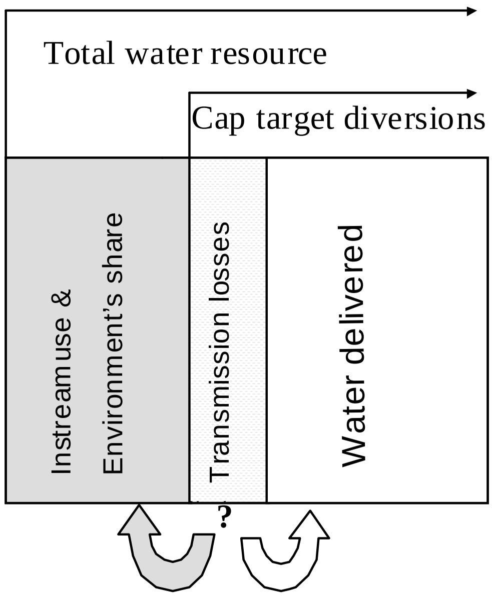


Figure 6.2 Diagram showing the relationship between total water resource, Cap target diversions and transmissions losses. Transmission losses are included in the Cap target diversions. Savings in transmission losses can either be allocated for consumptive use or returned for in-stream uses and the environment's share

The division of water outside of the Cap is poorly defined. It includes the environment's share and in-stream uses. The environment's share is water that is generally available for environmental flows. In-stream uses include water used for dilution flows, for maintaining minimum flows in rivers to retain access for riparian users, for navigation, and for recreation. It is likely that in the future there will be greater demand for water to be used for in-stream uses – particularly the demand for dilution flows as salinity increases. All water outside of the Cap, regardless of what it is used for, should be managed to improve the environmental condition of the river system. Any savings in in-stream use should also remain outside of the Cap.

To improve Basin sustainability, water saved by government-funded reductions in transmission losses should be removed from the Cap and allocated to the environment.

6.4 Protecting the Environment's Share

The New South Wales Governments submission argues that "*environmental allocations [are viewed] as being separate from the Cap*". How environmental allocations are viewed with respect to the Cap is of critical importance to the operation of the Cap, and particularly the ability of the Cap to limit future environmental decline.

The South Australian Government's submission to the Review expresses concern that not all changes to river operation that affect flows are being assessed under the Cap. *"It is essential that all activities affecting flows should be assessed, including all proposals for environmental enhancement, such as wetting and drying of wetlands and changes to the flooding regime of the floodplain."* The example given by South Australia is the Commission's adoption of the 'Edward-Wakool Rivers Floodplain Management Strategy - stage IV' which will result in the periodic flooding of an additional 2000 hectares of red gum forest in New South Wales. The increased flooding of this forest will result from the removal of levee banks along the Edward and Wakool Rivers. This will have a significant benefit to this floodplain by increasing connectivity with the river, but will inevitably result in lower flows in the Lower Murray. An important ecological principle is that both longitudinal and lateral connectivity is critical to the long-term health and sustainability of the river system. Water resource development has severely reduced connectivity, and whenever possible connectivity should be increased. In the example of flooding of the Edward–Wakool Floodplain, lateral connectivity of the floodplain with the river is being increased at this site. This is potentially at the expense of connectivity downstream, if there are lower flows in the river. While there are significant environmental benefits in proposals such as the Edward-Wakool, these must be assessed against any environmental dis-benefit downstream. If, on-balance, the environmental benefits accrued from an action outweigh the environmental dis-benefits then the water should be allocated from the environment's share. This decision should be coordinated at the Commission level, to ensure all downstream impacts are considered. The effectiveness of this coordination in achieving Basin-wide ecological outcomes would be assessed by the Ecological Audit (See Section 3.2).

The contrary effect to this is the installation of a regulator on Moira Lake in New South Wales to re-instate natural drying phases. Moira Lake's ecology was adapted to regular drying over the summer months, however delivery of irrigation water has resulted in unseasonally high flows in the Murray during the summer months, resulting in summer flooding of Moira Lake. Allowing Moira Lake to regularly dry out during summer will enhance the lake's environment and reduce evaporative and seepage losses. This environmental restoration project will also result in increased water in the River Murray because prior to the installation of the regulator, approximately 2,200ML water was lost through evaporation in the wetland during the summer irrigation period.

This water saving could be retained in the Murray (in Lake Hume, for example) for environmental use at an appropriate time or used consumptively (either by the environment or other users). On the River Murray floodplain of New South Wales, Victoria and South Australia, 37,000 hectares of naturally ephemeral wetlands have been degraded by permanent inundation (Pressey, 1986 cited in MDBMC 1998). However, a further 68,700 hectares of ephemeral wetland are being degraded by reduced frequency of inundation. Water saved from reducing the levels of permanent inundation in some wetlands is required by wetlands that have a reduced frequency of inundation.

An objective of the Cap is to *maintain and where appropriate, improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance the riverine environment*. Under no circumstances should trading 'excess water' from the environment's share or in-stream use be allowed to be traded into consumptive use – in the short or long term.

Basin-wide, the river system is suffering from a lack of water and at the Basin scale there is no 'excess water'. Water saved through schemes such as installation of the Moira Lake Regulator should be considered outside of the Cap and become part of the environment's share, and be managed accordingly. Every effort should be made to increase the environment's share by re-instating appropriate wetting and drying phases.

Similarly, if sections of the floodplain are isolated from the river by the construction of levees then the water that would evaporate or seep into the floodplain under natural conditions must remain part of the environment's share. The suggestion that this water should be transferred into the Cap, and can therefore be allocated for consumptive use is highly inappropriate.

The Basin-wide implications of environmental flow decisions must be considered. This will require the coordination of environmental flow management between the States and the ACT. The effectiveness of this coordination in achieving positive ecological outcomes would be assessed at the Basin-wide level by the Ecological Audit (See Section 3.2).

6.5 Efficient management of environment's share

The current Murray-Darling Basin river system has a human dominated flow regime. The Cap merely ensures that water in excess of the approved volume of abstractions is left in the river[15]. What remains in the river is divided into the environment's share and what is available for in-stream use (see Fig 6.2). Sustainability of the river system is constrained by how effectively the environment's and in-stream uses shares are managed. The development of effective flow rules for achieving environmental objectives with these shares is limited by:

- Current understanding of the ecosystem's water requirements;
- Physical and legal constraints on setting environmental flows;
- Continuing needs to provide irrigation flows that conflict with natural flow patterns; and
- State boundaries.

The assessment of river health and the development of environmental flow options are two of the most active research areas in freshwater ecology. These complex tasks are made even more difficult by the lack of adequate baseline information. Inadequate understanding of the system is reflected in the principle that environmental flows should attempt to mimic the natural flow regime – albeit with significantly less water. The translucent dam approach – where a proportion of inflows to the dam is released as it enters, during the dam filling period, is an example of this principle.

[15] The level of diversions permissible under the Cap varies from year to year reflecting climatic conditions and therefore the environment's share varies from year to year depending upon demand and supply of consumptive allocation..

The effectiveness of environmental flows and therefore the sustainability of the Basin are constrained by our limited knowledge of the environment's water requirements. This area requires urgent research effort.

The ability of water resource managers to deliver efficient environmental flows is constrained by physical limitations of water storage infrastructure. For example, the outlet structures on Wyangala Dam allow a maximum flow of 8,000 ML/day, which constrains the maximum flood pulse that can be achieved from Wyangala Dam. The ability to provide effective environmental flows is also compromised by the threat of legal action for compensation by owners of developments on the floodplain. As an example, the maximum flow in the Murray below Lake Hume is 25,000 ML/day. Flows greater than this will flow out onto the floodplain affecting private land. Whilst this may be high priority environmental goal (at the right time of the year), it is not seen that way by a number of floodplain land-holders.

The creation of "environmental floods" is constrained by the threat of legal compensation in a number of valleys throughout the Basin.

Under the Australian Constitution, primary responsibility for land and water, and therefore natural resource planning and management, rests with the Governments of the States and Territories (Commonwealth submission). Management of water for the environment protected by the Cap is therefore a State responsibility. All States are currently developing environmental flow rules for their regulated and unregulated streams, but implementation is patchy (Cullen et al. 1999). There is some interstate cooperation in setting environmental flows, for example the Border Rivers WAMP is being jointly undertaken by New South Wales and Queensland, however State boundaries still constrain the effective development of environmental flows – and therefore the sustainability of the Cap level of diversions. For example, the Condamine-Balonne WAMP considers the environmental effects of water diversions and environmental flow options within the Condamine-Balonne Valley, however downstream environmental water requirements are not considered. This is expressed in the Commission's submission to the Review of the operation of the Cap. "*The impact of [water abstraction] activities (both proposed and existing) in Queensland could be more adequately assessed if this impact was to be considered through to its impact on the River Murray*". The problem of State boundaries constraining environmental flow management is recognised in the South Australian Government submission to the Review of the Operation of the Cap. *"South Australia is in favour of a complete sustainable rivers program that would address flow regimes, timing and quality issues in addition to the volumetric rationale of the Cap*".

There is a need for coordination of environmental flows across the Murray-Darling Basin river system. The Commission should facilitate this coordination to ensure efficient, coordinated delivery of environmental flows, Basin-wide.

While State and territory boundaries have administrative relevance they have <u>no ecological relevance</u>.

Interstate cooperation is required to develop effective environmental flow regimes. This represents a challenge for the State water resource managers and is an area that could be facilitated by the Commission. The effectiveness of management of the environment's should be assessed by an Ecological Audit (See Section 3.2).

6.6 Compliance assessment models

A major outstanding project is the completion and approval for models that will be run at the end of each season to calculate the climate-adjusted Cap targets for each river valley. There are two models for determining Cap target, a diversion model and an end-of-valley flow target. The Diversion Model is to be used for the regulated rivers in New South Wales and Victoria and for assessing South Australian diversions. End-of-Valley flow regime is allowed in unregulated rivers and will be used for assessing all diversions in Queensland.

With the Diversion Model, the Cap target will be compared with measured diversions to determine whether the valley is complying with the Cap. The diversion model provides river management with a clear idea indication of when and where in the valley water is diverted. This is important when assessing the ecological impacts of water diversions along a river valley. The Review supports the use of diversion models for estimating water use.

The use of an end-of-valley flow target to assess diversions requires the actual flow regime to be compared to a target flow regime. The end-of-valley flow target could be expressed in a number of ways, for example as a flow duration curve or simply as annual valley discharge. The accuracy of using end-of-valley flows for determining diversions relies upon the accuracy of gauged flow. The complex network of distributary channels, floodplains and wetlands, the interconnectedness of groundwater and streamflows, coupled with the highly variable nature of stream flows in the Basin's rivers make both setting target flow regimes and gauging flow regimes prone to error. Furthermore, these models are usually at their most accurate for average flows, but become considerably less reliable at high and low flows.

Measurements of end-of-valley flows integrate all of the upstream effects of water resource development. Floodplain development can obscure increases in diversions. For example, reducing connectivity between the floodplain and the river channel can significantly increase total end-of-valley flows. Building levees alienates the floodplain from the river channel. Flood water that would have previously inundated the floodplain now remains within the levees. In effect, levee construction increases end-of-valley flow at the cost of reduced wetland and floodplain inundation.

It is not clear how compliance with an end-of-valley flow target would operate if streamflows in a river valley were reduced as a result of increased use in an upstream river valley (for example, increased use in Queensland impacting on flow regime set for Barwon-Darling River valley). Would diversions from the target river valley be reduced to meet that valley's end-of-flow target or would the end-of-flow target for the valley be altered to reflect changes in water delivery from an upstream valley? The sensible – and only practical – way of using and end-of-valley flow target is to consider the impact of all diversions from the catchment above the gauging point. Attempting to apportion changes in parts of a flow regime to upstream river valleys will have high levels of error.

If land use in the catchment reduces water yield (see Section 5.2), then maintaining an end-of-system flow target will protect the environment's allocation at the expense of the consumptive allocation.

The Commission's submission to the Review of the Operation of the Cap recommends against using end-of-valley targets. *"The Office [of the Commission] believes the expression of all Caps throughout the Basin should be in the form of a long term average target diversion… … since the accuracy of measuring and modelling diversions will always be much greater than the accuracy of measuring and modelling river flows which is made difficult by the variability of river losses"*.

There are clear technical problems with accurate assessment of end-of-valley flow regimes. Diversion models provide a more robust method of supporting the Cap than end-of-valley flow objectives, especially in highly variable rivers.

6.7 Climate adjustment does not support ecological sustainability

The Cap allows an annual diversion equivalent to what would have been diverted with the infrastructure (pumps, dams, channels, areas developed for irrigation, management rules, etc) that existed in 1993/94, assuming similar climatic conditions to those experienced during the year in question. The Cap defines a volumetric allocation for consumptive use. The environment's allocation is what remains after consumptive allocation has been determined.

In the southern half of the Basin, demand for water is higher in dry years than wet years, consequently a greater proportion of the total flow is diverted in dry years than wet years. In dry years climate adjustment, (which may be better described as demand and supply adjustment) maintains the historically high ratio of diversions to environmental allocation in the southern regions of the Basin. While this is an important feature of water supply for consumptive use (deliver water when it is required), climate adjustment constrains environmental sustainability.

For example, in the southern New South Wales valleys, diversions between 1983/4 and 1993/94 were inversely proportional to rainfall (DLWC 1999) – water use was higher in dry years than wet years. In the New South Wales Murray Valley, diversions during this period were approximately 1,797 GL when rainfall was 300 mm, and 31% higher at 2,351 GL when rainfall was 100mm. A simple linear relationship, such as this, has been used in some valleys to determine climate adjustment for the Cap until more sophisticated Computer Simulation Models are available. Demand models do not take account of the supply of water, and so in dry sequences of years they considerably over-estimate 1993/94 usage. For example, in the New South Wales Murray Valley the amount of water allocated for diversion under the Cap was a greater volume of water than was available for diversion in the dry years that occurred in 1997/98 and in 1998/99. The apparently illogical situation of a valley being 'resource constrained' rather than Cap constrained is a result of the use of the inadequate demand models.

Computer Simulation Models consider for the amount of water in storage at the beginning of the water year and so give a truer indication of the 1993-94 level of water usage. In a dry sequence of years the Cap is considerably lower than in a wet year. For example, the Lachlan Valley the Cap is less than 50 GL in dry years, whereas the long-term Cap target is 269 GL.

Demand models potentially result in setting a Cap that is considerably above what would have been abstracted in 1993/94 and therefore the use of demand models is a constraint on the sustainability of the Basin. Completion of climate adjustment models, which include both demand and supply, is an urgent priority.

The Cap enshrines the current long-term patterns of usage. This can be clearly seen on the effect of water diversions from the Lachlan valley. With the current infrastructure the long term inflow (from Wyangala Dam, Belubula River and the downstream tributaries) to the Lachlan River is 1,219 GL (Table 4.2). Under natural conditions (i.e. without diversions) the average flow at Oxley[16] was 235 GL, or 22% of inflows. The difference between total inflows and flow at Oxley represents reductions in flow that would occur naturally due to evaporation or seepage into groundwater.

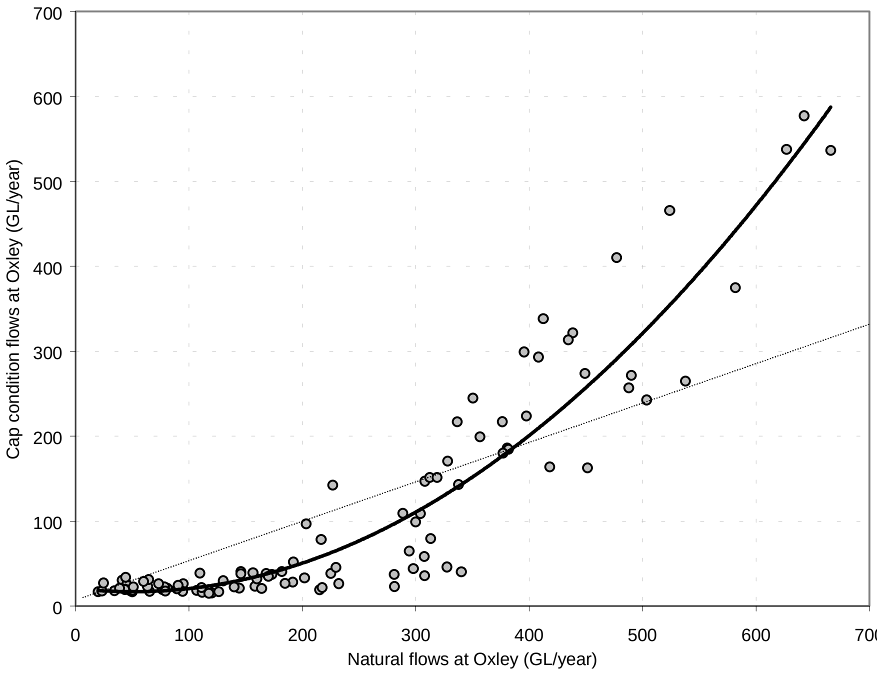
[16] Oxley is at the downstream (western) end of the Lachlan River, immediately upstream of the 50,000ha Great Cumbung Swamp. Flows at Oxley represent the end-of-valley flows from the Lachlan valley and the inflows to the Great Cumbung Swamp.

Table 6.2 Median and Average Inflows, diversions and end-of-valley flows in the Lachlan River. Data provided from the Lachlan IQQM by NSW DLWC.

	Average 1894-1996	***Median 1894-1996***
Total System Inflows	1,219 GL	925 GL
Cap Diversions	268 GL	314 GL
Percentage of average & median inflows diverted	22%	34%
End-of-system Flow at Oxley (Natural conditions)	235 GL	202 GL
End-of-system Flow at Oxley (Cap conditions)	107 GL	38 GL
Effect of diversions on flows at Oxley (percent reduction from natural flow conditions)	46%	18%

Under current operating rules (ie with the Cap in place) the average flow at Oxley is reduced to 107 GL. The median end-of-system flows is 38 GL which is about one third of the average. This is because the average is strongly influenced by the rare, but very high flows that do occur. The flow data in Table 6.2 indicates that water resource development in the Lachlan valley has its greatest effect on end-of-system flows in dry to normal years. Fig. 6.3 plots natural flows at Oxley against the flows with the Cap on the level of diversions. At Oxley the long-term average reduction in stream flow resulting from diversions is 46% (dashed line). However, the proportion diverted is considerably greater than this at when natural flows were less than approximately 300 GL The median flow at Oxley with the Cap operating is only 18% of the natural median flow at Oxley. This trend is similar throughout the Southern parts of the Murray-Darling Basin.

Figure 6.3 Natural and 'Cap' flows at Oxley (GL/year). The average affect of diversions is to reduce flows at Oxley by 46% (dashed line). However, at natural flows below 300 GL, the effect of diversions is much greater.



If in the southern parts of the Basin long-term stream flows are reduced, through for example, land use changes in the catchment or climate change, then the long term proportion of total stream flow abstracted will increase. This is because at lower streamflows the Cap allocates a greater proportion of the total flow for consumption. Therefore reductions in water yield from a catchment are at the expense of the environment share. This will increase hydrologic stress on the rivers and is a constraint on sustainability.

The Review recommends that over time the Cap be defined so that it limits diversions and guarantees a minimum proportion of stream flow for the environment, which in valleys like the Lachlan would need to consider the end-of-valley flow regime. A diversion model would still, however, be the primary method for assessment of Cap target compliance.

Defining an appropriate share for the environment reflects New South Wales Government water sharing policy, "*that flows needed to restore adequate river health continue to have a prior right over the provision of water for consumptive use*." (NSW Government 1999).

6.8 Community Confidence

Community confidence in the Cap is critical for its long-term acceptance. Submissions to the Review of the Operation of the Cap indicate at least five factors that are eroding community confidence in the Cap:

- Non-compliance with the Cap, whether non-compliance is perceived or real.
- Tardy implementation of the Cap
- Special conditions for some valleys
- No demonstrated environmental benefit from the Cap
- Confusion of the Cap with other water reforms

There is a community expectation on the State Governments to ensure that the Cap is clearly defined and implemented transparently across the Basin. Thus far, several jurisdictions have failed to achieve this.

There is a need for appropriately targeted information explaining the development of the Cap, its intent and the impacts of its implementation. The Review of the Operation of the Cap and the MDBC SI&E Riverine Sub Program Project R2 '*Explaining the science behind the Cap on diversions*' will increase the opportunity for the community to better understand the impacts of the Cap, and differentiate those from other water reforms.

The submission to the Review of the Operation of the Cap from Inland Rivers Network suggests, *"…describing the Cap level in terms of 'what it saves', both in terms of environmental benefits and protection of irrigation supplies, there would be much less confusion regarding how 'sustainable' these levels of extractions were. This would better permit society to better judge the trade-offs it makes in managing the Basin's rivers and wetlands".*

Describing the Cap in terms of what it attempts to achieve is likely to improve community ownership of the Cap, which is critical for its long-term acceptance. Developing a description of the Cap that better reflects the community's aspirations should be attempted by the Commission. This task may be undertaken as part of the MDBC SI&E Riverine Sub Program Project R2 '*Explaining the science behind the Cap on diversions*'.

6.9 Groundwater

The Victorian Government submissions to the Review of the Operation of the Cap argues, "*it is imperative that groundwater is recognised as a finite resource and allocated on a sustainable basis to ensure consistency with the Cap*". Similarly, the Commonwealth's submission argues that groundwater and surface management has to be integrated because the practise of shifting usage from surface water to groundwater *"could displace the environmental impacts from one component of the water cycle to another*".

There are clearly long term effects of groundwater usage on surface watre availability (and vice a versa), on natural ecosystems, and on the availability of water resources for future generations (MDBC 1999a).

Groundwater and surface water are physically interconnected, and for some users alternate sources of water. The Cap does not assess the extent of conjunctive use of groundwater and surface water and the level and extent to which capping surface water leads to switching groundwater use. It is critical that surface water and groundwater management is integrated if both resources are to be managed effectively.

6.10 The Cap protects high flows

Small to medium sized floods are critical to maintaining lateral connectivity of the river channel with the floodplain. Historically, in much of the Basin, off-allocation has been allowed during high flow events causing the smaller of these to be extensively harvested. Consequently, off-allocation and other water diversions have significantly reduced the duration and magnitude of the small to medium floods. The basin-wide expansion in off-stream storage seriously threatens the remaining high flow events. The Cap, once implemented, protects these flow events from further harvesting. This is clearly demonstrated in the Murrumbidgee Valley. Access to off-allocation water has been halved in 1999-2000 to a maximum of 220 GL, down from 440 GL in 1998/99. This reduction in off-allocation diversions is a response to the high diversions (with respect to the Cap) in the Murrumbidgee Valley in 1997/98, which where at the upper end of the confidence limit of the diversion model.

In general, the Cap is better at protecting high flow events than low flows. This is clearly seen in Fig. 4.3, which shows that the effect of diversions on flow in the Lachlan River at Oxley at different natural flow conditions. In wet years diversions impact flows at Oxley by less than 20%, compared to more than 80% in drier years.

By constraining access to off-allocation diversions the Cap enhances the sustainability of the river system.

6.11 Water Trading

Water trading provides a mechanism for the Cap to achieve its goal of restricting *growth* in diversions, without restricting development. "*With the Cap in place, new developments should be allowed, provided water for them is obtained by improving water use efficiency or by purchasing water from existing entitlements*" (MDBMC 1996). The COAG Water Resource Policy requires that State Governments provide the necessary institutional arrangements to facilitate the trade in water. The aim of water trade is *"…to maximise its [water's]* *contribution to national income and welfare, within the social, physical and ecological constraints of catchments,.."* (COAG, 1994).

Water trade supports the sustainability of the Murray-Darling Basin river system when it is undertaken within the ecological constraints of the catchment. A fundamental ecological principle that must be considered when assessing water trade is that the relationship between a volume extracted and river health is likely to be site specific. The relationship will depend upon flow regime, river morphology and the biota. This means that a volume of water diverted from one site is likely to have different ecological impact to the same volume diverted from a different site. This principle is particularly important when inter-valley trades are considered because different rivers will have different flow regimes and levels of abstraction.

> Water trade only contributes to the ecological sustainability of the river system if trade reduces the impact of diversions – by either moving abstraction to a more appropriate place or by reducing the total volume diverted.

7 Basin Scale Risks to the Health of Riverine Ecosystems

At a Basin scale, assess the potential hazards and level of risk to the health of the riverine environment (including algal blooms and salinity), and comment on the role of the Cap in containing these hazards and reducing the level of risk to riverine health.

There are many processes (eg. the development of nuisance algal blooms) or activities (eg. increased water extraction) that threaten the health of the riverine environment across the Murray-Darling Basin. The Cap influences these processes and activities. The influence may be positive or negative, however, we do not fully understand riverine processes or the consequences of our activities and so our understanding of the influence of the Cap is likely to change, as more information becomes available. Also, there are a number of threats to the Basin's riverine environment not addressed by the Cap including poor catchment management. This section assesses the role of the Cap in modifying the impacts of various threats to the Basin's riverine system.

7.1 Ecological benefits of the Cap

The adverse environmental impacts of the following processes and activities are likely to be reduced by the implementation of the Cap:

- Salination of the river system;
- Incidence of blue-green algal (cyanobacteria) blooms; and
- Increased water abstraction.

7.1.1 Salinity

The recently released Salinity Audit of the Murray-Darling Basin (MDBMC, 1999) re-confirmed salinity as a major threat to local and regional land and water resources, riverine biodiversity, and rural and urban infrastructure. The Salinity Audit identified trends in salt mobilisation and loads measured on the landscape and in surface waters for each of the major river valleys. It was found that much of the salt mobilised at the landscape level is not transported to the sea. Based on current trends, it has been estimated that by the year 2100 more than 10 million tonnes of salt per year will be mobilised to land surface across the Murray-Darling Basin (Table 7.1). This is double current levels and is likely to lead to:

- Declining water quality in rivers;
- Loss of productive land;
- Damage to built infrastructure such as building and roads;
- Degradation of the environment, including loss of biodiversity.

Table 7.1 Estimated quantity of salt mobilised to the land surface*, 1998-2100 (from MDMC, 1999)

State	Salt mobilised to land surface (tonnes per year)			
	1998	2020	2050	2100
South Australia	434,000	640,000	870,000	1,020,000
Victoria	740,000	825,000	1,150,000	1,370,000
New South Wales	3,707,000	5,000,000	6,140,000	7,690,000
Queensland	>186,000	>255,000	>256,000	>256,000
Total	>5,070,000	>6,720,000	>8,420,000	>10,340,000

* based on 54% of the Basin for which groundwater information exists

Three distinct groundwater regions have been identified in the Murray Darling Basin:

- The Murray Basin;
- The Darling River drainage basin that overlies the Great Artesian Basin; and
- A fractured rock region of the Great Dividing Range that includes south-central New South Wales and north-central Victoria.

The areas of greatest risk from land and river salinisation are the groundwater discharge areas of the Murray Basin and the fractured rock areas of the Great Dividing Range (Lovering *et al*., 1998). In the northern areas of the Great Dividing Range (e.g. Macquarie, Gwydir, Namoi, Border and Condamine Rivers), a significant proportion of the groundwater enters the Great Artesian Basin and is carried north and west out of the Murray Darling Basin.

Three important threshold salinity levels were identified in the Salinity Audit for assessing stream salinity across the MDB:

1. 800 EC[17] units threshold for maintaining safe drinking water ;
2. 1500 EC units for protecting aquatic ecosystems; and
3. 5000 EC units that divides fresh water from saline water.

The World Health Organisation (WHO) has recommended a salinity of 800 EC as the upper limit to ensure safe drinking water. The MDBC Salinity & Drainage Strategy (MDBC, 1989) adopted the WHO guideline as the basis for its target of maintaining salinity in the Murray River at Morgan, South Australia, below 800 EC for 95% of the time. The Salinity and Drainage Strategy also included the provision of dilution flows and the construction of salt interception works in order to meet this target and, therefore, protect a significant portion of Adelaide's water supply. The Salinity Audit (MDBMC, 1999) predicts that the average salinity in the Murray River at Morgan will increase from the current 570 EC, to exceed 800 EC in 50 to 100 years time. The current salinity at Morgan would be significantly higher if the current arrangements to provide dilution flows, along with salt interception schemes and other measures, were not in place. These current arrangements have maintained salinity at less than 800 EC for 92% of the time.

While the Salinity and Drainage Strategy focussed on salt export from irrigation areas, it was recognised that there was an underlying trend of increasing salinity due mainly to the influence of dryland salinity entering into the river system, either through rising saline groundwater contributions into tributary streams or overland flows. The large increases in salt export to the river system predicted in the Salinity Audit will be primarily from the dryland catchment rather than irrigation areas. Based on current trends, the Salinity Audit predicts that salinity in rivers such as the Macquarie, Namoi, Lachlan, Castlereagh and Bogan Rivers of NSW will rise to above the 800 EC safe drinking threshold within the next 50 years. Salinity in rivers such as the Condamine-Balonne, Border and Warrego Rivers in Queensland are expected to exceed the 800 EC threshold within 20 years (Table 7.2 to Table 7.5). The Salinity Audit clearly indicates that the salt concentrations of many of the Basin's rivers will increase. This will result in greater demand for in-stream use of water – for dilution flows. The Cap reserves water for environmental and in-stream uses and without the Cap there would be less water available for this purpose.

[17] EC = Electrical Conductivity units, which is often measured as micro-Siemens per centimetre (μS/cm). 1500 EC units is equivalent to a salt concentration (or Total Dissolved Solids) of approximately 1000 mg/L.

Queensland has yet to implement the Cap on diversions and the level of water extraction in some Queensland valleys has increased significantly since 1993/94. Also, Cap target allocations have been exceeded in other river valleys of the Murray-Darling Basin. The Salinity Audit predicted river salt concentrations assuming no growth in water abstraction beyond the 1993/94 level. If diversions increase, the volume of water remaining in the rivers decreases – the inevitable consequence is an increase in the salt concentration of the rivers (it is unlikely that diversions will reduce salt load in the long-term).

Additional diversions from the Basin's rivers beyond the 1993/94 levels will result in the Salinity Audit's predictions to be *underestimates* of salinity trends for the Basin's river system.

Table 7.2 Estimated river salinity, South Australia, 1998-2100 (from MDBMC, 1999)

River Valley	Average river salinity (EC)			
	1998	2020	2050	2100
River Murray				
Murray Bridge	590	730	870	980
Morgan	570	670	790	900
Berri	430	520	610	690
Renmark	400	480	550	620

Table 7.3 Estimated river salinity, Queensland, 1998-2100 (from MDBMC, 1999)

River Valley	Average river salinity (EC)			
	1998	2020	2050	2100
Warrego River	210	1,270	1,270	1,270
Condamine-Ballone	210	1,040	1,040	1,040
Border Rivers	310	1,010	1,010	1,010

Table 7.4 Estimated river salinity, NSW, 1998-2100 (from MDBMC, 1999)

River Valley	Average river salinity (EC)			
	1998	2020	2050	2100
Murrumbidgee	250	320	350	400
Wagga Wagga	140	170	190	220
Lachlan	530	780	1,150	1,460
Cowra	330	440	690	880
Darling River				
Menindee	360	430	490	530
Bogan	730	1,500	1,950	2,320
Macquarie	620	1,290	1,730	2,110
Narromine	440	900	1,200	1,450
Castlereagh	640	760	1,100	1,230
Namoi	680	1,050	1,280	1,550
Gunnedah	580	930	1,150	1,400
Gwydir	560	600	700	740
Macintyre	450	450	450	450

Table 7.5 Estimated river salinity, Victoria, 1998-2100 (from MDBMC, 1999)

River Valley	Average river salinity (EC)			
	1998	2020	2050	2100
Murrumbidgee	250	320	350	400
Wagga Wagga	140	170	190	220
Lachlan	530	780	1,150	1,460
Cowra	330	440	690	880
Darling River				
Menindee	360	430	490	530
Bogan	730	1,500	1,950	2,320
Macquarie	620	1,290	1,730	2,110
Narromine	440	900	1,200	1,450
Castlereagh	640	760	1,100	1,230
Namoi	680	1,050	1,280	1,550
Gunnedah	580	930	1,150	1,400
Gwydir	560	600	700	740
Macintyre	450	450	450	450

Average salinity levels in some of the major rivers in the Murray-Darling Basin are expected to exceed 1500 EC during the next 100 years (e.g. Avoca River, Bogan River, Namoi River). This is a commonly accepted threshold, beyond which adverse biological effects are expected in rivers, streams and wetlands. While 1500EC remains a convenient benchmark, for many taxa, abundance will decline at lower salinities, and the effect may not be noticeable for some time. Long term average salinity can mask high salt concentrations that occur for relatively short, but critical, periods of time (e.g. the intrusion of highly saline groundwater into rivers or wetlands during key periods of the breeding cycle of aquatic plants or animals such as fish). Increasing salinity in the Basin's rivers and streams will increase the risk of adverse biological and ecological effects, for example on the development of aquatic plants and fish larvae (James and Hart, 1993; O'Brien, 1997). The rate of change of salinity in freshwater ecosystems, as predicted by the Salinity Audit, will be much higher than the rate at which freshwater biota can evolve or adapt.

Variations in salinity in important floodplain habitat such as wetlands are linked to river flows and wetting and drying cycles. These are both impacted by the rules that control the management and operation of river flows. However, there is little information available to river managers on the relationship between flow patterns, salt levels and environmental damage. Nor is there any information available on how a combination of changes in flow and salt concentration affect river and wetland health, synergistically. This knowledge gap has been identified in a recent Draft Discussion paper "Ecological Effects of Dryland Salinity on Aquatic Ecosystems" produced by the CRC for Freshwater Ecology.

The availability of dilution flows, the volume of which is protected by the Cap, will be an increasingly important constraint on salinity management in the future.

7.1.2 Blue-Green Algae

Provisions in the Cap that have helped to protect low flow conditions, especially in highly regulated rivers, has improved the management of nuisance algal blooms in waterways across the Murray-Darling Basin. For example, Oliver *et al*. (1998) reported the findings of a three-year field study of factors controlling algal growth in the Darling River, NSW. The study showed that major blue-green algae (cyanobacteria) blooms in the Darling River were assisted by a sequence of events related to flow conditions. Reduced flow increases water residence times in weir pools and increases the likelihood of thermal stratification of the water column. The development of anoxic conditions following stratification results in changes to chemical and biological processes in river sediments and bottom waters, that in turn promote the release of nutrients such as phosphorus and nitrogen from the sediments in forms readily available for uptake by algae (Donnelly *et al*., 1999). Groundwater inflows during times of low flow can increase salinity, which in turn precipitates the turbidity in the water column, increasing light penetration through the water.

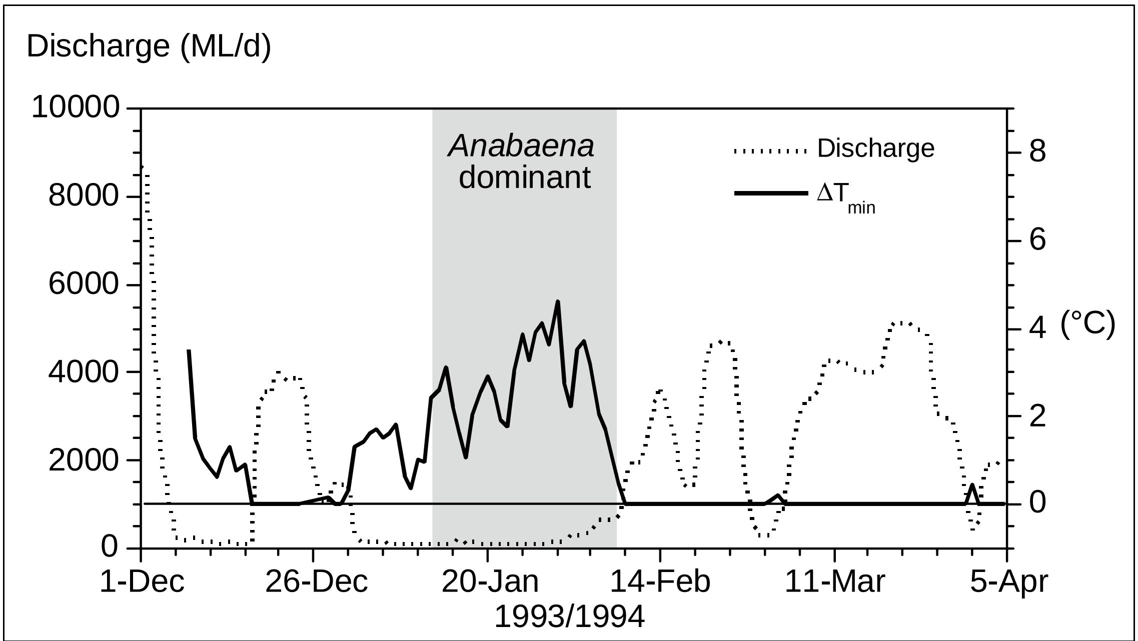


Figure 5.1 Relationship between discharge, stratification and Anabaena in Maude Weir pool, Murrumbidgee River, December 1993 to April 1994. Source: Webster et al. (1997)

Overall, the combination of increased light and available nutrients in slow moving water favours the growth of blue-green algae and the formation of blooms. Investigations of blue-green algae in the Murrumbidgee River at Maude Weir (Webster *et al*., 1997) found that *Anabaena circinalis* counts were highest when discharge through the weir was low and increased water temperature in the surface layer led to stratification (Fig. 5.2). In short, the blue-green alga *Anabaena* blooms under low flow conditions and is reduced to very low numbers at moderate flows.

Increasing extractions from the Basin's rivers would result in reduced flows and also less capacity to provide dilution flows. Lower flows would favour the growth of blue-green algae. Reducing the volume of water for in-stream use (dilution flows) would reduce the ability of managers to provide flushing flows, one of the few proven techniques for managing blue-green algal blooms. The Cap, in isolation, will not lead a reduced frequency and intensity of algal blooms – this will require a coordinated nutrient and flow management strategy.

7.1.3 Water extraction

The effect of water extraction on riverine processes, and the role of the Cap in reducing further degradation has been discussed extensively in other Sections of this Review.

7.2 Potential ecological problems exacerbated by the Cap

Processes or activities whose environmental effects may be increased by the implementation of the Cap include impacts due to reductions in long-term runoff & stream flows, including:

- Reduced stream flow due to climate change
- Reduced stream flow due to changes in land use

7.2.1 Climate change

Changes to stream flow resulting from climate change (e.g. due to the Greenhouse Effect) may vary considerably across the Basin. For example, increased temperatures may result in increased rainfall intensity and frequency in summer rainfall (northern) areas, while rainfall may be reduced in winter rainfall areas (DASET, 1992). Modelling results reported by Bennett (1999) suggest that flows in the Upper Murray, Kiewa, Ovens and Goulburn Rivers in Victoria may decline by up to 36% over the next 30 years in a worse-case response to global warming (Table 5.6). The worse-case scenario also suggests that the frequency of flooding would decrease and that the frequency of drought would increase (Table 5.7). Similarly, modelling suggested that flows in the Macquarie River above and below Burrendong Dam in NSW may decline by up to 30% and 37% respectively. While these are the upper limits of changes modelled in the studies reported by Bennett (1999), and modelling predictions about the sustainability of water resources and agriculture should be treated with caution (Henderson-Sellers, 1996), they highlight the fact that climate change may significantly alter flows in the rivers of the Murray-Darling Basin. If climate change results in reduced streamflows, then the volume of water available for apportioning between diversions, in-stream use and the environment is reduced. Reduced water for in-stream use reduces the availability of water to manage rising salinity and nuisance algae.

Table 7.6: Scenarios for the year 2030 on the effect of climate change on precipitation and streamflow in snow affected (Mitta Mitta and Kiewa Rivers) and snow free catchments (Goulburn and Ovens Rivers) in Victoria (from Schreider *et al.* (1997) reported in Bennett, 1999)

	Scenario	Precipitation (% change)	Streamflow (% change)
Snow free	Most dry	-7	-36
Snow affected		-6	-30
Snow free	Most wet	+13	0
Snow affected		+13	+9

Table 7.7 Scenarios for the year 2030 on the effect of climate change on floods and drought in snow affected (Mitta Mitta and Kiewa Rivers) and snow free catchments (Goulburn and Ovens Rivers) in Victoria (from Schreider *et al.* (1997) reported in Bennett, 1999)

	Scenario	August – October floods (% frequency)	January – March drought (% frequency)
Snow free	Most dry	-82	+36
Snow affected		-83	+36
Snow free	Most wet	+41	+5
Snow affected		+62	+1

Reduced stream-flow, due to climate change, will be reflected in the climate adjusted Cap diversion target for the year in question – once appropriate Computer Simulation Models have been developed. However, reduced stream-flows in the Southern parts of the Basin will result in the long-term proportion of total stream flow diverted to increase. This is because at lower stream-flows, the Cap allocates a greater proportion of total flow for consumptive use (See Section 6.7 for further discussion). Reductions in water yield from a catchment therefore, disproportionately impact on the environment's share. This will increase hydrological stress on the rivers and is a constraint on sustainability.

The Review recommends that over time the Cap be redefined so that it guarantees a minimum proportion of stream flow for the environment.

7.2.2 Land use change effects

There are plans to significantly increase plantation areas across the Murray-Darling Basin. For example, the Victorian Government is to invest $8 million in the Replanting Victoria 2020 program (DNRE, 1999) as part of its response to Greenhouse effects and other land and water management issues. Much of the new plantation areas are expected to replace what is currently grassland. It is well known that evapotranspiration rates in plantations are higher than in grasslands, yet there is scant acknowledgment of the fact that stream flows will decline significantly from afforested catchments (Vertessy, 1999).

In a study of 28 sub-catchments of the middle Murrumbidgee River basin, Vertessy and Bessard (1999) reported that the greatest impacts of afforestation might be expected in higher rainfall areas. Average annual runoff declines of up to 500 mm were considered possible with the conversion of grassland to pine plantations, with declines by 100 mm (1.0 ML/ha) possible for 75% of catchment area and 290 mm (2.9 ML/ha) possible for 25% of the catchment area that may potentially be afforested.

Afforestation in Victoria is expected to reduce runoff by approximately 2ML/ha (Government of Victoria submission). As 200,000 ha are expected to be afforested in coming years, runoff reductions in the order of 400 GL may result. This is equivalent to 25% of Victorian abstractions from the Murray valley.

Large-scale bushfires can significantly reduce water yield from a catchment in the medium term until regenerating forest matures. An examination of the long-term hydrologic effects of the 1939 bushfires in the Maroondah catchment near Melbourne suggested that water yield decreased by up to 24% after 48% of the catchment had been converted to regrowth forest. The long-term trend in declining in yield commenced 3-5 years after the fires and reached a maximum after 15-20 years (Langford (1975) in Kuczera, 1985). Further modelling undertaken by Kuczera (1985) for the Murrindindi catchment (Goulburn River catchment) suggested reductions in average annual water yield of approximately 200mm (2 ML/ha) from pre-1939 fire conditions. The modelled reduction in water yield was greater in Melbourne water supply catchments; for example modelling suggested that water yield reductions in the order of 300 - 400mm in the Maroondah catchments. Major bushfires in the forested catchments in SE Australia (for example above Lake Eildon, Victoria) will significantly reduce stream flows in the medium term.

Williams and Karoly (1999) reported that the seasonal fire danger in southeastern Australia is higher in years of strong negative Southern Oscillation Index (SOI), and that the daily Fire Danger Index (FDI) has more days with extreme fire danger during these periods. If climate change were to results in more frequent and sustained periods of negative SOI (increase in El Nino events), then an increase in bushfire frequency might also be expected. While, current global climate models cannot yet reproduce the behaviour of ENSO events reliably enough to understand the potential effects of global warming and, therefore, test the likelihood of this scenario (Pittock and Henessy, 1996) the potential for increased fire frequency and its impact on medium-term changes in stream flow should be considered.

Reduced stream-flow resulting from land use change will be reflected in the climate adjusted Cap diversion target for the year in question – once appropriate Computer Simulation Models have been developed. However, as with climate change, reduced stream-flows from landuse change in the Southern parts of the Basin will result in the long-term proportion of total stream flow diverted increasing. Reductions in water yield from a catchment therefore, disproportionately impact on the environment's share. It should also be noted that long-term reductions in water yield, regardless of whether it's the result of climate change or landuse, will also result in lower availability of water for consumptive use.

8 Case Study: The Lower Murray

8.1 Introduction

This study outlines the nature of the Lower River Murray and the hydrological and ecological changes associated with flow regulation. It then considers the hydrological and ecological significance of the Cap, designed to limit diversions to levels that prevailed in 1993-94. Four scenarios are considered:

1. Modelled natural flows (no diversions)
2. Actual flows 1979-91
3. Cap Diversion Target
4. Full Development Scenario

8.2 Study Area

The 830-km course of the 'Lower Murray', from the Murray-Darling confluence at Wentworth to the sea near Goolwa (Fig. 6.1), includes floodplain wetlands and woodlands, a spectacular limestone gorge, reclaimed riparian swamplands and shallow freshwater lakes near the mouth. The river is strongly influenced by a series of regulating weirs, and by variable flows from the Darling. It is a distinct 'environmental unit' in terms of ecology and management, and as much of the region (648 river km) is within South Australia, it also has some political unity.

Most flow in this tract originates from the Murray above Wentworth. Flows are governed by upstream dams and diversions, and regulated by 10 weirs (height 3 m, capacity 13-64 GL, pool length 29-88 km) between Wentworth and Blanchetown. In addition, the lowermost reaches (274 river km) are controlled by riverbank levees and barrages along the seaward margins of Lake Alexandrina. The Darling's contribution is highly variable, but averages about 12% of the system's long-term annual discharge.
There are four main sections:

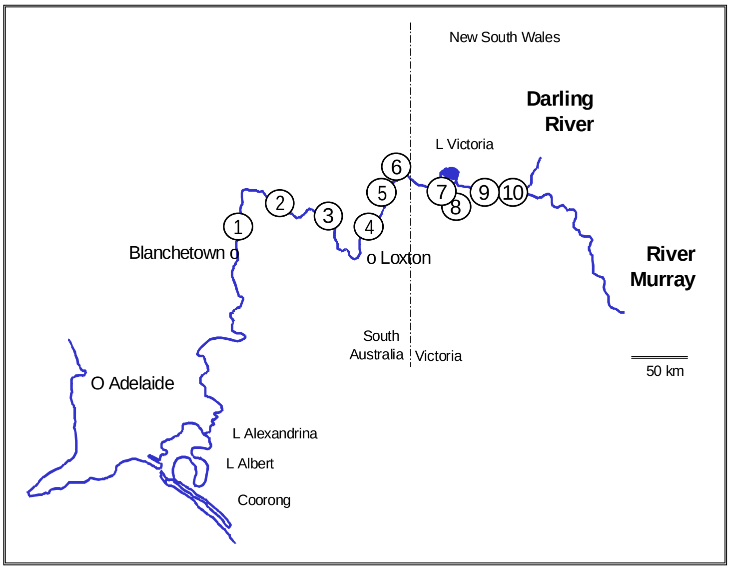
Valley: Wentworth to Overland Corner (400 river km), including Locks 3-10. Lake Victoria (680 GL) is managed as an offstream storage. The river meanders over a 5-20 km wide floodplain with many anabranches, billabongs and deflation basins, particularly in the Chowilla region (above Lock 6).

Gorge: Overland Corner to Mannum (280 river km), including Locks 1-2. The river flows in a 30-m deep gorge where the floodplain is constrained to 2-3 km and long, straight reaches are aligned by geological faults. Most wetlands are in channel swales, and are physically less diverse than those of the Valley.

Swamplands: Mannum to Wellington (74 river km). The river is flanked by reclaimed swamplands, protected by some 40 km of earthen levees planted with willows (*Salix* spp.). There are no weirs, but river levels are raised 450-600 mm by the barrages further downstream.

Lakes and Coorong: Wellington to the sea (76 river km), via Lake Alexandrina (2015 GL) and a series of barrages that exclude sea water from the lower reaches. Near the river mouth, the system connects with the Coorong, a narrow, shallow 90-km lagoon that grades from fresh or marine water, depending on discharge from the Murray, toward hyper-saline water (>35 g/L) at its other extremity.

Figure 8.1 The Lower Murray



8.3 Effects of Regulation

8.3.1 Hydrological Effects

Base flows to South Australia are set by an annual 1,850 GL ‘entitlement’, determined by parliamentary legislation, although the quota is exceeded in most years. Other hydrological effects of regulation have been to reduce the magnitude and variability of seasonal and annual flows and to limit interchange with floodplain environments (Jacobs 1989; Close 1990; Thomson 1992; Walker and Thoms 1993; Maheshwari et al. 1995; Walker et al. 1995).

Average annual flows in the Lower Murray are now substantially lower than they were under ‘natural’ conditions (simulated flow in the absence of diversions). Annual discharges in 1894-1993 ranged from 1,626 to 54,168 GL, with mean 10,090 GL and median 8,489 GL. The median annual natural flow now is exceeded only 8% of the time (cf. 50% under natural conditions). The average flow at Blanchetown has been reduced by more than half, and flow at the river mouth is reduced by about 80%; indeed, the mouth was closed by shifting sand in 1981 and closure is again imminent (February 2000). The demand for water from other states is such that the 1998 flood in the Darling, statistically a 1-in-30-year event, had no appreciable impact on flows in the Lower Murray.

Regulation has reduced the variability of mid-range flows so that the present regime is dominated by low flows with occasional high flows. Low flows (<5,000 GL) occur 66% of the time under regulation, but only 7% of the time under natural conditions. Despite the prevalence of low flows, the weirs maintain base water levels, and did so even during the major drought of 1967-68. Ninety five percent of annual regulated (in-channel) flows are between 0 GL to 15,000 GL, compared to 2,500GL to 20,000 GL for natural flows. Big floods (recurrence 20+ years) are little affected.

The seasonal extremes of monthly flows still tend to a natural summer–autumn minimum and winter–spring maximum, despite irrigation use. The *magnitude* of the seasonal peak, however, has decreased markedly.

8.3.2 Nature of the Cap

Annual diversions from the Murray-Darling Basin (excluding Queensland) increased from 3,000 to 11,000 GL in 1930-91, and were "capped" at 1993-94 levels in 1995 (MDBMC, 1995). The Cap is administered differently in each state, and in South Australia's case the agreement of the Ministerial Council permitted a minor increase above the initial Cap. The Cap is indexed to inter-annual climatic variations, so that ENSO cycles, for example, are taken into account (See. Section 6.7). The rules for administering the Cap appear to be based on *ad hoc* judgements rather than a fixed protocol.

Annual statistics may convey a misleading impression of environmental effects. Variability is the hallmark of dryland rivers like the Murray, seen in the dynamics of water and sediment transport and the ecological and evolutionary character of the native flora and fauna. Regulation has altered the degree of variability at various temporal and spatial scales. At a *seasonal* scale the river now is more stable, but in some areas there are *daily* changes associated with weir operations (see below) so that, depending on the observer's viewpoint, regulation has both decreased and increased variability. The significance of spatial scale is illustrated by contrasting *hydrological* changes with smaller-scale *hydraulic* changes that affect local erosion and deposition of sediment, the presence of snags and stands of water plants.

8.3.3 Hydraulic Effects

Discharge and volumes are common currency for river operations, including administration of the Cap, but they are difficult to relate directly to biological effects. To characterise the water-regime tolerances of plants and animals, biologists need information about parameters like the depth, timing and duration of inundation, the rates of rise and fall and the time since last wetting. Further, the scale of these changes is much smaller than those implied by discharge variations measured in gigalitres. Some river-edge plants are vulnerable to stage fluctuations of as little as 10 cm (Blanch et al. 1998a). Comparable differences in floodplain elevation determine flooding frequency and hence the localised distributions of familiar plants like river red gum (*Eucalyptus camaldulensis*) and black box (*E. largiflorens*).

Stage-discharge relationships developed for the Lower Murray lack sufficient accuracy for most biological applications. This is true, for example, of the *River Murray Hydraulic Model* maintained by SA Water (Maheshwari et al. 1993; Blanch et al. 1998b). More refined models are under development (e.g. Andrew Close, MDBC).

In this analysis we comment on the sensitivity of ecological (biological) phenomena to variations in stage, but it will be clear from the foregoing that predictions are difficult given only information about discharge at a hydrological scale.

8.3.4 Effects of Weirs

The emphasis on water levels (river stage) in ecological comparisons partly reflects the dominance of weirs as regulating structures on the Lower Murray. Isolated weirs may have minor effects, but the cumulative effects of 10 serial weirs are considerable. Their mere physical presence creates discontinuities in the amplitude of stage variations between successive weirs, and there is little scope to offset these effects by manipulating the crest height or panel and stop-log configurations (Lee et al. 2000). Routine operations by the weir keepers are designed to maintain a nominal tolerance of 50 mm above pool level, and these adjustments typically cause stage fluctuations of ±20 cm daily in the tailwaters (3-5 km) below each weir (Walker et al. 1992). At flows exceeding 60 000 ML d^{-1} all of the weirs are partly dismantled and present minimal obstructions to flow.

The weirs have changed patterns of sediment transport in the Lower Murray (e.g. Thoms and Walker 1992. Following the era of construction (1922-37), the river initiated a sequence of channel adjustments whereby sediment was eroded from the banks immediately below each weir and deposited in the pool above the next downstream weir. In effect, the river is assuming a stepped profile (3-m risers) in response to the imposed hydraulic gradient. This process is still incomplete in some pools, and the system may require another 100 years or more to develop a new quasi-equilibrium.

Salinity in the River Murray at Morgan is predicted to rise above 800 EC by 2010, due mainly to the effects of dryland salinity (MDBMC, 1999). In 1978 it was estimated that about one quarter of all salt entering the Murray in South Australia was attributable to the localised hydraulic effects of the weirs (EWS, 1978). Removal or lowering of weirs is not an immediate remedy, however, as there may be short-term increases in river salinity and restoration of a balance would take decades (e.g. NEC, 1988). Saline inflows are exacerbated also by sudden falls in the level of the river, as in the aftermath of a big flood (e.g. DEP, 1988).

8.3.5 Water Quality

Anecdotal evidence suggests that water quality in the Murray has declined, but there are few substantive data. For example, many long-time residents believe that turbidity has increased in the last 40 years. If so, this may have been due to the loss of wetlands (and wetland plants), poor land management and, in localised areas, the effects of carp (*Cyprinus carpio*). Regulation is also implicated, in that much of the sediment transported by the Murray is derived from the river banks rather than the catchment (Thoms and Walker 1992).

Regulated inflows of water from the Darling also contribute to turbidity in the Lower Murray. During the El Niño episode of the late 1980s, the demand for irrigation water was such that flows to the Lower Murray were made up mainly by Darling water stored and released via Lake Victoria (Mackay et al. 1988; Walker et al. 1992). Although South Australia’s water needs were met, the characteristically high turbidity of Darling water had striking effects on the growth and distribution of river-edge plants (cf. Walker et al. 1994; Blanch, 1998).

Nutrient levels are likely to have increased, reflecting agricultural and urban inputs (Gutteridge 1992), although the latter have largely been contained. Sedimentation in the weir pools may have increased nutrient storage in the channel and the limited exchanges with the floodplain will have reduced nutrient export.

The frequency of blue-green algal (cyanobacterial) blooms has increased (Codd et al. 1994; Webster et al. 1997), reflecting the coincidence of high phosphorus concentrations, thermal stratification, warm surface water and low flows, promoted by summer irrigation diversions.

8.3.6 Flora and Fauna

As regulation has increased there have been declines in the range and abundance of many species of native plants and animals, including fish, crayfish, turtles, frogs, birds and mammals. In their place, species like carp and willows have become naturalised.

Less obvious changes have occurred in the composition of littoral biofilms (e.g. Burns and Walker 2000). Rapid changes in water levels appear to have favoured the development of algae, rather than bacteria, in the biofilms that provide food for grazing invertebrates. This change may explain the decline of aquatic snail species in the Lower Murray (Sheldon and Walker 1997).

Littoral plants are a prominent feature of the channel, but it is not widely realised that prior to regulation the banks were largely bare (Walker et al. 1994; Blanch et al. 1999, 2000). Reeds (*Phragmites australis*), cumbungi (*Typha* spp.) and other plants formerly were best represented in floodplain wetlands, but have invaded the margins of the weir pools. The present riverine littoral community is an artefact of weir construction, but also a refuge for plants and animals, especially those typical of wetlands.

Changes in the flow regime have had major effects on floodplain environments. The eucalypt woodlands are degraded by lack of flooding (hence recruitment), salinisation, grazing and land clearance (Partners et al. 1990). Some wetlands receive flooding less often than they did under regulation, and others are permanently inundated by water backed up behind weirs. The state of wetlands, and limited opportunities for exchanges with the channel, are responsible for the decline of many aquatic species.

8.4 Analysis

8.4.1 Diversions after 1993-94

The Water Audit (MDBMC 1995) indicated that, if all 1993-94 water entitlements were realised, 12,344 GL would be diverted annually from the Basin. This assumes no significant increases in off-river storage or inter-valley water trading was allowed. In fact, private water-storage capacity has increased 2% annually (5,700-6,200 GL) since introduction of the Cap, substantially so in Queensland (MDBC unpublished data). Trading is also increasing. In 1997-98, 852 GL were traded temporarily or permanently – trading will increase further as rules are clarified. Given these changes, it may be useful to re-assess diversions under the *Full Development Scenario* of the Water Audit.

If the projected demand for water in Australia were constrained by economic activity alone, and not by water availability, demand in the Murray-Darling Basin would rise at about 2% annually to 18,000 GL/year by 2021 (Thomas 1999). The 1993-94 Allocation Limit of 17,392 GL /year includes *sleeper* and *dozer* licences[18] and off-allocation diversions, and from the practise of allocating more water than is available knowing that not all entitlement holders will use their full allocation. Since introduction of the Cap the Allocation Limit has decreased (15,707 GL in 1997-98 (MDBC unpublished data), mainly through restrictions to off-allocation.

The capacity to supply diversions is obviously limited by availability of water in the Basin. In an average year, the Basin water yield is 24,500 GL. Less than half would reach the sea under natural conditions, given losses to evaporation and seepage. Without the Cap, inter-valley trading and storage of off-allocation flows would drive diversions toward the allocation limit, within constraints imposed by climate and water availability.

Total climate-adjusted diversions from the Basin under 1993-94 levels of development (including the Lachlan) were 11,361 GL. Water use has exceeded this in three of the last 5 years, however until the Commission adjusts these diversions for climate it is difficult to ascertain whether they represent increased diversions since the Cap was introduced. The high water-use years are close to the *Full Development Scenario* of 12,344 GL.

8.4.2 Scenarios

This study compares four scenarios, using 1979-91 data provided by the Commission:

1. Modelled natural flows (no diversions)
2. Actual flows between 1979-91, (average diversions between 1979-91 were 8,532 GL/year)
3. Modelled flows under Cap Diversion Target (average diversion 11 309 GL y^{-1} which is a 25% increase in 1979-91 average diversions)
4. Modelled flows under Full Development Scenario (average diversion 13 097 GL y^{-1} which represents a 50% in 1979-91 average diversions).

Scenario 3 is close to the Cap target (11 361 GL/year). Scenario 4 is slightly above the Water Audit *Full Development Scenario* (13,097 GL/year compared to 12,344 GL/year), but is likely to represent diversions that would occur without the Cap, given demand, the increase in off-stream storage and water trading.

[18] 'Sleepers' are entitlements that have never been used; 'dozers' are entitlements that have been partially used.

The scenarios were used to generate hydrographs at three sites (Wentworth, Lock 1, Barrages, Fig.s 8.2a - 8.2b). Abstractions were increased monthly by 25% and 50% to represent the Cap *Diversion Target* and *Full Development Scenario* described by the Water Audit. At Wentworth and Lock 1 the minimum flow was set to the South Australian 'Entitlement Flow' (1850 GL y^{-1}), and at the Barrages it was set at zero. Abstractions were subtracted from actual flows until the difference fell below the minimal flow threshold, and the deficit then was re-apportioned among months with sufficient flows. This process was repeated until the increase in diversions was removed, and the data were used to generate monthly hydrographs (Figs. 8.2a, 8.2b) and flow duration curves (Fig. 8.3).

8.4.3 Hydrological Effects

Without the Cap, flows would have been reduced to base levels, meeting legal entitlements, between 80 and 90% of the time under the Full Development Scenario or 44% to 73% under the Cap Diversion Target compared to the 1979-91 20%. The average duration of periods of base flow would increase from 6 months to 13 or 8 months under Full Development or Cap Diversion scenarios respectively.

Table 8.1. Flow regime parameters (1979-91) under the four scenarios described in Section 8.4.2).

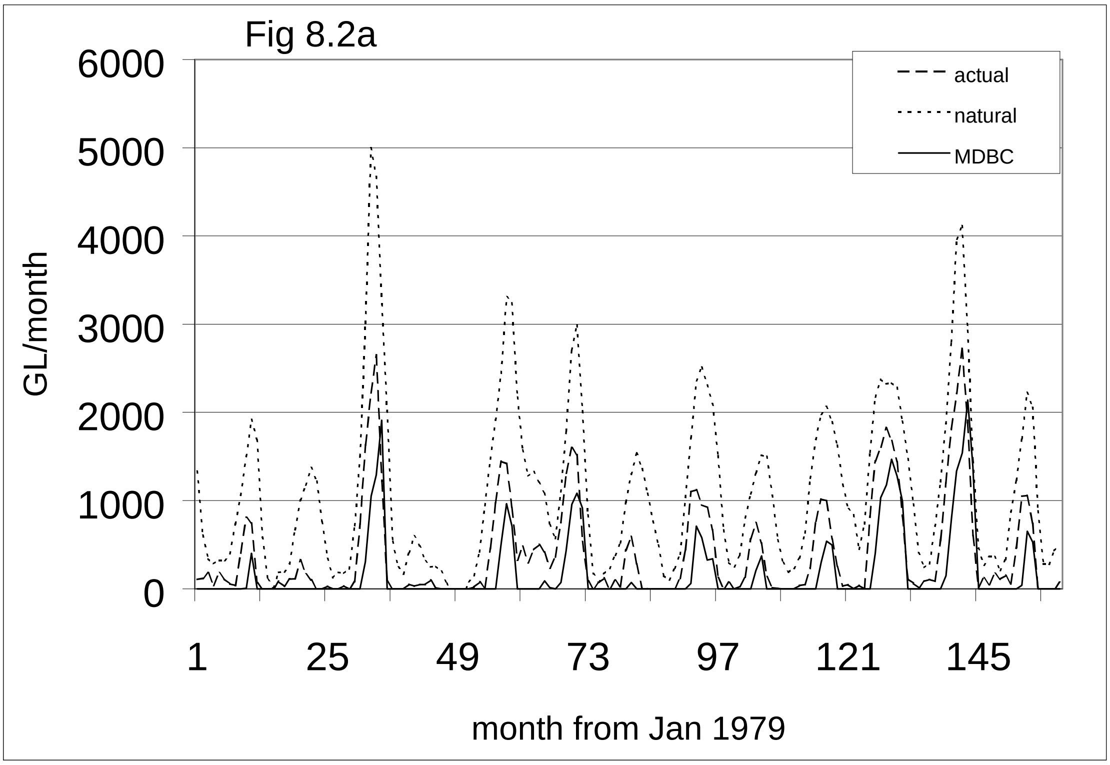
	Natural	Actual 1979-91	Cap Diversion Target	Full Development Scenario
Standard Deviation	1,193	658	345	540
Coefficient of Variation	0.92	1.11	1.45	1.23
% Time at low flow	2	10	27	42
Pairs of months with no flow change (%)	0	0	21	71
Minimum flow events	3	12	18	9

In the absence of the cap:

- Short-term variations in flow and stage would be reduced.
- The magnitude, duration and frequency of floods would be reduced. Flood magnitude would be reduced by 30-50%, depending on antecedent conditions.

Table 8.2 shows the frequency and duration of critical flow events (30 GL d^{-1} to inundate in-channel benches; 60 GL d^{-1} to inundate the floodplain downstream of the gorge; 100 GL d^{-1} to inundate the floodplain upstream of the gorge).

Figure 8.2a & 8.2b Discharge (ML/month at the Barrages. Natural = modelled natural flows with no diversions, Actual = Actual flows between 1979-91 (average diversion during this period was 8,532 GL/year, MDBC = Modelled flows at approximate Cap diversion target (average diversion 11,300 GL/year) and Full Development = Full Development Scenario (average diversion of 13,100 GL/year). Flows at the barrages under the Full Development Scenario (8.2b) are much lower than under the Cap Diversion Target (8.2a). Similar trends were observed at Loch 1 and Wentworth (data not shown).



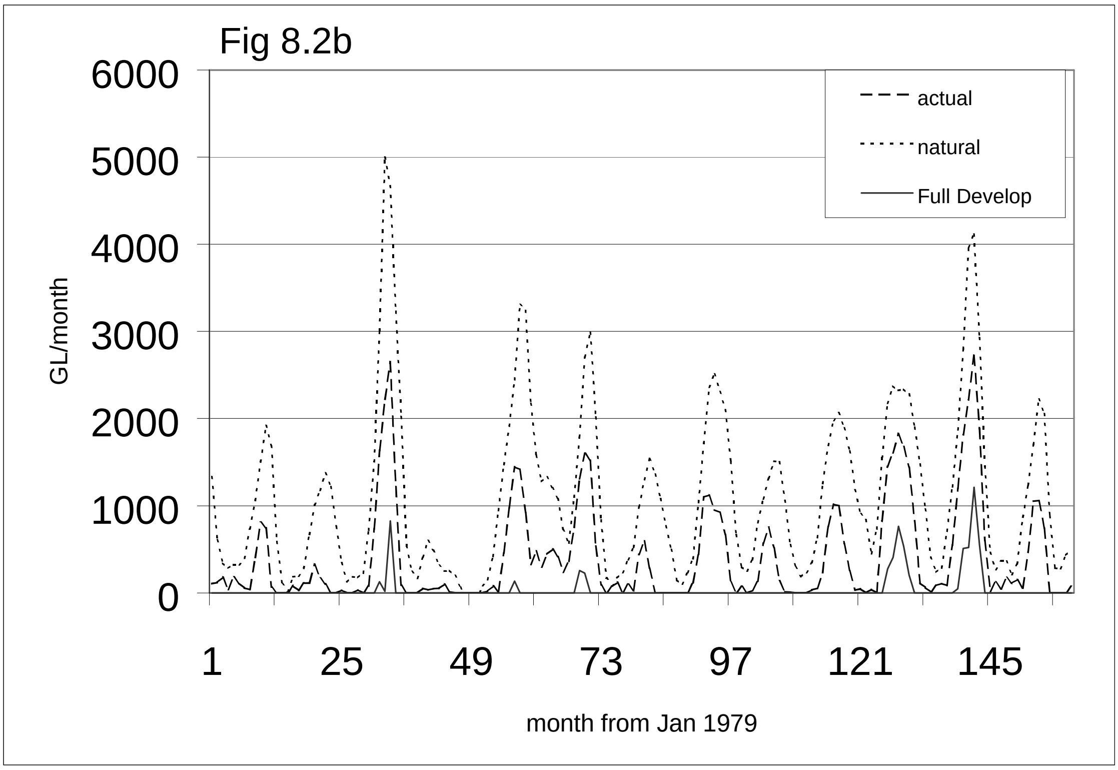


Figure 8.3 Flow duration curves for Natural = modelled natural flows with no diversions, Actual = Actual flows between 1979-91 (average diversion during this period was 8,532 GL/year, Cap Diversion Target = Modelled flows at approximate Cap diversion target (average diversion 11,300 GL/year) and Full Development = Full Development Scenario (average diversion of 13,100 GL/year). Graphs represent percent time flows (GL/month) are exceeded.

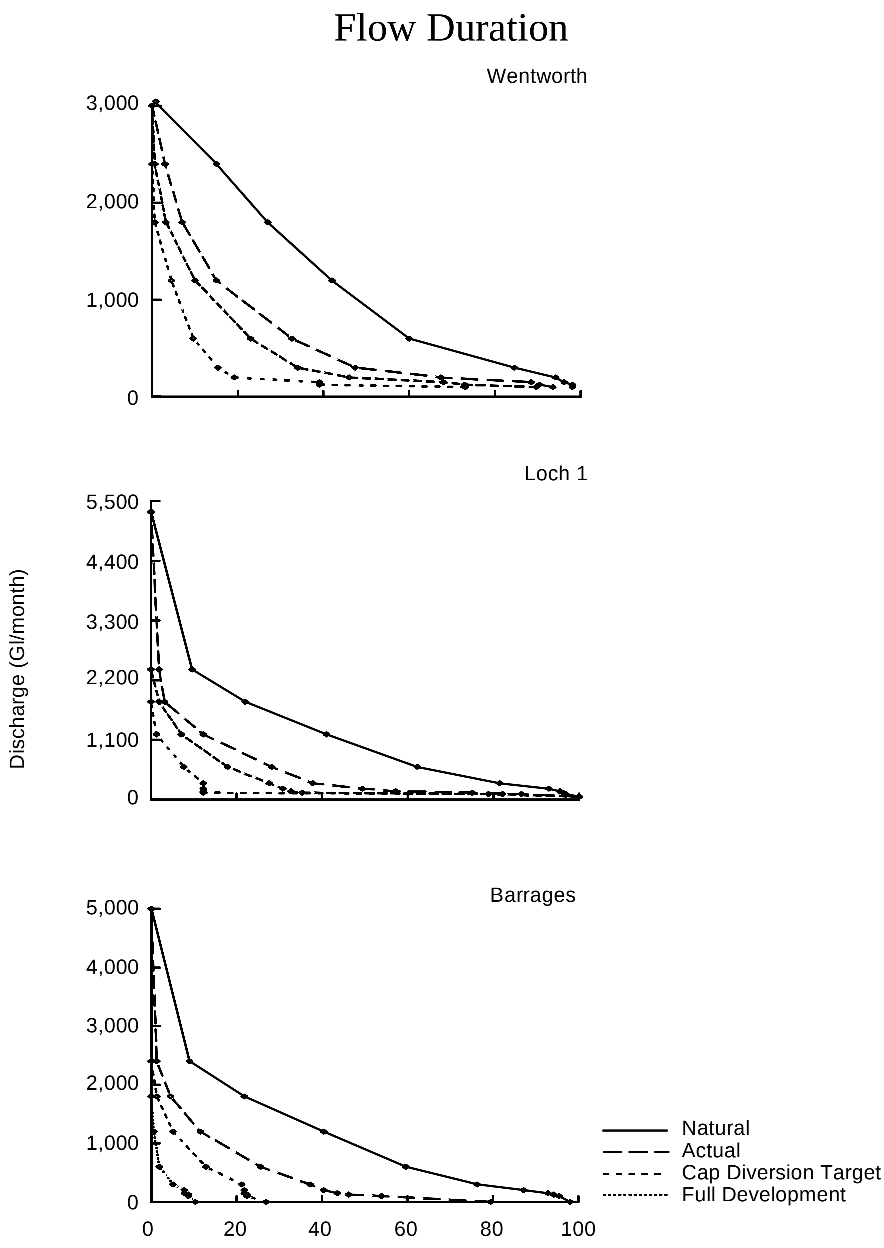


Table 8.2. Critical flow events with and without the Cap. The first number in the No Cap column refers to the Full Development Scenario while the number in brackets refers to the Cap Diversion Target.

	Percent of Months		Frequency of Occurrence	
	Actual	No Cap	Actual	No Cap
In-Channel Benches	20	7.5 (15)	9	4 (8)
Downstream Floodplain	7	1 (3)	5	1 (3)
Upstream Floodplain	2	0 (0.7)	2	0 (1)

The two development scenarios are founded on two assumptions. The first is that rainfall will remain constant, although global warming models suggest that SE Australia will receive less rainfall. Given lower rainfall, the Cap would protect the current levels of diversion and allow a greater proportion of the available water to be used, decreasing the water available for in-stream use.

The second assumption is that land management practices (hence infiltration and run-off relationships) will remain the same. This may be invalid:

- Global warming, increased demand for paper and declines in native forests point to the growth of agro-forestry, which may decrease water reserves.
- Present legalistic problems with definition of a 'water course' are allowing new farm-dam construction and floodplain harvesting in some regions.
- Groundwater utilisation may affect surface water availability. If the Cap induces people to increase groundwater abstraction, discharge to rivers and wetlands would be reduced.

8.4.4 Ecological Effects

8.4.4.1 Channel

The changes described by our scenarios would exacerbate the loss of habitat diversity, reduce the frequency and duration of exchanges between channel and floodplain and change the metabolic functioning of aquatic ecosystems.

Water Quality

Without knowing the relative contribution of Darling water to the Murray, it is not possible to predict the impact of increased diversions on turbidity. If development were to proceed equally across the Basin, and the protocols for regulation were to remain similar to those at present, the proportion of Darling water would remain roughly what it is today, subject to ENSO and other climatic cycles. If most development occurs in the north, the proportion of Darling water, and the turbidity, in the Lower Murray may decrease.

The effect of high turbidity on littoral plants was mentioned earlier (Section 6.3). When the late-1980s El Niño subsided there were dramatic changes in the diversity, distribution and abundance of water plants in the Lower Murray. The MDBC later commissioned Water EcoScience (Mt Waverley, Vic.) to determine whether there was a statistical link between high turbidity and low invertebrate diversity, but the analysis was inconclusive. Subsequent experiments suggest that turbidity does affect both the biofilm and the associated invertebrate community (Cooke, 1999).

Depending on the nature of the suspended material (Darling sediment is colloidal), more stable water levels and increased salinity could increase settling and thereby increase water clarity. This may promote growth of some aquatic plants (e.g. ribbonweed, *Vallisneria americana*), and also promote the development of algal blooms.

Reduced flows may reduce the nutrient load, but lead to evaporative concentration and accumulation of nutrients in sediments. Anoxic sediments will release phosphorus, but lead to denitrification. This may further increase the incidence of nitrogen limitation, and encourage blue-green algal blooms, given calm weather. If high-alert levels are to be avoided a flow of over 4000 ML d^{-1} between November and April is recommended (Jones, 1997). Present data suggest that under the *Full Development Scenario* flows would exceed the threshold in November in only two of 13 years (1979-91).

Algal Production

Without the Cap, discharge and short-term flow variation would have been reduced, altering the disturbance (light, exposure, shear stress) regime for biofilms. Low flows would promote biofilms dominated by blue-green algae (Cyanobacteria), but only in the superficial zone that receives light (Mullen, 1998; Burns and Walker 2000). These biofilms are not good-quality food for invertebrates (Sheldon, 1997).

High turbidity will also limit biofilm and macrophyte production and may promote planktonic production dominated by filamentous green and blue-green algae. These do not represent a good food source for zooplankton.

During high flows and floods, coarse organic material is exported from the river to the floodplain. As flow is reduced, CPOM accumulates in areas of low flow. Over time this will lead to oxygen depletion and this will slow the rate of decomposition as anoxic bacteria dominate. This process will reduce the availability of terrestrial carbon sources, effectively reducing metabolic activity in the river. It would also have the effect of releasing phosphorus from sediments, which is then available to planktonic algae. This effect is particularly prevalent in weir pools, but long-term problems are avoided by the regular removal of the weirs which allows the organic matter to be flushed downstream. The *Full Development Scenario* indicates that the frequency of weir removal would have decreased to three years in 10.

Invertebrates

Invertebrate communities apparently decline in abundance and species richness downstream from Mildura to Tailem Bend (Bennison, 1989). This decline has been attributed variously to increased salinity, turbidity due to Darling inflows and less seasonal variation in water level, and it may also reflect changes in fauna related to the prevalence of pool habitats and, given a change in faunal composition, the efficacy of the artificial samplers used in sampling. With increased diversions, salinity would increase and flow variability would decline. These factors alone suggest that the invertebrate community would have declined had the Cap not been imposed.

Reduced incidence of high flows will depress the numbers of animals dependent on flowing water and promote those typical of still water. This would reinforce the pattern whereby the channel now supports typical wetland species rather than riverine species, illustrated by the spread of the yabbie (*Cherax destructor*) and the virtual regional extinction of the Murray crayfish (*Euastacus armatus*).

The permanent wetlands associated with the Lower Murray provide an indication of the likely impact of less variable flow. Permanent inundation leads to a decline in invertebrate abundance and diversity (Maher, 1984 ; Maher, 1984).

Fish

The Lower Murray fish community is severely depleted, with 29% of 55 native species missing and others present in very low numbers (Harris, 1997). Native species represent only about 5% of the fish biomass, and the community is dominated by introduced carp and gambusia. Regulation has contributed by changing the physical habitat, including barriers to fish movement, favouring introduced species and changing the flow regime in ways that impact upon recruitment (cf. Humphries, 1999).

Without the Cap, three factors would be prominent:

1) *Migration*. Weir removal or over-topping during high flows are necessary preconditions for extensive fish movements in the regulated Lower Murray. Under present conditions, some weirs are removed seven years in every 10, and all would be removed two years in every five. Without the Cap, these figures would decrease to three years in 10 and <1 in 10, respectively. This would favour some species and discourage others (those dependent on floods for spawning or migration). The weirs may need to be removed for maintenance more frequently than these figures suggest, but the timing of weir removal may not coincide with high flows and peak fish movements.

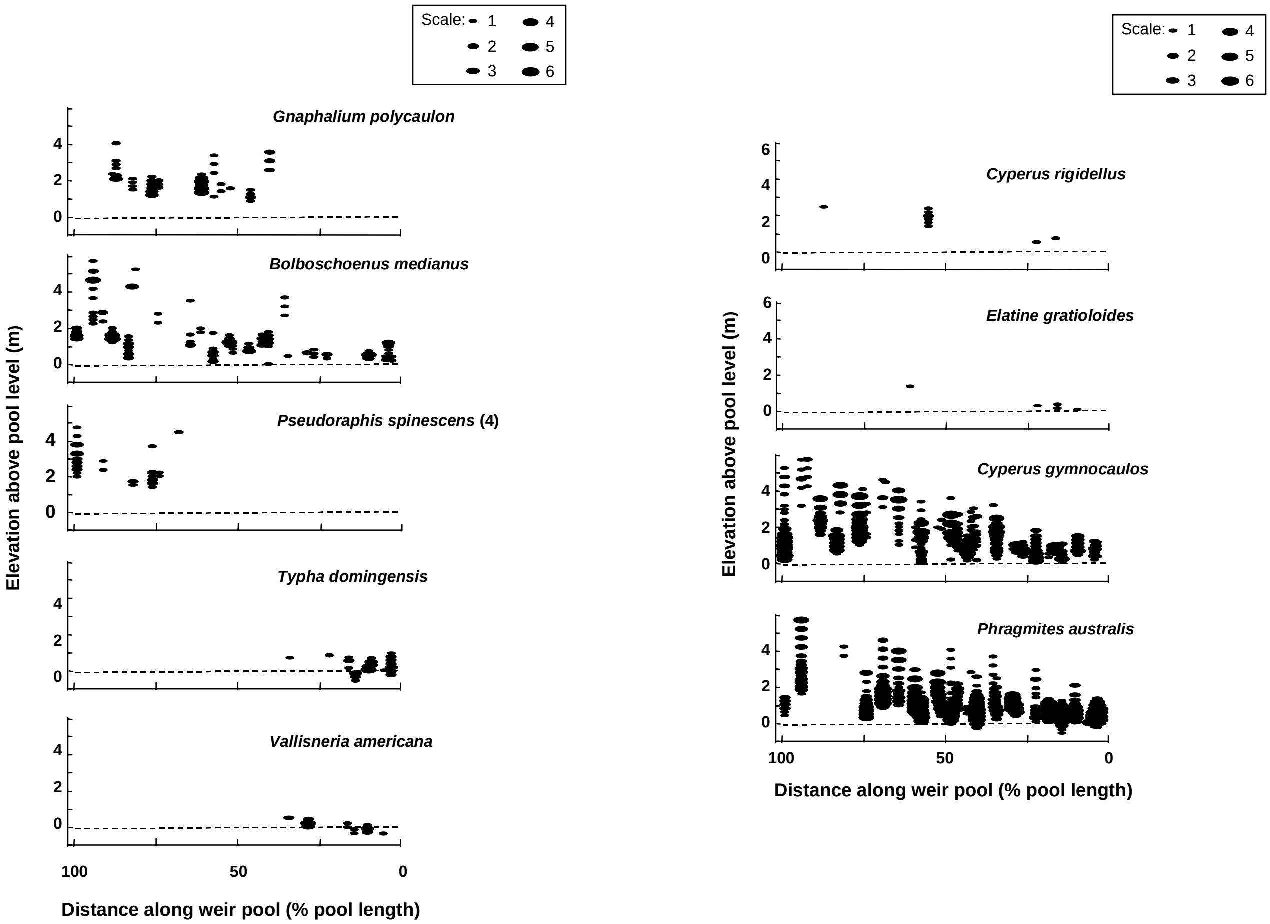
2) *Loss of floods*. Minor flooding (>60,000Ml/day) occurred twice in the 13 years examined, but without the Cap there could be no floods for even more prolonged periods. This would limit recruitment opportunities for many native fish. Even long-lived species like Murray cod (*Maccullochella peeli*) probably require floods at *minimal* 5-7 year intervals to maintain the population against fishing, predation, disease and other factors. Murray cod populations in the Lower Murray already are depleted, and a decrease in flood frequency would prejudice their survival, and that of many other species.

3) *Decreased flood duration*. Several native (e.g. bony herring, *Nematalosa erebi*; golden perch, *Macquaria ambigua*) and introduced species (e.g. carp) utilise floodplain habitats to spawn during floods. Carp make the most rapid use of these events, while native fish spawning is comparatively delayed (Ebner and Wilson, *unpublished*). Shorter floods may encourage carp and deny access to native fish.

Littoral Plants

Surveys of aquatic and semi-aquatic plants along the weir-pool margins show that the composition and distribution of species are strongly associated with gradients of water-regime, related to weir operations (Walker, 1992; Walker, 1994; Blanch, 1998; Blanch, 1999; Blanch, 1999). ‘Water regime’ here refers to patterns in the spatial and temporal distribution of water; it is the key environmental variable for wetland plants in habitats prone to drying.

Fig. 8.6 Distributional data for selected littoral plant species with distributions shown as a proportion of weir-pool length rather than absolute distances**.**



A summary of distributional data for selected species is shown in Fig.6.6 with distributions shown as a proportion of weir-pool length rather than as absolute distances. To illustrate, the herb *Gnaphalium polycaulon* occurs in areas flooded to >0 cm for a median 299 in 730 days, and in areas exposed by >100 cm for a median 157 in 730 days. This accords with its observed range of 40-85% along a pool, at 1-4 m elevation. Similarly, ribbonweed occurs where flooding is virtually continuous (median 729 in 730 days flooded to >0 cm), and never where exposure is >100 cm.

Forty-one of 48 surveyed species occurred at 4-6 m elevation above pool level in the uppermost 10% of weir pools, where levels fluctuate most, but 1-1.5 m in the lower 10%, where levels are more stable. All are species tolerant of flooding and exposure (e.g. common reed, *Phragmites australis*), equipped to occupy essentially any sites (except those below pool level) at 25-100% along a pool. Typical adaptations include clonal growth (e.g. *Paspalum vaginatum*), rapid seed production (*Xanthium* spp.), below-ground storage (*Bolboschoenus medianus*) and a rapidly elevating canopy (*P. australis*).

The remaining seven species, confined to within ±1 m of the water surface in lower-pool reaches, in water sufficiently shallow to allow photosynthesis (turbidity 30-80 NTU), included aquatic macrophytes like ribbonweed, cumbungi (*Typha* spp.) and ‘mudmats’ (e.g. *Glossostigma elatinoides*).

Without imposition of the Cap, our scenario indicates that flow variations would be restricted in frequency and/or magnitude. This would restrict the range of elevations where littoral plants occur. In effect, tighter control over water levels, as would occur in the absence of the Cap, would cause the littoral plant fringe to become narrower.

Littoral plants are a habitat for a variety of animals including birds (Clamorous reed warbler, *Acrocephalus stentoreus*) and small fish (Lloyd, 1986). It is likely that reductions in the distribution and abundance of plants would also lead to a loss of riparian faunal biodiversity.

It is a minor paradox that the littoral vegetation so conspicuous along the pools of the Lower Murray is an artefact of weir construction. Historical records suggest the banks of the unregulated river were devoid of plants for long periods, but the pools and seasonally more stable flow regime have allowed numerous wetland plant species to invade the channel, where they provide habitat for many aquatic and terrestrial animals.

8.4.4.2 Floodplain

Wetlands

Wetlands are productive and diverse environments providing water purification, flood mitigation, nutrient cycling, food production and other ‘ecosystem services’. Some Lower Murray wetlands have retained sufficient ecological integrity to warrant regional and national significance. Examples include Chowilla, Lindsay River and Walpolla Creek.

Few are unaffected by regulation. Some are dry for longer, or more often, than they were prior to regulation, and others are wet for longer, or more often, than prior to regulation. Without the Cap, most wetlands would receive shorter, less frequent periods of inundation. The effect would become more pronounced with distance downstream. The exceptions would be those associated with weir pools; these would receive less variable flows, given their direct connection to the channel.

Salinity levels would increase in permanent wetlands, in keeping with the river, and levels in some offstream wetlands would increase due to evaporative concentration. and seepage continue at the same rates. This would also increase nutrient concentrations, and may increase the frequency of blue-green algal blooms.

For permanent wetlands increasing abstraction above current levels may have little additional impact, although the loss of flood flows will further reduce their productivity, and thereby reduce the abundance of some invertebrate groups such as chironomids and yabbies. In the long-term changes in salinity during droughts and changes to water availability in the riparian zone may have an impact on the diversity of both higher plants and invertebrate groups.

Ephemeral wetlands will be far more dramatically affected. In the natural state these wetlands are more productive and diverse than permanent wetlands or the main river channel. Declines in the duration and frequency of inundation will reduce the diversity of those groups which emerge from resting stages in wetland sediments (eg rotifers and other zooplankters). Reduced duration may limit the ability of some groups, particularly fish and birds to complete their breeding cycles. This may have implications for populations of these animals in the main river channel or possibly across the basin. Overall damage to these systems would represent a major form of degradation for the whole river system.

8.4.4.3 Lake Victoria

Introduction

The management of Lake Victoria is currently under review. It is currently used as a water storage to ensure that the SA entitlement are available through summer when the Barmah choke would otherwise restrict water delivery. The Lake has also been used for flood mitigation through pre-releases and surcharging. The operation of the lake has been modified recently, primarily in order to ensure protection of culturally sensitive sites around the lake margins. The dynamics of the saline groundwater are also a priority as the operation of the lake has led to the formation of a freshwater halo around the lake and beyond that a rising mound of saline water. . There is very little information available about the ecology of the lake, but other deflation basin lakes in the region support abundant populations of native fish, birds and invertebrates.

If abstractions were to increase by to the Full Development Level, the flow regime in Lake Victoria would change quite significantly. The lake is currently essentially permanent although it does experience quite large fluctuations in water level. The amount of water available to fill the lake would decrease, while demands from downstream would increase or remain at current levels. Absolute evaporative losses would probably decrease due to reduced volumes in the lake, but as a proportion of the total volume held in the lake, losses would increase. This would result in the lake filling less frequently and having an increased probability of either drying completely or drying to a residual pool.

Water Quality

The most worrying possibility from this scenario is that the lower water levels and the potential for an extended dry phase during a drought would lead to the movement of highly saline groundwater into the lake. This saline groundwater would have a dramatic impact on the ecology of the lake and significantly reduce water quality for downstream users.

Maintaining the lake at a lower level is likely to have a detrimental impact on other facets of water quality. Shallow water exposes more of the lakebed to wave action that would increase turbidity. Greater proportional evaporative losses would lead to higher levels of salinity and nutrients which may not cause problems within the lake itself but may pose problems once the water is returned to the river.

Biodiversity

If Lake Victoria were to experience saline groundwater intrusion then the ecology would be dominated by this event. Increased salinity would have a rapid and detrimental impact on the diversity and abundance of all groups of plants and animals, with the possible exception of birds. At salinity levels of around 1500 EC the abundance of a limited number of invertebrate taxa can be quite high which can provide food for wading birds.

If saline intrusion could be avoided, the fluctuations in water level could be expected to lead to an increase in diversity of invertebrates and birds, although possibly a decline in fish species. The transition from terrestrial to aquatic habitat provides a greater diversity of habitats and allows some predator sensitive invertebrate species (eg fairy shrimp) to complete their life cycles.

Changes in Lake Victoria's flow regime and ecology would have a significant impact on the ecology of the river. Decreasing the average volume and therefore depth of the lake may have a beneficial impact on bird populations, but would have a detrimental impact on some other groups of animals, such as native fish (see below).

Fish

The greater variation in water levels may restore some of the boom-bust cycling to the dynamics of the fish community. If the lake experiences pronounced wetting and drying the fish community in the river will assume greater importance as a source of colonists. The absence of the Cap would probably have had a detrimental impact on the riverine fish community, which may have a significant impact on the fish community's ability to respond to the occurrence of favourable conditions in the lake. This would probably mean that over time, the fish community would be highly variable, but diversity would almost certainly decline.

8.4.4.4 Lakes Alexandrina and Albert

Introduction

Lake Alexandrina and Albert are large lakes that were once part of the Coorong complex, but are now isolated from marine influences by the barrages. The barrages ensure that the water within the lakes and lower river remains fresh to meet the requirements of Adelaide's urban supply and Mannum's and Lower Lake irrigation supply.

Increases in abstraction will result in these two lakes being terminal lakes for considerable periods of time. Our scenario predicts that there would be no flow leaving the lakes through the barrages 90% of the time.

Water Quality

The lakes already have significant water quality problems with frequent blue-green algal blooms of *Anabaena* and *Nodularia* and increasing salinity. The dramatic reduction in flow to the lakes would undoubtedly increase the frequency of these blooms. Without frequent floods to flush out sediments and nutrients and no through flow for most of any year the lakes would experience higher rates of sedimentation, increases in nutrient concentrations and increases in the temperature of surface waters. This would increase the likelihood of thermal stratification and phosphorus release from sediments.

With salinity already predicted to increase in this section of the Murray, further reduction of flows would magnify this effect in the lakes, because, although loads will decrease, concentrations will continue to increase as will evaporative concentration as water temperatures rise. As salinity now falls below acceptable levels for diverters, the frequency and severity of this problem would undoubtably have increased, which would have significant impacts on the economic viability of the surrounding irrigation developments.

The lack of flows and associated increases in sedimentation would also lead to the accumulation of metals and agri-chemicals in the sediments of the lakes.

8.4.4.5 Coorong and Murray Mouth

Introduction

The Coorong is a complex of marine, estuarine, hypersaline and freshwater wetlands of regional, national and international significance. Its importance is reflected in its status as a National Park, a RAMSAR Wetland and its protection under Japan-Australia and China-Australia Migratory Bird Agreements. Protection of the unique character of the Coorong is dependent on maintenance of the quality and diversity of aquatic and riparian habitats, which is dependent on flows through the Murray Mouth.

During winter and spring high flows maintain flows out of the mouth of the Murray, but during the dry summer months and drought years, the tide creates semi-marine conditions around the mouth.

Our scenario indicates that Murray flows into the Coorong would be dramatically reduced without the cap. There would be no significant flow 90% of the time. This would mean that habitat diversity within the Coorong would be reduced and that the dynamics of the Murray mouth would become dominated by marine influences. This would increase the probability of mouth closure, which would in turn lead to further degradation of Coorong habitat and flooding on the rare occasions that water passes the barrages.

Water Quality

Overall water volume will be reduced due to the lack of inflows, which would be exacerbated by closure of the Murray mouth.

Salinity is the over-riding determinant of the distribution of plant and animal communities in the Coorong. Prolonged periods of no freshwater inflows will lead to a significant increase in salinity. A short period of no flow during an El Nino cycle in the early eighties resulted in salinities rising to 140ppt in the south and 35ppt at the mouth (Geddes and Hall, 1992). This increase would be the minimum expected under conditions of increased abstraction. With closure of the Murray mouth and subsequent loss of exchange with the ocean, evaporative concentration would lead to much higher salinities.

Our scenario suggests that the only way that the only way that the Murray mouth could be maintained would be through dredging. The frequency of dredging would depend on the weather and tides but would represent a significant ongoing cost to the MDBC. The environmental cost to the Coorong would be reduced volumes of water that would lead to habitat loss. This scenario would also mean that salinities within the Coorong could only be 35ppt or higher, essentially destroying the Coorong’s estuarine character.

Biodiversity

The Coorong is diverse because of the range of habitat types that are present. These habitats are defined by the salinity regime. The dramatic reduction in freshwater inputs would reduce the diversity of habitats and thereby reduce diversity in the Coorong as a whole. Some vegetation types may be extirpated. The productivity of other vegetation types such as *Ruppia* spp is likely to be reduced. Prolonged periods of no flow may also reduce water level fluctuations in the Coorong, which would also affect the growth and survival of *Ruppia* spp. This would have a dramatic impact on the birds that use *Ruppia* for food (Edyvane et al., 1996).

The invertebrate community in the Coorong is already depauperate with only 21 species. It is thought that this is due to rapid changes in salinity caused by the operation of the barrages. The predicted increases in salinity would worsen the situation. While diversity is low, the abundances of some groups, such as isopods, are quite high. These invertebrates provide a rich source of food for fish and wading birds. An increase in salinity would reduce the available habitat to these animals as salinity increased above their tolerance threshold of 55ppt.

The bird community includes up to 85 species of water bird that are also dependent on the diversity of habitats provided within the Coorong and Lower Lakes. The lakes are particularly important as a drought refuge for many species.

Fish

The Coorong supports 15 species of native fish, seven of which have some commercial significance. A significant number of these require estuarine conditions to spawn. One example is Black Bream who require floods to achieve spawning condition. Congolli are primarily found in freshwater, but may require estuarine conditions to spawn. Our development scenario would result in prolonged periods, in which these fish would not be able to reproduce, which would significantly increase the risk of their extirpation from the Coorong.

The zooplankton of the Coorong is also dependent on inflows from the Murray. The zooplankton provides an important food source for small fish and the larvae of larger species. Loss of the seasonal inputs of zooplankton may result in decreases in the abundances of fish.

8.5 Conclusions

The projected increase in diversions to the *Full Development Scenario* would have a detrimental impact on the Lower Murray. The lower volumes passing down the river would mean a great deal less habitat variability, a significant reduction in the extent of interaction between the main river channel and it's floodplain, and a significant reduction in productivity. These changes are likely to compromise the ecosystem services currently provided by the river-floodplain ecosystem.

One of the most obvious ecosystem services in the provision of clean water. Increases in diversions would have a significant impact on water quality in the Lower Murray. This decline would inevitably have a negative impact on the human communities dependent on the river. It would also have an impact on the diversity and abundance of several groups of organisms including littoral plants and invertebrates.

Under current diversion levels there is some flexibility in the way that weirs, Lake Victoria and the barrages are managed. This flexibility allows water to be used to achieve social, cultural or environmental objectives. Our scenario indicates that if diversions were not capped then this flexibility would be lost and the river would operated purely and simply as a piece of water delivery infrastructure.

While current climactic and rainfall-runoff conditions persist, the Cap provides a measure of protection for the Lower Murray. It ensures that there is at least some water available to maintain natural linkages. Due to the variability of the system, and long lag times between the imposition of a stress and the ecological response it is not possible to say whether the Cap has halted the decline in the integrity of the Lower Murray. It is possible to say that if the Cap had not been imposed, the move toward a Full Development Scenario would have resulted in further dramatic declines in the condition of the river. This decline would have affected areas such as the Coorong and Lake Victoria far more severely than other ecological components.

9 Case Study 2 : The Condamine Balonne

9.1 The catchment

The Condamine Balonne catchment located in South West Queensland comprises 14 percent (143,000 km^2) of the Murray Darling Basin. The catchment headwaters are near Killarney, on the Great Dividing Range, and the river flows in a south westerly direction joining the Barwon Darling in north west New South Wales upstream of Bourke. The Condamine Balonne River system is an allogenic river – it forms in a well-watered headwater area and flows for most of its length across a dry landscape.

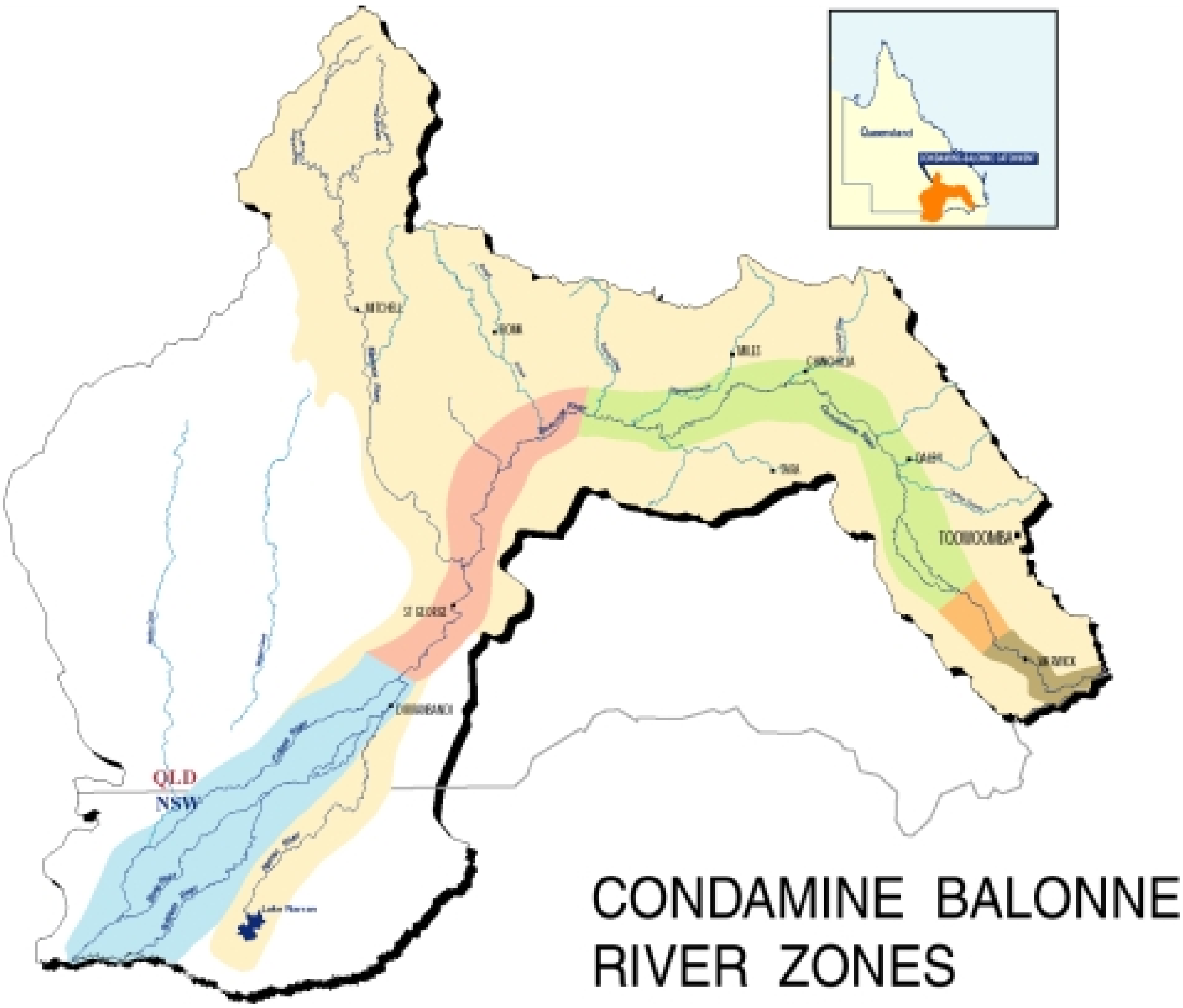


Figure 9.1: River zones of the Condamine Balonne system.

The Condamine Balonne is a geomorphologically complex river system. Thoms and Burgess (1997) have identified five main river zones (Figure 9.1) each with its own distinct set of riverine habitats. These are described as follows.

- *Constrained upland zone* dominated by a high energy, boulder / cobble bed channel that has no floodplain.

- *Armoured zone* characterised by relatively immobile bed sediment, riffle/pool sequences and small flanking floodplains.

- *Mobile zone* with highly active river bed sediments and channel morphologies.

- *Meandering zone* with extensive floodplains, sandy in-channel sediment deposits, and numerous billabongs and abandoned channels on the floodplain.

- *Anabranch /anastomosing zone* with multiple channels and extensive floodplain wetland system.

A significant feature of the Condamine Balonne system is the large inland floodplain wetland complex located downstream of St George (Figure 9.1). It is listed as an ecologically important Australian Wetland (DRP001QL) and is typical of many floodplain wetland complexes in the Darling catchment. Also located in this region is Lake Narran a RAMSAR listed wetland.

Flow variability is a feature of the Condamine Balonne River system. The co –efficient of variation in average annual discharge ranges from 85 in the Culgoa River at Woolerbilla to over 200 in the Briarie Creek at Hebel. Flow variability is considered to be an important element contributing to the ecological productivity of the riverine ecosystems in the catchment. The Condamine Balonne catchment contributes approximately 20 percent of the long term median annual flows in the Darling River at Menindee. However, there are limited high quality flow data for the river downstream of St George, due large quantities of water conveyed across the extensive floodplain surfaces.

Across the region European settlement commenced in the 1830s, but large-scale intensive irrigation and flow regulation began relatively recently (Thoms *et al*., 1995). Whilst there are no large dams in the catchment there are a number of smaller structures that essentially regulate flows for irrigation developments and have a significant impact on the hydrology of the river (Table 9.1). Moreover, irrigation development in the catchment is extensive resulting in loss of floodplain area (Table 9.2).

Table 9.1 Hydrological change in the Condamine Balonne system at St George. Simulated flow data (IQQM) are given for the 1900 – 1998 period. [ARI = Average Return Interval)

	Natural	Current	% Change
Median annual (ML)	976,997	688,457	- 29.53 %
1.5 ARI (ML/Day)	31,813	16,672	- 47.59 %
2 ARI (ML/Day)	56,287	43879	- 22.04 %
5 ARI (ML/Day)	123,663	118,268	- 4.63 %
10 ARI (ML/Day)	183,788	166,832	- 9.22 %

Table 9.2 Floodplain development in the Condamine Balonne downstream of St George.

	1988	1999
Cropped area (ha)	4, 300	38, 650
Dam storage capacity (ML)	54, 750	592, 500
Dam surface area (ha)	1, 825	19, 750
Total area (ha)	6, 125	58, 400

9.2 Water management in the Condamine Balonne

The Department of Natural Resources (DNR) administer water management in Queensland under the Water Resources Act 1989. The Water Allocation and Management Planning (WAMP) process (WAMP) implemented by DNR aims to provide guidelines that will encourage efficient and ecologically sustainable use of water. This process has been accepted, by the Ministerial Council's Independent Audit Group, as the means by which Queensland will comply to the cap. The Queensland Cap is to be established in terms of end of valley flow objectives following completion of the Condamine Balonne WAMP.

A WAMP plan provides environmental and hydrological analyses with the aim of providing a framework for fair, efficient and ecologically sustainable use of water. There is a defined process for developing a WAMP, this being:

1. Define total water resources in the catchment
2. Identify existing entitlements in the catchment
3. Determine environmental flow provisions
4. Reserve additional priority water requirements
5. Define water resources available for further allocation
6. Existing entitlements will be defined under the hydrologic model and, where appropriate will become tradeable
7. Rules for further allocation and management will be described.

At present the Condamine Balonne WAMP has not been implemented. A Cap will be implemented upon completion of the WAMP. However, a condition of the allocation of Bulk Water Entitlements under the WAMP is the development of a River Operations Management Plan (ROMP). The ROMP details the operational procedures and rules to be applied to actually achieve the Environmental Flow Objectives and Water Entitlement Objectives detailed in the WAMP.

Under the Queensland Water Act, water rights are linked to a property therefore water trading requires buying and selling property. Some individuals, particularly those in the lower Balonne, rely on flooding to fill floodplain waterholes and these users are not licensed. Currently there is no provision in the Queensland legislation to control the diversion of water that is not contained within the bed and banks of a watercourse ie, floodwaters. Hence the interim Cap arrangements in the Condamine Balonne are restricted to instream diversions. Floodplain development and water harvesting of floodwaters has continued to occur beyond 1993/94 levels.

9.3 Relevant reports to assist with Water management

- Condamine Balonne WAMP Environmental Flow Technical Report, 138pp.
- McCosker, R. O., (1996) *An environmental scan of the Condamine - Balonne river system and associated floodplain*. Queensland Government Department of Natural Resources - South Region.
- Sims. N., Thoms, M.C. and Ogden, R.W., (1999*). Large scale habitat mapping of the lower Balonne floodplain*. Report to the Lower Balonne Floodplain Management Committee.
- Sims, N., Thoms, M.C., Levings, P.F. and McGinness, H.M., (1999). *Large scale vegetation response to wetting on the Lower Balonne Floodplain*. Report to the Lower Balonne Floodplain Management Committee.
- Wylie, P. B., (1993) Land use in the Condamine-Balonne-Culgoa catchment. **In:** *Water quality management in the Condamine-Balonne-Culgoa catchment* (S. J. Kenway, ed.), pp. 1-50. Condamine-Balonne-Water Committee, Dalby, QLD.

9.4 Issues with the ecological sustainability of the Cap in the Condamine Balonne Catchment

The Condamine Balonne WAMP has not as yet been implemented. Hence, the following addresses those issues that are likely to occur upon implementation and compliance to the Cap in the Condamine Balonne.

The hydrological regime is recognised as an important factor in determining the distribution and structure of plants and animals in riverine ecosystems (Clausen and Biggs, 1997; Poff and Allan, 1995; Beumer, 1980; Jowett and Duncan, 1990). The science of environmental flow allocation is concerned primarily with the maintenance of appropriate hydrological regimes in such a manner as to facilitate natural populations of biota and physical and chemical processes. There are many models used for developing environmental flow requirements, such as the Instream Flow Incremental Methodology (IFIM) developed by the United States Fish and Wildlife Service (Bovee, 1982), the physical habitat component of IFIM (PHABSIM) (Jowett, 1982) as well as the Building Block Methodology (King, 1999). The differences between alternative environmental flow models are considerable; however, the basic premise of maintaining an ecologically sustainable hydrologic regime is common. Emphasis is placed on deriving a regime rather than providing a simple allocation of water.

Rivers are nested hierarchical ecosystems and hydrological change through water resource development may influence all or some of the various hierarchies. Following the scalar approaches of Schumm (1988) for the investigation of geomorphic processes and Salo (1990) for biological communities, it can be shown that ecological processes in rivers may respond to three scales of hydrological behaviour (Thoms and Sheldon, 2000): the *flow regime* (long term, statistical generalisation of flow behaviour - macro scale influences that extend over 100's of years*); flow history* (the sequence of floods or droughts - meso scale influences between 1 to 100 years); and, the *flood pulse* (a flood event – micro scale influences that generally extend less than one year). It is apparent that water resource development in the Condamine Balonne catchment has had a marked but variable impact on all three hydrological scales.

The Cap, does not recognise the importance of flow changes to the entire hydrological regime. Capping diversions in the Condamine Balonne at the 1993/94 level only addresses *flow regime* issues. Flow history and flood pulse parameters will also have important influences on the structure and functioning and ultimate health of riverine ecosystems. For example, Baldwin and Mitchell (2000) suggest that changes in wetting and drying cycles (*flow history*) can have a significant influence on the flux of carbon and nutrient between rivers and their adjacent floodplain. Thoms and McGinness (in press) calculate reductions of up to 85 percent in the potential supply of dissolved organic carbon from the lower Balonne floodplain due to changes in the wetting/drying regime associated with water resource in the Condamine Balonne.

Hydrological analyses of flows in the Condamine Balonne by Thoms and Sheldon (2000) also suggest that flow variability is a feature. This variability is important for the flora and fauna of these rivers. For example Walker *et al*., (1995) suggest that where floods are unpredictable in terms of their timing, species with flexible life cycles are likely to have a selective advantage (Baird *et al*., 1987). In contrast, sedentary organisms such as attached algae or attached aquatic macrophytes will be at a disadvantage in those environments that experience rapid rise and falls in water levels (a *flood pulse* parameter). Similarly increased rates of draw down due to water abstractions on the falling limb of the hydrograph have been reported to have increased rates of bank erosion in the Condamine Balonne.

In order to determine a suitable flow regime the hydrological character of a river system, to be managed, must be defined. Clausen and Biggs (1997), Hughes and James (1989), Poff (1997), Puckridge *et al.* (1998), Richter *et al.* (1996) and Toner and Keddy (1998) have all presented methods in which to define the key hydrological components of river systems.The Cap assumes that changes in flow will have a major influence on the health of the Condamine Balonne. River health, however, is a function of many factors (Norris and Thoms, 1999). Catchment conditions and in particular the nature of adjacent floodplain surfaces (Thoms et al., 1999) can also influence river health. Lateral connectivity where there is a periodic connection between the river channel and its floodplain is important for the transfer of materials and the resetting of river ecosystems.

Extensive floodplains are a feature of the Condamine Balonne. However, they have been subjected to large scale development resulting in substantial loss of natural surfaces (cf. Table 7.2). This can be expected to have a significant influence on the lateral transfer of carbon and nutrients between the floodplain and its river channel, an important feature in maintaining the integrity of river-floodplain systems. In the lower Balonne, Thoms and McGinness (in press) calculate reductions ranging from 8 to 40 percent in the potential supply of dissolved organic carbon from the lower Balonne floodplain due to the presence of developments on the floodplain for a range of floods (Figure 7.2).

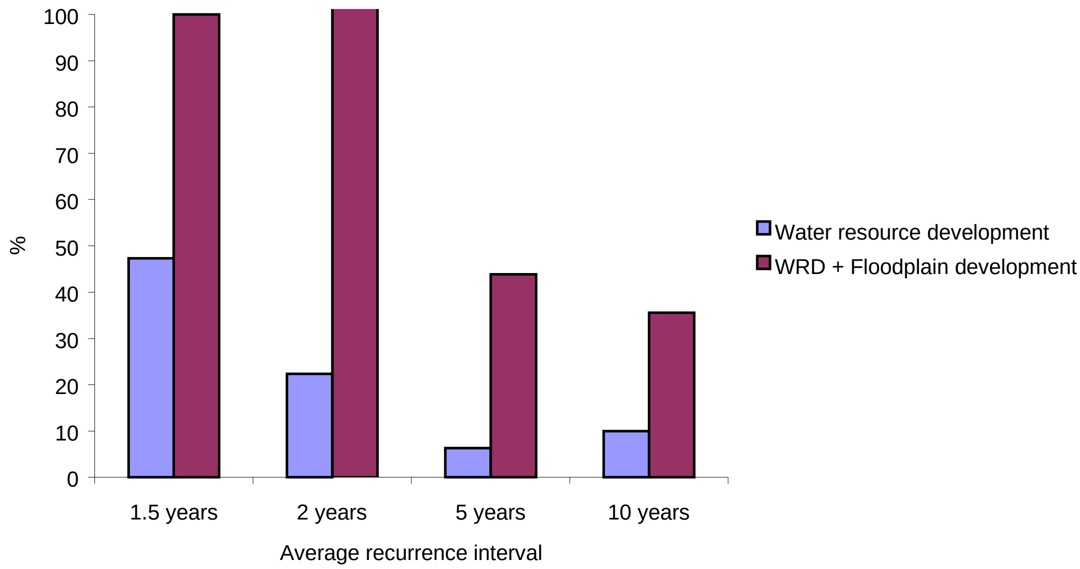


Figure 7.2 The reduction in potential dissolved organic carbon supply from the lower Balonne floodplain (Thoms and Mc Ginness, in press).

Floodplain ecosystems are an important component in the overall health of river systems in the Murray Darling Basin. However, Cap compliance in the Condamine Balonne has only focused on instream issues – a major flaw in this part of Murray Darling Basin. Moreover, floodplain development still continues in the Condamine Balonne and current levels far exceed 1993/94 levels. Moreover, significant floodplain water harvesting is associated with these developments. These activities are not licensed and appear to continue unabated.

Continued floodplain water harvesting has the potential to significantly influence the long term ecologically sustainability of the lower Balonne floodplain system. A study by Sims *et al*., (1999) on the long term vegetation response to inundation in the lower Balonne has demonstrated that the vigour of floodplain vegetation increases dramatically during a 5 to 40 day period following a flood. However, between 1985 and 1999 there has been a slight but significant decline in the median Normalised Difference Vegetation Index (NDVI), a commonly used index of vegetation vigour, for the entire lower Balonne. This has resulted from increased water stress and is associated with significant water resource and floodplain development in the region. Indeed some floodplain regions experienced marked changes in NDVI with noticeable declines since 1993. The response of floodplain vegetation to environmental disturbances such as water stress, lags the onset of disturbance. Hence, if a Cap were to be implemented in Condamine Balonne *under present conditions ecological degradation would still continue.*

As outlined earlier river systems respond to three scales of hydrological behaviour: the *flow regime; flow history* and the *flood pulse*. It suggested here that the initial impact of water resource development will always be centred on a change in the nature of the flood pulse, and that continued change will result in a change in flow history leading eventually to change at the scale of the flow regime. The time scale of ecological change through this hierarchy from organism level responses, through population and community changes and finally ecosystem change will depend on the organism, or group of organisms or ecosystem component in question. This suggests that with any hydrological change there will be a 'lag time' before the ecological response can be detected, and the extent of this lag time will change with the component in question. For many of the more familiar organisms (large fish, riparian trees) there would be a considerable 'lag-time', where recent hydrological development may take decades to be transferred into detectable environmental impact. For example, Thoms and Walker (1993) have demonstrated that the physical responses of the lower River Murray to weir construction are still incomplete after 70 years.

A major objective of the WAMP is to provide recommendations for ‘end of valley flows’ in the Condamine Balonne. Downstream of St George the Balonne bifurcates into six channels, the Culgoa, Balonne Minor, Briarie, Ballandool, Bokhara and Narran Rivers. The majority of these flows flow into the Barwon River in New South Wales. However, hydrological modelling and river assessment completed for the WAMP ceases at the Queensland – New South Wales border, some 100 kilometers from the Barwon confluence. Very little attention has been paid to the ecological downstream of the border crossings. This serves to illustrate that Cap compliance within the Murray Darling Basin appears to be focused at the sub catchment level. There is little emphasis at the Basin or whole catchment scale.

Catchment areas are highly variable in their physical, chemical or ecological character. For example, it is well known that some sub catchment areas are relatively more important that others in the supply of water at Menindee in the Barwon Darling catchment. Preliminary studies on dissolved organic carbon sources in the Barwon Darling Basin suggests that up to 73 percent of the potential supply at Bourke is derived from the Condamine Balonne catchment.

Further development in the Condamine Balonne catchment is likely to have a dramatic impact on ecological functions and eventually the sustainability of the river system downstream of Bourke. There is a serious risk that a Cap implemented in the Condamine Balonne (based on the WAMP) will fail to recognise the relative importance and potential impact of water resource development in this sub catchment on the ecological sustainability of the entire Basin.

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11 Appendix

11.1 Appendix 1: Summary of Government and CAC Submissions

Government and CAC Submissions to the Review of the Operation of the Cap addressing Ecological Sustainability of Rivers. Submissions are prefaced by a short description of that States implementation of the Cap.

Submission	***Summary of main points relevant to Ecological Sustainability of Rivers***
Commonwealth Government submission	• The Commonwealth has supported the Murray Darling Basin Cap from its inception based on the need for immediate action to ensure the long-term health of this river system and to ensure agricultural industries and the rural communities they support have a viable and profitable future. • The MDB contains 30,000 wetlands, which include eight recognised under the Ramsar convention as wetlands of international importance. • There is little doubt that the health of the rivers of the MDB depends upon how much water is removed from them and when it is removed. • Probably the single biggest and most widespread effect of water harvested from the catchment of MDB for agriculture, urban or industrial purposes has been to reduce the number of small to mid-range floods in the river. • Wetlands have suffered from reduced flows with Macquarie Marshes 50% smaller in area, Victorias marshlands 70% smaller and the Lower Gwydir couch wetlands 90% of their original size. • Measuring the environmental benefit of the Cap is difficult because: - Long term baseline data on river health is limited or unavailable - Impacts of water regulation on river health are compounded by the impact of water regulation, and - Differentiating between the impact of the Cap from other water management strategies is difficult • As knowledge of environmental flow requirements improves, the provision of environmental allocations is likely to require adjustment to the level of the Cap to remain consistent with the COAG water reform requirements. • A list of future research projects is presented which includes: - Developing and implementing methods for assessing the effectiveness of the Cap in achieving ecological sustainability, including an assessment of existing databases - Determining the environmental costs including the value of ecosystem services provided by the riverine environment, and - An investigation to be undertaken of options for returning water to the environment from water savings paid by the Commonwealth. • The Cap must include increased diversions to private storages including farm dams. • The impacts of the Cap on groundwater abstractions must be identified so that groundwater sustainability is not jeopardised by tighter controls on surface water extraction. Water resource management should be holistic.
New South Wales Government Submission	Cap compliance in New South Wales varied between valleys. The Cap was considered to be exceeded in four valleys, the Murumbidgee, Lachlan, Barwon-Darling and the Border Rivers.

	Diversions in New South Wales regulated streams totalled 6579 GL in 1997/98[19]. • "…the Cap is part of an evolving process that in combination with other water management initiatives will lead to improved long term environmental, economic and social outcomes for the Basin community." • In the Project Brief for the Review of the Operation of the Cap sustainability "infers the balance that our Basin community and Government seeks between supporting consumptive use for agricultural production and ensuring our rivers are resilient enough to maintain key ecological processes". New South Wales submission argues that this definition is too narrow and ignores other aspects of sustainability. New South Wales's argues that the definition must include the principles of Ecologically Sustainable Development, which includes: ∗ Precautionary principle. ∗ Inter-generational equity, ∗ Conservation of biodiversity and ecological processes ∗ The improved valuation and pricing of environmental resources • If the Cap is not maintained over time, hydrologic stress on our rivers will increase and the ecological improvements targeted by environmental flow rules and other initiatives will be diminished or not achieved. • Paroo and Warego Rivers originating in Queensland are two Basin rivers in a relatively (hydrologically) undisturbed state, and have highest conservation priority. Queensland's non-compliance with the Cap threatens these systems with environmental values in New South Wales threatened by developments in Queensland. • A list of indicators of ecological impacts of water diversions and river regulation presented. This includes rising salinity, loss in size and function of wetlands, impacts on riparian and floodplain vegetation, birds and fish, increases in algal blooms and a loss of conectivity between rivers, wetlands and their floodplains. • Can not separate effects of Cap from other water reform currently occurring in New South Wales.
Water reforms. A Stressed Rivers Approach to the management of water use in unregulated streams. 1997. DLWC. And Stressed Rivers Assessment Report. New South Wales State Summary. 1998. DLWC	• Stressed river classification has been undertaken in New South Wales for unregulated rivers. These are rivers which do not have major rural dams, and where water users rely on natural flows for their supplies. However, the flows in these rivers can be affected by town water supply dams and weirs. Regulated rivers in New South Wales are considered as stressed. • Past policies of allocating licences on unregulated streams have, in many cases, resulted in over-use of resources and damage to the riverine flora and fauna, including wetlands. • New South Wales embargoed all further licence applications when the Cap was introduced in 1993/94. • A key outcome of the stressed rivers analysis is the prioritisation of catchments for immediate attention. • A index of hydrological Stress was developed for unregulated streams. The index was derived by proportioning water extraction to the 80^{th} percentile flow (50^{th} percentile in some ephemeral streams). • Environmental stress was assessed separately by determining stream

[19] MDBC 1999 Water Audit Monitoring Report 1997/98

	health indicators. These indicators included geomorphological, biological and chemical indicators. • The results of the Stressed Rivers Assessment for New South Wales Unregulated streams in the MDB were that under existing conditions 85% of streams assessed indicated medium or high environmental stress with 49.6% of streams exhibiting a high degree of environmental stress. It is recognised that environmental stress reflects problems caused by factors other than water abstraction. Hydrological stress was however, one of the major stressors on the system. 32.5% of streams had a high level of hydrological stress (greater than 70% of 80th percentile flow extracted) and a further 24% with a moderate level of hydrological stress (between 40 and 60% extraction). This high proportion of streams exhibiting high hydrological and environmental stress has occurred under the current levels of diversions. The Cap does not reduce these levels of diversion. • The stressed rivers classification was also undertaken assuming full water licence development scenario. Under these conditions the proportion of streams having a high level of hydrological stress increases from 32.5% to 52 % and the number of low hydrological stress streams reduces from 43.7% to 25.8%. The Cap protects unregulated streams from unsuitable future development.
Long term water management in NSW - moving towards a sustainable future for the Murray-Darling Basin. NSW Government submission to Review, 1999.	• This paper indicates that NSW embraces Cap and argues that the Cap is as an essential step in the process of sustainable water management. • It also recognises that there is a fundamental limit to the level of diversions that can be sustained. • The Cap is seen as providing 'breathing space' to allow the development of environmental flows etc. • Water management plans will be the main vehicle for managing rivers. These plans will have clearly defined environmental objectives.

Victorian Government Submission	Victorian diversions were within Cap for 1997/98 for all valleys for which a Cap diversion target has been set. Total diversions were 3746 GL, 94.5% of the Cap diversion target of 3964 GL[20]. • *"Victoria, is very strongly committed to the Cap, …"*. A view endorsed by the newly elected government. • Victoria recognises that water harvested by upper catchment farmers can have serious consequences for downstream users and environments. • 200,000 ha of plantations in Victoria's NE will reduce inflows to the Murray by 400 GL, which is equivalent to 25% of Victoria's diversion from the Murray. This calculation assumes a reduction in runoff of 2 ML/ha when landuse is changed from annual pasture to plantation forestry. Submission argues that without downward adjustment of the Cap to account for lowered streamflows, the purpose of the Cap, to protect end of system flows, will be undermined. • Anomaly of groundwater being outside the Cap, given that the resources are physically connected. • Victoria has adopted the position that the Cap should be lowered to reflect any water returned to the Snowy. • Bulk Water Entitlements account for 98% of water diverted from Murray tributaries in Victoria. • Integrity of the Cap is threatened by if overuse in one year does not have to be "made good' in the following year.
South Australian Government Submission	Diversion for South Australia in 1997/98 was within Cap. Diversions (excluding Metro-Adelaide) totalled 478 GL, which was 85% of Cap diversion target. Metro-Adelaide's diversions were 153 GL. • "*The South Australian community is generally supportive of the Cap,* …..". The Cap has been widely identified and accepted, in South Australia, as a significant contributing factor in slowing the decline of the Basin water resources. • South Australia proposes a complete sustainable rivers program to address flow regimes, timing and water quality issues in addition to the volumetric rationale of the Cap. • The Cap does not effectively address ecological sustainability, although it has been effective in slowing its decline. Significant degradation of the riverine environment continues across the Basin. This indicates an inequity between consumptive users and the environment. • Submission argues that there is a need to identify and address impacts of farm dams on river flows. • The affects of all activities influencing flows, including all proposals for environmental enhancement, such as wetting and drying of wetlands and changes to flooding regime of floodplains, should be assessed form a whole-of-river perspective. • Greater communication between States on the downstream effects of water management decisions is required. • Degradation of strategic areas such as Chowilla floodplain, Coorong, Lower Lakes and Murray Mouth highlight the need to address flow management and timing through a whole-of-basin sustainable rivers program underpinned by the Cap.

[20] This figure does not include diversions from the Wimmera-Mallee where Cap diversion target has not yet been set. MDBC 1999 Water Audit Monitoring Report 1997/98.

Queensland Government Submission	Determination of a Cap for Queensland has yet to be completed. Diversions[21] of 741 GL were recorded for 1997/98, compared to 338 GL in 1993/94. • Water management is currently been determined through the Water Allocation Management Planning (WAMP) and Water Management Planning (WMP) processes. • Examples of how environmental water requirements are determined have been presented, for example the Condamine-Balonne Environmental Flows Technical Report and Current Ecological Condition of the Border Rivers (both reviewed later). • As part of the WAMP process, the current condition of the riverine environment was determined, as were the effects of flow diversion on the hydrology of the river using an IQQM.
Border Rivers Flow Management Planning Reports (3) 1999 QDNR/DLWC • Overview of Border Rivers Daily Flow Model (IQQM) • Water Use and Flow Performance • Current Ecological Condition of Streams in the Border Rivers Catchment & Addendum	These reports present an appraisal of the current ecological condition of the Border Rivers using a combination of site inspection and rapid assessment techniques to produce an Index of Stream Condition, AUSRIVAS data from MRHI program and some existing fish community information collected as part of an NRMS project (Moffatt). They also report on the development of an Integrated Quality Quantity Model (IQQM) which is used to generate flow statistics for the Border Rivers for the 1991/92, 1993/94, 1998/99 and double the 1998/99 levels of abstraction. The salient points are: • Abstractions continue to rise in this valley: Queensland and New South Wales on-farm storages have increased by >50% and 10% respectively, and capacity of Pindari Dam has increased from 37 GL to 312 GL since 1993/94. Mean annual diversions from the regulated system have increased from 264 GL to 350 GL (33%) since 1993/94. This has resulted in a significant decrease in a number of key flow statistics • The ecological data collected between 1996/99 indicates that the Border Rivers are currently in relatively good condition. However, ecological data collected after a run of four high flow years which have been favourable for river health • Reports emphasises the vulnerability of critical processes and ecological attributes of the Border Rivers to changes in flow regime (disappointingly does not point out the obvious temporal scale problem between very recent hydrological changes and longer term temporal changes)
DRAFT Condamine-Balonne WAMP Environmental Flows Technical Report 1999 QDNR	The primary aim of this DRAFT report is to provide existing ecological condition assessment for the Condamine-Balonne river system and to establish the basis for assessing the flow related implications of any particular water resource development and flow management scenario for the Condamine-Balonne river system. Flow statistics for the river system were derived from an Integrated Quality Quantity Model (IQQM) which can simulate flows and abstractions over a long period of time. Ecological information was collected using rapid assessment techniques, AUSRIVAS data from MRHI program and some existing fish community information collected as part of an MDBC NRMS project (Moffatt). Less than 30% of the Condamine-Balonne is regulated, however harvesting of overland flows has a considerable impact on the flow regime of this river. For the Condamine-Balonne river system to remain ecologically healthy it is

[21] MDBC 1999 Water Audit Monitoring Report 1997/98.

	important that all of the features of the highly variable flow regime remain as 'natural' as possible. • Considerable water resource development in the last 10 years has significantly altered hydrology of river system. The lag time before geomorphological or ecological response are measurable may be considerably longer than 10 years. • The important ecological aspects of the Condamine-Balonne flow regime that need maintaining are: ∗ The magnitude and duration of flow events ∗ Rate of water level decline ∗ The frequency of flow events, and antecedent conditions ∗ The timing of flow events, and flow seasonality ∗ Long term flow variability • Environmental flow assessments indicated that the Upper and Lower Condamine and the Upper Balonne continue to have a fair to good flow regime, while the Lower Balonne has generally a poor flow regime. • AUSRIVAS scores indicate a dramatic reduction in the number of expected macroinvertebrates downstream of Whyenbah (Lower-Balonne). Fish communities sampled at seven sites across the river system generally scored well, except for a site on the Culgoa River downstream of Whyenbah, which was routinely in poor condition. However, a convincing correlation between Index of Stream Condition Scores for hydrology, physical habitat, streamside zone and water quality with macroinvertebrate and fish scores was not found (pg 49). • Water birds predominantly assemble to nest when the RAMSAR listed Narran Lakes reach 100% capacity, and birds abandon their nest when water level drops below 86% capacity. Increasing the period between filling the lakes and increasing the rate of draw-down threaten bird populations.
Social Assessment Report for the Condamine Balonne Basin WAMP Process. 1998 QDNR.	The social assessment for the Condamine-Balonne WAMP was undertaken to provide an assessment of the communities of the Condamine-Balonne Basin to assist in the evaluation of the social implications of different WAMP scenarios. The environmental issues raised by the community include: ∗ A genuine desire to maintain or restore healthy rivers measured by maintenance of biodiversity and water quality ∗ Environmental water requirements need to be determined before significant water management decisions are taken. ∗ The ability of science to clearly explain and quantify river health is questioned. What is river health and can it be measured?
Australian Capital Territory Government Submission	A Cap process for the Australian Capital Territory has yet to be determined. Diversions for 1997/98 totalled 44 GL[22], compared to 1993/94 level of 29 GL[23]. • Australian Capital Territory's Water resources Act (1998) established a framework for the sustainable management of the water resource requiring that environmental flows are established and protected. The Act requires a Water Resources Management Plan which sets out Environmental Flow Guidelines guaranteeing an average of 63% of

[22] MDBC 1999 Water Audit Monitoring Report 1997/98.
[23] Australian Capital Territory Government Submission to Review of Operation of Cap.

	Australian Capital Territory's water resource is for the environment. • Argued that this is a generous environmental allocation which protects the aquatic environment of the Murrumbidgee R. • Much of the environmental flow left in-stream is used for irrigation further down the Murray and Murrumbidgee Rivers. • Australian Capital Territory has adopted a 'bottom up' approach to setting environmental water requirements. The submission argues that current abstraction is below assessed environmental water requirements. • Submission presents arguments, mostly on grounds of equity, for a Cap in excess of 1993/94 levels of diversions.
Community Advisory Committee of the MDBMC Submission	Summary comments from CAC of the Murray-Darling Basin Ministerial Council submission to the Review of the Operation of the Cap on Diversions. ***How should sustainability be defined for the purposes of the Cap?*** SUMMARY — Responses to this question range from the general, to the theoretical and quite specific in the case of unregulated streams. ***What does the science tell us about the suitability of the level at which the Cap is set?*** SUMMARY — Community feeling on this question is probably encapsulated by the response of "Not known yet" from the Lower Murray Darling Catchment Management Committee, New South Wales. Responses indicate that the community is unconvinced about the science, "science has really failed to tell us …" (Western Catchment Management Committee, New South Wales), and questions the ability of science to halt river health decline, the accuracy of information, and the rigour and scrutiny being applied to this side of the sustainability equation. If the intent of the Cap (ie. to achieve a balance between consumptive and instream uses of water) is to be valued and realised, considerable effort remains in convincing the community. This negativity is exacerbated by the inability to see any improvements in river health todate. Importantly, it is recognised that sustainability cannot be based merely on the idea that less water extractions will make our rivers healthier (Murray Darling Association); and "… the Cap alone cannot deliver ecological sustainability for the Murray Darling…the Cap should be viewed as the first step…" (Australian Conservation Foundation). ***What aspects of the operation of the Cap constrain or support the sustainability of the river system?*** SUMMARY — There is support for the need for environmental flows for the rivers, but concern about management and accountability for that water and the need to monitor the effectiveness of environmental flows. Industry groups are not able to distinguish improvements in river health as resulting from the Cap or a combination of reform initiatives. Responses for unregulated rivers consider the Cap as too blunt an instrument for those systems and suggest instead that environmental flows be used for an appropriate end-of-valley flow regime or other appropriate differences in Cap arrangements; and also comment on a number of environmental issues that should be considered in an integrated way rather than focussing on irrigators. There is wide support for the need to consider groundwater resources in any discussion on the Cap. This inter-connectivity between surface and ground water has been recognised by the Community Advisory Committee for several years and has been provided in ongoing advice to the Ministerial Council. In considering aspects of the operation of the Cap for the sustainability of river health, an important question comes from South

	Australia who “gave away the opportunity to use above entitlement flows. This must be the single greatest action to ensure sustainable ecosystems. Can all communities agree with this?” (Lower Murray Catchment, South Australia). A number of issues with Cap operation are also raised in relation to enforceability and relationship between the Cap and environmental flow rules. Comment is also made on the potential impact of the Snowy on River Murray environmental flows and the Cap. A suggestion worthy of further development is that there be a process for individuals to ‘donate’ water for environmental purposes and perhaps the use of incentives. ***At a Basin scale assess the potential hazards and level of risk to the health of the riverine environment (including algal blooms and salinity) and comment on the role of the Cap in containing these hazards and reducing the level of risk to riverine health.*** SUMMARY — Issues raised in response to this question include the urgent need for monitoring (without which the sustainability of the river will be known only in theory), the need to re-adjust flows in low flow periods to assist with salinity and algae control, bank erosion and water-logging due to high irrigation flows in summer, and the impact of river regulation and diversion of water resources. A separate issue is the impact of the Cap on event-based unregulated streams such as the Barwon-Darling where it is felt the Cap has done little to improve what is still a healthy river system but has impacted on sustainability of development. An issue that is raised on several occasions through this submission is the impact of forestry plantations on catchment yields, this is obviously an area of research which will be required for community awareness of trade-offs for the future of the Murray-Darling Basin.

11.2 Appendix 2: Submitters directly to the Review

Submissions of Basin stakeholders made directly to the Review of Operation of the Cap addressing Ecological Sustainability of Rivers.

No.	State	From	Pages	Overarching	Ecological Sustainability of Rivers
1	NSW	Murray Catchment Management Committee	18		✓
2	NSW	Murray Irrigation Ltd	9		✓
3	NSW	Southern Riverina Irrigation Districts Council	10		✓
4	NSW	Murrumbidgee River Management Committee	8		✓
5	NSW	Murrumbidgee Irrigation, Ricegrowers Assoc & MIA Council Horticultural Associations	11		✓
6	NSW	MIA Council of Horticultural Associations	9		✓
8	NSW	Murrumbidgee Valley Licensed Pumpers' Association	7		✓
9	NSW	Murrumbidgee Unregulated Streams Management Committee	3		✓
10	NSW	Coleambally Community Action	13	✓	
12	NSW	Lachlan Shire Council	2	✓	
13	NSW	R Caldwell	9	✓	
15	NSW	Namoi Valley Water Users' Association	3		✓
17	NSW	Gwydir Valley Irrigators Assoc	3		✓
18	NSW	Twynam Pastoral Co	14		✓
23	NSW	Brewarrina Shire Council	4		✓
24	NSW	Bourke Cotton Growers Association	4		✓
25	NSW	Walgett Water Users Association	5		✓
26	—	Inland Rivers Network	8		✓
27	NSW	National Parks Association	1		✓
30	VIC	Goulburn – North East – Water For Agriculture – Ministerial Committee	3		✓
31	QLD	Toowoomba & Region Greens	1		✓
32	VIC	Australian Dried Fruits Association	2		✓

11.3 Appendix 3: Relevant Reports submitted

Reports provided by MDBC relevant to the Ecological Sustainability of Rivers component of the Review of the Operation of the Cap.

REPORTS	***SUMMARY OF MAIN POINTS RELEVANT TO CAP***
An Audit of Water use in the Murray-Darling Basin. 1995. MDBMC, Canberra.	This document describes the water audit carried out in the Basin. This document clearly identifies surface water use in the Basin, the growth in water diversions and the likely implications of this on water users and the environment. The report details changes to the flow regime of a number of the Basins rivers including changed seasonality and reduced total flow. By providing descriptions of what the Cap aims to protect against (for example, declining river health with increasing algal blooms and salinity, decreased areas of wetland as well as issues of security of supply) the rationale for introducing the Cap is made clear.
Review of Cap implementation 1996/97 & 1997/98 MDBMC Canberra.	These reports, prepared by the Independent Audit Group, provide a state by state assessment of Cap implementation for that water year. For each of the 22 valleys the reports provide details of diversions, and where available Cap targets. A description of water resource management and planning for the valleys are also given. The 1997/98 report contains responses by the four State Governments. These reports provide a valuable independent assessment of compliance with the Cap. However, these reports do not attempt to interpret the impact of the Cap, either on the environment or the community. The reports do not link the management of the Cap with the flow regime of the river systems. It is not possible to assess the effectiveness of the Cap without this information.
Water Audit Monitoring Reports 1996/97 & 1997/98 MDBC, Canberra	The aim of the Water Audit Monitoring Reports is to ensure that the development, management and operation of the Cap is an open and transparent process. This is achieved by reporting water use in each State by region. This is reported against Cap target diversion when it was available. The reports include a summary of the climatic conditions in the Basin during the water year. Descriptions of water trading and water availability are also given. Actual flows are reported against modelled natural flows where available (currently only Victoria). The report also outlines States proposed water management activities. The Water Audit Monitoring Reports provide an overview of water usage and management across the Basin. The reports do not attempt to assess the ecological, social or economic impacts of the Cap. These reports provide the information necessary to get an overview of water use across the Basin. However, by not attempting to assess the Cap against what it is intended to achieve (eg healthy river environment and security of supply) it is not possible to assess the success of the Cap (over its life, or over a year).
River Murray Barrages Environmental Flows. 1998. Jensen A, Good M, Tucker P & Long M. MDBC	Objective of this project was: *to identify key environmental flow requirements in relation to management of flow through the barrages, as it relates to maintaining the ecosystem of the Lower Lakes, the Coorong estuary and Coorong Lagoons* The project identified changed water regimes of the lakes and river as being a key issue in driving the serious degradation of the environmental values in

	the Lower Lakes and Coorong. Specific flow-related points include: • Median flow the Coorong estuary is reduced by 80% and average flow is 37% of original flows with frequency of extended no-flow periods increased from 1 in 20 to 1 in 2. Minor to medium floods (up to 1 in 7 year) have been eliminated. (78) • Without increased freshwater flows the Lower lakes (Lakes Alexanderina and Albert), the Coorong Lagoon and estuary are likely to further degrade (pg 79) • Reduced through-flows are contributing to the unsustainability of the current operating system for the Lower Lakes • Reduced freshwater inflows to the Coorong lagoons are allowing seawater to dominate conditions which has negative impacts on biota and fishing industry • Low through-flows in the Lower Lakes have reduced the health of the aquatic plant communities and habitat diversity in the Lower Lakes • The progressive restriction of the Coorong Lagoon and channels near the Murray mouth is related to the reduced median flows in the Murray, with the frequency of prolonged no-flow periods at the mouth increased from one in twenty to one in two years (pg 27) The report makes specific recommendations which are relevant to the operation of the Cap: • Controlling diversions from the Murray-Darling system is a key issue for the sustainability of the Coorong and Lower Lakes (pg 19) • Flow management of the River Murray must consider the flow regimes and ecological needs of the remnant Coorong estuary, the Coorong, the mouth channel and the offshore zone • Management aim is to increase environmental flows from the barrages through ongoing basin-wide water allocation reviews (pg 67) • Management aim is to increase environmental flows to meet ecological needs of the Lower Lakes and Coorong through ongoing basin-wide water allocation reviews
Report of the river Murray Scientific panel on Environmental flows. River Murray - Dartmouth to Wellington and the Lower Darling River 1998 MDBC.	The major objective of the project was to: *Identify changes in river operations for the River Murray and lower Darling River that should result in general improvements in the environmental condition of these river reaches whilst considering the current needs of existing water users.* • Prior to river regulation, the River Murray had a highly variable flow regime. The river channel and floodplain were configured to accommodate these flows and the plants and animals were adapted to this natural variation. • Water resource development has imposed a more stable water regime (less variability over daily, seasonal and inter-annual scales) which is resulting in significant long term, detrimental ecological changes in the River Murray. Flow management activities that threaten ecosystem health include: constant flow for sustained periods, unseasonal flow patterns, increased minimum flow, decreased frequency of flooding periods, reduced duration of individual floods, rapid rates of rise or fall and he development of weir pools. • A number of management recommendations to reduce the ecological impacts of regulation and abstraction are made in this report. Those that are likely to require a reduction in current abstraction include: * re-instate a flooding frequency of no less than 50% of what it was under natural conditions with a duration as close to possible as natural.

	* Introduce greater flow variability by allowing a passing flow through major storages during June to September as they fill. * Minimum base flows should not drop below 8000ML day through weir pools in the lower Murray for periods of greater than one to two weeks between November and April to reduce risk of blue-green algal blooms
Assessment of the flow needs for the Lower Darling River 1998. MDBC/DLWC Green D, Shaikh M, Maini N, Cross H, Slaven J.	This project aimed to improve the management of the in-stream, floodplain and wetland habitats of the Lower Darling River by preventing and, where possible reversing, environmental deterioration resulting from the operation of the Menindee Lakes Storage Scheme. The study consisted of 3 main components, an analysis of wetland inundation by remote sensing, analysis of changes in the hydrologic regime using modelled and historic data and an analysis of the current status and flow requirements of the ecological components of the Lower Darling River. The project reports: • Significant reductions have occurred in monthly flow volumes, flow duration and peak monthly flows (decreased 30-50%) for all except the very lowest flows. • Under natural conditions, the Darling River at Burtundy would have ceased to flow 4% of the time in winter and 8% in summer. Under current conditions cease to flow occurs 2% of the time, or less for all months. • Minimum flows of 2000 ML/day in winter and 5000 ML/day in summer are required to disperse an algal bloom at Weir 32. • Flows of at least 7000 ML/day at Weir 32 are required to allow fish passage, which is critical to the ecology of native migratory fish • The flow required to fill 50% of the wetlands on the Lower Darling happens less frequently since river regulation. The time between filling events has doubled from 106 days to 236 days, with the maximum period between events increasing from 2.3 to 6.2 years. Floodplain vegetation, particularly river red gums and black box were in poor health which is likely to be a result of reduced flood frequency • Flooding frequency of benches in the Lower Darling has been reduced. While benches are a source of food for aquatic animals it remains unknown what the effect of reduced inundation on river health is. • The report recommends a number of flow management changes which include increasing the frequency and height of flooding events on the Lower Darling River.
Scientific panel Assessment of Environmental Flows for the Barwon-Darling River. 1996. DLWC. Thoms MC, Sheldon F, Roberts J, Harris J, & Hillman TJ.	The objective of this study was to assess the condition of the in-stream ecosystem and determine its flow requirements. This provides a basis for interim flow rules for the Barwon-Darling River between Mungindi and Menindee to be formulated. The assessment was undertaken by an expert panel. The assessment included visiting 20 sites along the river and consultation with stakeholders. The study did not consider large out-of-channel flows. Key findings relevant to the operation of the Cap are: • Abstractions have had a significant impact on flows in the Barwon - Darling River. Diversions above Menindee, with 1994/5 levels of development, were equivalent to ~60% of the natural average annual flow at Menindee which translates to a reduction of average annual flow at Menindee of about 40%. • Water abstraction has resulted in an increase in the rate of flood recession, decreases in the rate of flood rises, a decrease in flood

	duration and an increase in the time between floods.
	• The Barwon-Darling riverine ecosystem responds to flows at several time scales; the long-term quantity of water, the pattern of individual flow events, and day-to-day variation in river heights.
	  * In the long-term, floods and droughts have major ecological roles which should be protected
	  * The maximum flow, duration, and rate of rise and fall are ecologically important characteristics of individual flow events
	  * Short-term variability is significant in maximising aquatic biodiversity and productivity and in maximising bank stability and loss of habitat values.
	• The time-lag between alterations in flow regime and a measurable change in the environment may be longer than the period between the onset of significant water abstraction and data collection for the report
	• The report recommended a number of actions to maximise the environmental quality of the Barwon-Darling which included:
	  * An immediate moratorium on additional abstractions and the transfer of licences upstream, and
	  * No abstraction of water for irrigation below the 80^{th} percentile flow (during low flow periods).

Social Assessment Report for the Condamine Balonne Basin WAMP Process. 1998 QDNR.	The social assessment for the Condamine-Balonne WAMP was undertaken to provide an assessment of the communities of the Condamine-Balonne Basin to assist in the evaluation of the social implications of different WAMP scenarios. The environmental issues raised by the community include: * A genuine desire to maintain or restore healthy rivers measured by maintenance of biodiversity and water quality * Environmental water requirements need to be determined before significant water management decisions are taken. * The ability of science to clearly explain and quantify river health is questioned. What is river health and can it be measured?
The Murray-Darling Basin CAP. Issues on the Darling River. 1999. Filetti S. prepared on behalf of Darling River Food and Fibre (DRFF).	• DRFF state that a healthy riverine environment is a prerequisite for a healthy, sustainable irrigation industry. • The Cap is a logical means of controlling over-development of water resources. • Have concerns about the validity of the IQQM developed for the Barwon-Darling River valley. • DRFF will support a Cap if it it could be scientifically established and that its eventual outcome had long-term environmental, social and economic gains.The areas developed for irrigation have increased by 14% (2000 ha) on the Darling and by 55% (6300 ha) since 1993/94, though this does not necessarily reflect a similar increase in water use. • Annual extractions from the Darling River are now at about 120 GL. • DRFF supports the Low flow rules for the Darling aimed to protect flows of less than 1000 ML/d from diversion. • DRFF supports and end-of-valley flow based CAP, and is strongly against a diversion model based Cap.
Water management in the Darling River. Beyond 2000. 1998. Darling River Food and Fibre (DRFF)	• DRFF vision statement is "*Balancing river health and economic productivity for the Darling River such that we achieve both a sustainable river environment and long-term prosperity for the regional community*" • Argue for the Darling and Barwon to be considered separately in the formulation of flow management rules. • Argue that the key issue is not so much the volume of water taken, but rather, when it is diverted.

	• Major river health issues in the Darling River are: ∗ Changed flow regimes ∗ Fish management ∗ Water quality nutrients ∗ Poor knowledge base ∗ Riparian zone/floodplain management • Many of the environmental problems of the Darling River are inherited from upstream, where significant diversions occur in the headwater streams. • Ask the question "How far back towards natural do we have to go before the impacts on economic productivity be too great?" • Identify the lack of knowledge about the Barwon-Darling as limiting their confidence in the need for stringent flow management rules. • The Cap distorts water market when there is significant (50%) sleeper licences.
Managing Natural Resources in Rural Australia for a Sustainable Future. A Discussion Paper for Developing a National Policy. Dec 1999. Gorrie, and Wonder, B. 1999	• Water is a community asset and has economic, social and environmental values…. The way in which water is stored, extracted, delivered, used and disposed of can have profound ecological and economic effects. • The decline in water quality results largely from contaminants from agricultural and urban developments and high allocations to consumptive use resulting in inappropriate flow regimes in terms of both volumes and the seasonality and duration of flows. • Actions to improve the ecologically sustainable management of our rivers and water resources include (pg 54-55): - Introduction of environmental flow regimes and other measures to improve the quality of water in streams and rivers… - Understanding the role of groundwater in environmental flows - Improved integration and understanding of questions associated with the conjunctive use of ground water and surface water - Investigating and improving the valuation of water to improve allocation for environmental uses, including developing effective performance indicators for the management of environmental flows. - Improve planning to support sustainable use of floodplains, wetlands and rivers - Increased support for appropriately planned river restoration activities - Further developing water trading markets • Management activities should not diminish our natural resources' ability to sustain ecological processes at the farm and regional levels (pg 79). Indicators that show whether the use of natural resources is sustainable at the regional and at the farm level should be developed (pg 80). These sustainability indicators should be capable of monitoring change in the condition of the natural resource base, other environmental values, net economic returns, and social well being.
Fish and Rivers in Stress the New South Wales Rivers Survey. New South Wales Fisheries & CRCFE. 1997	• Rivers sustain a large proportion of New South Wales total biodiversity but the State's degraded riverine ecosystems are rapidly losing their biodiversity. Evidence is especially clear in the Murray region, particularly in rivers regulated for water supply. The Darling ecological region produced nearly 10 times as many fish of the more heavily regulated Murray Region (which includes the Lachlan and Murrumbidgee systems) with nearly double the number of native fish per site in the Darling system than in the Murray system. • Carp are the most dominant fish of the Murray and Darling River systems. Their numbers are aided by human modifications of rivers especially flow regulation.

	• An Index of Biotic Integrity (IBI) was developed as a river-health indicator for New South Wales rivers. The IBI rankings show that the Murray region rivers are in a degraded condition. • Flow regulation generally had a negative impact on native fish abundance but had a positive effect on some alien species, including carp. It was concluded that flow regulation has reduced the resilience of New South Wales Rivers and native fish communities to invasion by alien fish. • While rivers in the Darling region contained the highest numbers of alien species, the Murray region had the highest proportion of alien individuals with 57.5% of fish being alien in comparison to the Darling with 25.1%. • Recommendation 1 pg xv. *'The primary recommendation from the Rivers Survey .is to accept that our riverine heritage in New South Wales is in a generally degraded condition and in urgent need of restoration. River biota is reflecting problems of river habitats: aquatic biodiversity is rapidly being lost; productivity of natural resources is seriously declining, especially recreational and commercial fisheries; and the values and supply of the basic resource, fresh water, have been damaged. Restoration of river-ecosystem components is needed, especially flow regimes, thermal regimes and river catchments, particularly in the riparian zones. There is an urgent need to control carp and to restore fish passage at barriers such as dams and weirs.'*
Young, W.J. (Ed) (2000) "Rivers as Ecological Systems – the Murray-Darling Basin”, in press.	• This book presents a summary of the current scientific knowledge of the interactions between riverine ecology and flow regimes in the Murray-Darling Basin. • Models of river function are presented that incorporate the key elements of the Basin's climate, geomorpholgy, and hydrology. The model explains how sediment and nutrient transport, and riverine productivity change with flow and position in the river system. • The book argues that flow regime is central to controlling river form and function. • When published, this book will provide a valuable reference on the functioning of the Murray-Darling basin's river system.

11.4 Appendix 4: Literature Search.

Results of a search of the *Streamline* database for articles about the Cap on diversions in the Murray-Darling Basin. Streamline is an Australian database that attempts to include published material from a broad base including LWRRDC and government publications.

Title	***Abstract (reprinted directly from Streamline)***
Close A (Murray Darling Basin Commission) 1999. How does the Cap work? Australian Landcare, 1999-03, ISSN 14404397, p38-39, 1 photo.	In 1995, the Murray-Darling Basin Commission imposed a Cap on any further increase in water diversions throughout the Basin to reverse a perceived decline in water quality and riverine environments and to halt the continuing erosion of the security of supply to existing irrigators. This paper explains the way in which the Cap will be determined and applied in each state, how it will vary between wet and dry seasons and what it will mean for irrigators.
Brennan D (University of Sydney, Department of Agricultural Economics); Scoccimarro M (Australian National University, Centre for Integrated Catchment Assessment and Management) 1999. Issues in defining property rights to improve Australian water markets. Australian journal of agricultural and resource economics, 1999-03, 43 (1), ISSN 1364985X, p68-89, 1 fig, refs.	With the announcement of the 'cap' that marked the end to the expansionary phase of the water industry in the Murray-Darling Basin, there is a need to address water market reform as a means of reallocating water between existing uses. This article discusses the key practical issues associated with defining property rights to water use, in the context of broadening the scope of the market for transferable water entitlements. In particular, the third party impacts of water trade and the need for improved water trading rules are discussed. Some of the issues associated with defining the reliability of water rights, including the design of appropriate dam management policies, are also discussed.
Currey A (Irrigation Association of Australia) . 1999. More dams for NSW? Irrigation Australia, Autumn 1999, 14 (1), ISSN 08189447, p12-13.	A 'cap' limiting water use for irrigation at 1993-94 levels throughout the Murray-Darling Basin was agreed to by the four states who are members of the Murray-Darling Basin Commission, the Australian Capital Territory and the Federal Government, as a means of more sustainably managing the water in the basin. Some irrigator groups in New South Wales have seen the Cap as an obstruction to further irrigation development and have been vociferous in their opposition. The leader of the New South Wales National Party, Mr George Souris, promised more dams for the state, a review of the Murray-Darling Basin Cap and flagged the establishment of water property rights, which has been interpreted as a threat to pull out of the agreement on the cap. Reaction to these proposals is discussed.
Whittington J; Hillman T; (Murray Darling Freshwater Research Centre) 1999. Sustainable rivers: the 'cap' and environmental flows. Cooperative Research Centre for Freshwater Ecology, Canberra ACT, 1999, 13p, figs, photos.	By the 1990s nearly half of the mean annual runoff from the Murray-Darling Basin was being diverted for urban, industrial and agricultural use. From July 1997, the Murray-Darling Basin Ministerial Council set an upper limit on the amount of water that could be taken from the river system (the 'cap'). This report justifies the 'cap' in terms of river health, water temperatures, ecosystems, environmental flows and sustainability.
Connell D (Murray Darling Basin Commission); Sharley T (Primary Industries and Resources South Australia) 1998. Flow-on benefits: South Australia and the Murray-	The Murray-Darling Basin is an integrated approach by governments, agencies and communities to manage natural resources irrespective of State boundaries. The position of South Australia at the end of the Basin system has encouraged the State to take a whole of catchment approach to managing its part of the

Darling Basin. Environment South Australia, 1998, 7 (2), ISSN 10379010, p19, 35, 1 photo.	Basin. The Salinity and Drainage strategy has reduced water salinity in the lower Murray and the Cap on further water diversions has pegged the decline in water volumes flowing to South Australia in years not dominated by major droughts or floods. Work has been undertaken in the upper catchments to reduce the impact of dryland salinity on streams and water quality and throughout the Basin to reduce the pollutants and nutrients entering the waterways, reducing the likelihood of algal blooms in the river and lower lakes. Development of environmental flow policies, cost sharing for dryland salinity works and increased funding programs are currently being urged.
South Australia, Environment Protection Authority 1998. State of the Environment Report for South Australia 1998. South Australia, Department of Environment, Heritage and Aboriginal Affairs, 1998-10, ISBN 0730858529, 2 v, tables, figs, refs.	Since publication of the 1993 State of the Environment (SOE) Report some major achievements have been realized. Air quality is good and continues to improve and the Montreal Protocol targets for phasing out ozone depleting substances continue to be met. The creation of catchment management boards since 1995 has provided funding and mobilized community groups to initiate projects to progressively improve inland waterways and reduce stormwater pollution of coasts. A Cap has been placed on water diversions from the River Murray to prevent unsustainable growth in diversions and overuse of the resource. Environment Improvement Programs (EIP) have been negotiated to reduce the discharge of nutrients to the marine environment from four wastewater treatment plants. All soil conservation districts are now covered by soil conservation boards, most of which have published district management plans. National parks and wildlife reserves now cover 21.4% of the state, with 3.2% of coastal waters in marine protected waters. The release of the rabbit calicivirus led to a 80- 95% reduction in rabbit numbers in some areas of the arid zone and a consequent increase in natural regeneration of native plants. Recommendations for future actions to improve the South Australian environment are provided.
Samaranayaka D; Freeman F; Short C; (Australian Bureau of Agricultural and Resource Economics) 1998. Water trading in the Murray-Darling Basin: some preliminary observations. Outlook '98, Proceedings of the National Agricultural and Resources Outlook Conference, 3-5 Feb 1998, Canberra ACT, Proceedings. Australian Bureau of Agricultural and Resource Economics, Canberra ACT, 1998, vol 1, ISBN 0642266182, p157-164, 13 tables, 1 fig, refs.	In the past five years, the Council of Australian Governments (COAG) has introduced water reforms, provided for environmental flows, implemented the Cap in the Murray-Darling Basin and, set a moratorium on groundwater licences and removed bans on sleeper licences (unused water licences) and doser licences (infrequently used water rights) in New South Wales. One objective of this reform was to encourage water use at its highest value among both consumptive and non-consumptive users, while ensuring that the use was ecologically sustainable. This was to be done by allowing for the movement of water to take place within and between consumptive and non-consumptive users through water markets. This paper reports the results of surveys in the Loxton SA, Sunraysia VIC, and Murrumbidgee NSW irrigation areas of water use and rights traded.
Independent Audit Group. 1997. Review of Cap implementation 1996-97: report of the Independent Audit Group. Murray-Darling Basin Ministerial Council,	The Murray-Darling Basin Ministerial Council (MDBMC) in June 1995, decided to introduce a Cap upon diversions of water from the Murray-Darling Basin. A Cap on the volume of diversions associated with the 1993-94 level of development was seen as an essential first step in establishing management systems to achieve

Canberra ACT, 1997-08, ISBN 1875209824, 26p, 5 tables, 1 fig.	healthy rivers and sustainable consumptive uses. This report reviews the performance of each State in progressing the implementation of the Cap during 1996-97 to ensure an accountable and transparent process is in place.
Dick A 1997. States work out water Cap ruling. Australian farm journal, 1997-12, 7 (10), ISSN 10366474, p26-29, 1 photo.	The rivers of the Murray-Darling Basin have become stressed from over use, resulting in a range of environmental, water supply and quality problems. Four State governments (Queensland, New South Wales, Victoria and South Australia) and the Federal Government are engaged in implementing a 1995 decision to Cap water extractions at 1993-1994 levels of development. However, implementation of this ruling must overcome a host of complexities, as each State has a different system of assigning water and each uses different terminology.
Connell D; (Murray Darling Basin Commission) 1997. What have we achieved in water management? Landcare Changing Australia: National Conference, 16-19 Sept 1997, Adelaide Convention Centre SA, Proceedings, Mathison, M (ed). Primary Industries South Australia, Adelaide SA, 1997-09, vol 1, ISBN 0730802051, p41-42.	Fundamental changes in the approach to water management in Australia have been coordinated through the Council of Australian Governments program for water reform. Aiming to promote increased economic efficiency, less waste, lower costs, fairer distribution of benefits and improved environmental management, the program concentrates on the institutional structure of the water industry, water allocation and pricing policy, water trading, environmental management and programs for improved public consultation and education about the need for change. The basic features are demonstrated by implementation in the Murray-Darling Basin and the Ministerial Council has introduced a wide ranging program of reforms including establishing a water business to operate the structures used in river regulation and water distribution system, billing for services, a water Cap on any further increase in water diversions from the Basin, encouragement of water trading and an integrated catchment management approach to water resource management.
Mussared D. 1995. Irrigation at the crossroads. ECOS, Spring 1995, 85, ISSN 03114546, p17-18, 3	The three main problems which face the irrigation industry are shortage of water in some areas, excess of water in others and degradation of rivers and catchments in all areas. Sustainability needs to be improved, because excessive use of irrigation has mobilized salt, bringing saline water tables to the surface and feeding saline drainage water into creeks and rivers. In 1995, the Murray-Darling Ministerial Council agreed to an interim Cap on further increases in water diversions and identified as an urgent priority the definition of a balance between water for the consumptive uses of irrigation, domestic and industrial and the environmental flows needing to be left in rivers.