Review of Achievements and Outcomes of Environmental Flow Initiatives Undertaken on the extended River Murray System to August 2002

Report to the Living Murray initiative of the Murray-Darling Basin Commission

by

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March 2003
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Executive Summary

Introduction
The community has expressed a clear need for the Murray-Darling Basin Commission to demonstrate what has been achieved with environmental flows projects in the past, and to reinforce the scientific basis of its future environmental flow work. Demonstration of improvements in river health requires collection and analysis of appropriate data.

This report reviews the on-ground environmental flows work undertaken so far in the River Murray System, and assesses the work with respect to an 'adaptive management' framework as a way of guiding future environmental flow management initiatives. In aggregate, this report contains considerable evidence that environmental water allocations can be utilised to yield environmental dividends.

Background to Environmental Flows in the River Murray System
The River Murray System has a highly diverse range of aquatic environments. The extensive system of regulation of the river has impacted upon the hydrology in different ways in different zones of the river, and consequently the environmental impacts have been complex and spatially variable. It is important to recognise that the River Murray System, although generally degraded, retains environmental values worthy of conservation and rehabilitation, including internationally significant wetlands, and rare fish species.

The idea of providing water specifically for environmental benefit is not new in the River Murray System. Environmental water allocations (EWAs) are volumes of water set aside specifically to target environmental benefit. A number of EWAs have been created along the River Murray System and key tributaries.

The knowledge generated by research scientists, the work of the expert panels and the objectives agreed to by the Ministerial Council consistently suggest a set of environmental flow management actions that hold promise for improving river health. These include:

- Varying in-channel flow
- Providing more natural wetland watering and drying regimes, including drawing down of some weir pools to promote drying cycles of wetlands that are typically inundated, and raising of some weir pools to water wetlands that are now typically dry;
- Pulsing flows to disperse blue-green algae
- Flushing flows to move sediment from the Murray Mouth
- Releasing flows from storages to mimic the shape of natural hydrographs
- Managing in-stream structures to allow fish passage

Review of Implemented Environmental Flow Initiatives
Several environmental initiatives have been implemented in the River Murray System in recent years. The initiatives have been diverse, addressing issues of in-channel needs, the needs of wetlands, water quality improvement, fish passage and sediment flushing. Many of these initiatives originated from River Murray Water (the Commission's internal business unit responsible for operation of the River Murray system) in consultation with partner
government agencies and ecologists. Other initiatives have been instigated within jurisdictions and local communities.

Examples of recently implemented environmental flows initiatives follow.

**In-channel variation of flow**

One effect of regulation of the Mitta Mitta River by Dartmouth Dam has been reduced flow variability. From mid-November 2001 a small variation in flow was introduced to simulate the response to a rainfall event. The variation was based on a fortnightly cycle, with a short rise over 2 days followed by a recession over 12 days. The flow variation was hypothesised to reduce the potential for bank erosion, provide some wetting and drying of riparian vegetation and biofilms, as well as stimulating fish migration. A detailed monitoring program demonstrated that even a modest variation in the flow release pattern was able to produce statistically significant positive environmental benefits in the Mitta Mitta River. A 4-day pulse in the lower River Murray in South Australia at the same time did not stimulate a significant response by fish, possibly because its duration was too short.

**Wetland watering using specific flood event or allocation**

The most common form of implemented environmental flows in the River Murray System is watering of wetlands using EWAs. Seven projects were reviewed.

The project Watering of Wetlands on Private Land in the Murray Irrigation Limited area (NSW) conducted in late-2001 established that such a management policy was politically, socially and technically feasible. The project conducted targeted monitoring, using a before and after design. The well-planned objectives, high level of community approval, agency support, and scientifically demonstrated success of the trial were major factors that encouraged the expansion of this management policy in the following year. This project demonstrated that long-dry and grazed floodplain wetlands can be rejuvenated (at least in the short-term) in terms of plants and waterbirds through 'artificial' watering. The project also demonstrated that the local community is willing to support and become actively involved in this form of management action.

Implementation of environmental flows to enhance natural flooding in the Barmah-Millewa Forest from October 2000 to January 2001 confirmed the research and modelling that provided the scientific basis for development of the flow rules. Provided a suitable natural flood occurs, and provided a large enough allocation is made to supplement that flood, enhanced duration of forest flooding can provide real ecological benefits to the Barmah-Millewa Forest floodplain wetlands.

The November 2001 Werai Forest (NSW) watering trial was mainly a hydrological trial, although some ecological monitoring was also conducted. The ecological monitoring suggested that the trial may have produced positive ecological results, despite limited sampling.

At the time of the first release of an environmental water allocation to Wanganella Swamp (NSW) in December 2000 there was no formal monitoring evaluation plan in place. The decision to release the environmental allocation relied solely on a visit to the site by a team of scientists at a critical time when birds were starting to abandon their nests. With advance warning, the allocation could have been made earlier, which may have enabled maintenance of water levels, and prevention of nest abandonment.

In general, the project to inundate South Australian wetlands in October 2000 demonstrated that increasing floodplain inundation through flow enhancement and weir surcharging created environmental benefits, and few if any environmental costs. In contrast to the wetland flooding experiments undertaken on private wetlands in the MIL area (which produced a flourish of aquatic plants), here the seedbank did not respond, possibly because the duration of inundation was too short.
The process for implementing the Victorian Murray Wetland EWA, which began in 1994/95, is well developed, and utilises various criteria to make decisions about how the allocation is distributed from year-to-year, including monitoring results. It is recognised that the monitoring program will involve interpretation over the short-term for year-to-year management, and over the longer-term (5 years plus) to determine trends in wetland health. While it appears that the EWA process achieves its year-to-year management goals, the longer-term interpretation of wetland health trends is not yet available.

The process for managing the hydrology of the Barmah-Millewa Forest is adaptive, with management responding to short- and long-term monitoring results. The relative health of the Barmah-Millewa Forest, and changes in Forest health over time, have not been documented in such a way as to allow evaluation of the response of Forest health to management initiatives. The monitoring to date is not necessarily hypothesis driven, so it may take some time before it is possible to unequivocally link water management policies to improved health of the Forest. There is an emphasis on delivery of readily observable outcomes (such as waterbird breeding) with less emphasis on the ecological functions that underpin such outcomes.

**Restoration of natural wetland hydrological regimes**

The adaptive management projects at Lake Merreti and the Gurra Gurra Lakes Wetland Complex in South Australia’s Riverland, which began in 1995, are aiming to achieve improved local wetland management, and also to improve understanding of fundamental ecological process. The hydrological restoration does not involve use of EWAs; rather, it involves better use of currently available water. The adaptive nature of the project was grounded on an admission of scientific uncertainty about the details of ecological functions within wetlands and a commitment to learning. Management actions have resulted in overall demonstrated improvements in wetland health. On-ground adaptive management works well at the local scale of the hydrological unit. The opportunities to manage at this local scale are determined by management of the hydrology by Regional and State agencies at the floodplain and river reach scale.

The Moira Lake (NSW) Hydrological Management Plan, first implemented in 1998, has been successful in restoring the natural hydrological regime. To date the biological response information, while positive, is largely descriptive. There has been an emphasis on delivering readily observable outcomes (such as waterbird breeding and carp removal), with less regard for the ecological functions that underpin such outcomes. One important outcome of the project was the achievement of an annual 2,027 ML of water savings.

**Mildura Weir drawdown**

Mildura weirpool was drawdown in May 2001 and May-June 2002 for a short period (about two weeks) for weir maintenance purposes. The opportunity was taken to undertake some monitoring of these drawdowns. Monitoring focussed on water quality, because fears over a poor water quality response (i.e. increased salinity of the water) was thought to be one of the likely reasons why some stakeholders may object to a drawdown for environmental purposes. Thus, the monitoring did not measure the environmental benefits of drawdown. Salinity increases during these drawdowns were not high and perhaps this was largely because river flow at the time was moderate and assisted in diluting increased saline inputs. With longer duration drawdowns, higher salinity impacts can be expected, and this aspect will need to be taken into consideration.

**Operation of Barrages to scour sand from the Mouth**

Although the December 2000 Murray Mouth sediment flushing experiment did not achieve its objective, the operation provided useful information for the development of strategies for management of the Murray Mouth (i.e. it is known that any future sediment flushing flows must be higher than those used in the late-2000 experiment). Research work is continuing on
two alternative policies, namely, an annual flushing flow using additional water temporarily stored in the lower Lakes, and additional flows delivered through the Murray Mouth each month.

**Flows for dispersal and suppression of blue-green algal blooms on the lower Murray and lower Darling Rivers**

In early 2001 high blue-green algal cell counts were recorded in the lower River Murray and lower Darling River due to conditions of low flows and high temperatures, and at the same time rainfall had occurred in the upper catchment, creating an opportunity to boost flows to the lower river. Although the cell counts declined at the time of the increased flows, it cannot be certain that this was a response to the increased flows, because weather conditions also became less favourable for algal growth. When conducting field-scale management experiments there is always a chance that unexpected factors will confound interpretation of the results.

**Use of the Murrumbidgee River ECA**

The Murrumbidgee River Environmental Contingency Allowance has been applied to meet water quality needs and algal bloom suppression, fish breeding and forest and wetland watering. The monitoring of the 1998 allocation has been detailed and scientifically sound, being hypothesis driven. Information on how the river and wetland ecosystems of the Murrumbidgee are responding to the environmental flow rules has not yet been published.

**Other initiatives**

Since 2000, Stevens Weir (NSW) pool is drawn down as an annual event, beginning at the end of May. The main reasons for this are to allow vegetation on the banks of the Edward River upstream to dry out before high water levels in the next irrigation season, and to allow for unimpeded fish passage. Monitoring of Stevens Weir drawdown has not been undertaken so it is not possible to quantify the success of this policy. However, the Winter timing of the drawdown is such that it would appear to be of marginal benefit to native fish for passage. For example, silver perch, golden perch, bony herring, Australian smelt, shortheaded lampreys and Murray cod are not known to migrate in the River Murray over the period late Autumn to early Spring.

In the first River Murray flood of October 2000, an attempt was made to partly inundate Hattah Lakes (Vic) by enhancing the river flow with a small release achieved through drawdown of Euston Weir pool. However, this flow was insufficient to achieve filling of the Lakes. Although not used successfully in 2000, the strategy is now in place for potential future utilisation.

Flood operation of Menindee Lakes over recent years has been aimed at mimicking the shape of the natural flood hydrograph in the lower Darling River. Specific monitoring of this practice has not been implemented. Data collected during routine monitoring of the lower Darling River may enable this policy to be evaluated.

In November 2000, a period of high flows allowed the opportunity to raise and fully open all gates of Torrumbarry Weir, providing a 12-day period of ‘open river’, which enabled unrestricted passage for biota through the weir, although fish passage was the stated major objective. This management action was opportunistic, and biological assessment of the ‘open river’ conditions was not undertaken. However, the Spring timing of the event coincided with a period when several native fish species are known to migrate upstream.

To reduce the risk of very low flows passing Mildura Weir resulting from increased weekend pumping, and the assumed associated increase of blue green algae concentration, River Murray Water pulse the flows downstream of Euston Weir on a weekly basis during periods of low regulated flows in summer and autumn. This
practice increases variability of flow downstream of Euston Weir on a weekly basis, and reduces the incidence of very low flows at Mildura. The assumption that this operational practice reduces blue-green algal counts in the Mildura and Wentworth weir pools is yet to be scientifically tested.

**Have Environmental Flows Improved River Health?**

Scientists believe that properly implemented environmental water allocations will lead to measurable improvements in the health of the River Murray. The findings from this review support this belief.

River Murray System environmental flow management actions that have been trialed were justified on the basis of ‘best available knowledge’, and may have produced improvements in river health; this table summarises whether such improvements were achieved.

<table>
<thead>
<tr>
<th>Environmental Flow action</th>
<th>Successful implementation?</th>
<th>Scientifically demonstrated improvement in river health?</th>
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<tr>
<td>In-channel variation of flow</td>
<td>Applied on the upper and lower river system</td>
<td>Demonstrated ecological benefit on the Mitta Mitta River.</td>
</tr>
<tr>
<td>Wetland watering through delivering allocations, and enhancing natural floods</td>
<td>Applied on private and public wetlands. Environmental allocations achieved.</td>
<td>Demonstrated ecological benefit on private wetlands within the MIL area, the Barmah-Millewa Forest, Moira Lake, Weraia Forest, Wanganella Swamp, and Victorian Murray wetlands.</td>
</tr>
<tr>
<td>Restoration of wetland hydrological regime using local structural and operational manipulation</td>
<td>Applied on Moira Lake and SA Riverland wetlands</td>
<td>Demonstrated short-term ecological benefits; overall long-term improvements in ecological health not yet evaluated.</td>
</tr>
<tr>
<td>Flows to disperse blue-green algae</td>
<td>Applied on lower Murray and Darling Rivers</td>
<td>Some limited evidence of ecological benefit.</td>
</tr>
<tr>
<td>Weir pool drawdown</td>
<td>Applied from time to time for maintenance at several weirs, and annually for environmental reasons on Stevens Weir; some resistance to experimental environmental drawdown elsewhere</td>
<td>Salinity impacts within tolerable range at Mildura for short drawdown. Salinity impacts may be significant if river flows are low or if drawdown is for an extended period. Ecological benefits not yet demonstrated at Mildura Weir or at Stevens Weir</td>
</tr>
<tr>
<td>Weir pool surcharging associated with flood enhancement</td>
<td>Applied on the lower River Murray (Lock 5)</td>
<td>Demonstrated ecological benefit</td>
</tr>
<tr>
<td>Sediment flushing flows</td>
<td>Applied at the Murray Mouth</td>
<td>Applied flow insufficient capacity, so sediment flushing not yet demonstrated</td>
</tr>
<tr>
<td>Mimic shape of natural hydrographs</td>
<td>Applied on the lower Darling River</td>
<td>Not monitored.</td>
</tr>
<tr>
<td>Temporarily open weir gates to allow fish passage</td>
<td>Applied at Torrumbarry Weir and Stevens Weir</td>
<td>Open passage demonstrated; overall significance to fish movement not measured</td>
</tr>
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Conclusions and recommendations

- Environmental water has been allocated the River Murray System and in key tributaries, and used to enhance environmental values. This review provides ample evidence that environmental flows implementation has been based on science and that it can lead to improvements in river health.

- Environmental flow actions have generally involved monitoring, although this has been undertaken using various levels of scientific rigour.

- Management agencies and stakeholders across the River Murray System have demonstrated willingness to experiment with, and learn from, environmental flow implementation.

- In general, managers appear to be well informed regarding ‘best management practice’, and there is a high level of interest in learning more about and embracing adaptive management consistent with recent Council directions.

- A high level of community participation should be encouraged from the very earliest stages of projects (including formulation of policies to be tested). For example, simple computer models with graphical map-based output should be developed with stakeholders when an environmental flow action is to be implemented using adaptive management principles.

- In wetland management there appears to be an emphasis on managing for, and publicising, waterbird breeding. This is understandable given the strong community concern for birds. While bird surveys are valuable, it appears that aquatic vegetation and macroinvertebrates may be more reliable indicators of changes in wetland health.

- Past implementation of environmental flows in the River Murray System has not followed a consistent approach in regard to adaptive management, with most of the projects being of the 'passive adaptive' or 'trial-and-error' types (definitions are in Chapter 4).

- Ten river zones are currently being used by the Regional Evaluation Groups in the Living Murray scientific process for modelling environmental flow benefits using the Murray Flow Assessment Tool. It is remarked that these zones are also appropriate in size and geographical coverage for creating opportunities for environmental flows. Smaller, local-scale hydrological units may be required for successful on-ground implementation and monitoring of environmental flows.

- Managers may rightly feel uncomfortable about bold hypothesis testing in areas where threatened species legislation and Ramsar responsibilities apply. While caution is needed, positive adaptive management of high priority species and areas is recommended.

- Monitoring needs to be tailored for each project, it is recommended that managers seek professional statistical and scientific advice regarding experimental design and statistical testing.

- As well as utilising monitoring data for regular year-to-year management, projects should also carry out periodic reviews of data that examine medium to long-term changes in ecological health with respect to water management policies.

- Given limited resources available for monitoring, it is necessary to establish criteria for prioritising projects according to the quality and usefulness of the knowledge likely to be gained. High priority projects should be well-resourced adaptive management interventions, with lower priority projects either not monitored, or monitored using a very limited number of indicator variables.
Consistent with the Ministerial Council’s expectations on adaptive management for the *Living Murray* initiative, the Commission has initiated establishment of an adaptive management framework. This framework needs to be tailored to suit the physical, ecological, social, economic and political conditions that prevail in the River Murray System. When developed, the Commission should actively encourage adoption and maintenance of the framework. Some key points on adaptive management is provided in the box below.

### Key points on adaptive management.

(Further details are provided in Chapter 4.)

Adaptive management (AM) is a structured approach to the evaluation and solution of environmental management problems. Adaptive management is also known as ‘learning by doing’ through carefully planned and monitored interventions (i.e. it is not 'trial-and-error' learning). River managers might argue that they have always practiced AM, through implementing works and then trying different approaches if problems arise. However, this is a superficial understanding of AM. Adaptive management explicitly recognises uncertainty, so policies (and resultant on-ground actions) are seen as experiments that, if carefully designed and monitored, can provide information about the system. Under an AM philosophy, management is involved in development of best-practice, rather than passively adopting new technologies when they become available.

The focus here is at the scale of on-groundwater management decisions, which can be altered on the basis of improved knowledge, whether or not the total annual allocation varies.

Four main categories of river management that could be regarded as adaptive are: evolutionary or ‘trial and error’ approach; reactive adaptive approach; passive adaptive approach; and active adaptive approach. Further details are provided in Chapter 4.

Experience in other countries has demonstrated that without a concerted effort to assist its adoption and avoidance of its pitfalls, adaptive management is likely to fail. The problems are grounded in a complex web of inadequate institutional structures and processes, organizational norms and belief systems, and internal and external sanctions. Collectively, these forces interact to stymie efforts to experiment, learn, and innovate. Based on its overseas track record, it appears that AM has a high chance of failure. However, the reasons for failure have been identified and articulated, so it should be possible to avoid repeating these mistakes in the management of the River Murray System. The main caution in the literature seems to be that AM is not worth attempting unless it is well resourced and taken seriously from the outset. The wetland rehabilitation work in the Riverland area of South Australia is a good example of the successful implementation of adaptive management.

Most of the environmental flow projects reviewed in this report did not explicitly set out to follow an active adaptive management model. This is not surprising, given that most of the initiatives pre-date the Ministerial Council’s directive to follow an adaptive management approach, and the Commission does not yet have a framework to provide advice on how best to implement adaptive management in the River Murray System. Work is commencing to develop this framework.
1 Introduction

The need to balance competing demands for water through a single integrated approach to managing flows in the River Murray System was recognised by the Commission in 1999 with the establishment of the project entitled “Environmental Flows and Water Quality Objectives for the River Murray”. This was later expanded into The Living Murray.

The Living Murray initiative aims to provide improved environmental quality of the River Murray system whilst minimising any associated impacts on consumptive water users. This initiative currently includes the analysis of environmental, social and economic impacts associated with water recovery for the environment, and achievement of improved environmental outcomes based on current operating rules through structural and operational measures (MDBC, 2002a).

River Murray Water (RMW) is the Commission’s internal business unit responsible for operation of the River Murray System and the management of associated assets such as major dams and weirs. System operation, including release of water from storages, is undertaken in accordance with the Murray-Darling Basin Agreement and associated operating rules. RMW has been closely involved with the Commission process of development of environmental flow activities, including the implementation of environmental flow initiatives in recent years (MDBC, 2001b).

Reports on impacts of flow regulation in the River Murray System associated with current operating rules have indicated that regulation of flow has played a major role in causing environmental degradation of the river (e.g. Norris et al., 2001; Gippel and Blackham, 2002; MDBMC, 2002). The Living Murray initiative (MDBC, 2003a) is addressing these issues of concern, so that some of the impacts can be halted or reversed.

Other Commission supported programs are addressing the fundamental dimensions of river rehabilitation, such as riparian vegetation, fish passage and in-stream habitat (MDBC, 2003b). No single approach can deliver a healthy River Murray, and significant synergies are expected from combining increased flows with habitat rehabilitation and structural and operational changes.

Although the agreed structural and operational works, valued at $150 million, are yet to be implemented, and the suggested range of future flow changes is still being evaluated, RMW and other River Murray management agencies and groups have already begun to utilise the growing ecological knowledge of the river by managing some aspects of flow to provide environmental benefits. Practical experience gained from these initiatives can help guide future work. Also, these activities can provide evidence of the effectiveness, or otherwise, of providing environmental water.

Community engagement is an integral element of The Living Murray initiative. The community have expressed a clear need for the Commission to demonstrate what has been achieved with environmental flows projects in the past (MDBC, 2003c), and to confirm the scientific basis of its environmental flow work (MDBC, 2003d). Demonstrating an environmental dividend associated with operational changes requires careful scientific collection and analysis of data.

The Living Murray initiative is just one of the Commission’s programs that have a need for monitoring data. Currently, data are gathered extensively through a variety of
programs by various agencies and consultants. Although a wide range of data is collected on the River Murray (particularly in regard to water quality), The Living Murray initiative to date does not have a dedicated monitoring or scientific research program in relation to environmental flows. Past water monitoring programs have tended to focus more on human use values than ecological processes (i.e. they catered for the main community concerns of the time); the focus was on measuring water quantity and quality, with less emphasis on biological variables.

The Sustainable Rivers Audit (SRA) is a Basin-wide river health monitoring program currently being piloted. The SRA will report on river health (using five environmental themes) at the ‘valley scale’ across the Basin (Wittington et al., 2001). This program will provide information to help direct management actions, and inform the development of targets for river health. This is a surveillance approach to monitoring, and there is a separate need for targeted assessment, or ‘campaign monitoring’, to measure and understand environmental response to specific management interventions.

Adaptive management (AM) is a structured method of managing the environment whereby management actions (associated with expected outcomes) are developed by stakeholders, implemented, scientifically studied, and the results used to revise policy strategies (Holling, 1978; Lee, 1993; Walters, 1990, 1997; The Ecological Society of America 1996). Adaptive management is also known as ‘learning by doing’ through carefully planned and monitored interventions (i.e. it is not ‘trial-and-error’ learning). AM has a scientific basis, and is usually more rigorous than the trial-and-error or reactive approaches that have been traditionally used in river management in Australia and elsewhere. The Ministerial Council specifically directed the Living Murray initiative to follow an adaptive management approach.

Adaptive management in the context of environmental flows can also mean having flexible legislative requirements that allow for re-allocation of environmental water on the basis of periodic reviews (Dyson, 2002). Although relevant and important to the debate, this aspect lies beyond the scope of this report. The focus here is at the scale of on-ground water management decisions, which can be altered on the basis of improved knowledge, whether or not the total annual allocation varies.

This report reviews the environmental flow initiatives undertaken so far in the River Murray System. On-ground work aimed at improving river health through structural changes (such as building fishways over weirs), or habitat rehabilitation (such as reintroduction of large woody debris) is not within the scope of this report. This project has four main objectives:

- To inform the Commission regarding the successes and failures of on-ground environmental flow initiatives undertaken to date.
- To evaluate the way environmental flow initiatives have been implemented and monitored with respect to an adaptive management framework.
- To provide information relevant to policy making based on past environmental flow initiatives.
- To provide information to the community engagement process regarding achievements of environmental flow initiatives to date.

This report begins with a brief summary of the impact of flow regulation on the River Murray System, reviews the monitoring efforts to date, documents the genesis of The
Living Murray initiative, and lists the existing environmental water allocations. The environmental flow initiatives so far implemented on the River Murray System are then reviewed. This is followed by an explanation of the adaptive management approach, which the Ministerial Council requires for management of River Murray flows. The reviewed environmental flow initiatives are then assessed with respect to an adaptive management framework, as a way of guiding future environmental flow management initiatives.
2 Background to Environmental Flows in the River Murray System

2.1 Impacts of flow regulation on the River Murray environment

One major problem faced in determining impacts of regulation on the River Murray is the difficulty in isolating changes in the aquatic environment that are due to flow regulation from those that are due to other factors such as changes in catchment land use, fishing pressure, introduced species, riparian vegetation disturbance, large woody debris removal, and natural variations in flow regime. Another major problem in determining the environmental impacts of flow regulation of the River Murray is that it has occurred progressively over a long period of time, as water resources were developed to meet demands. While availability of data allows for detailed characterisation of changes in the River’s hydrology, this is not the case for the ecological consequences of these changes. This is partly because collection of suitable data did not begin until the regulated flow regime was well established, and also because ecological responses are complex, often delayed, and can manifest in a location that is distant from the site of the hydrological disturbance (Gippel et al., 2002).

A review of the impacts of flow regulation on the health of the River Murray System (Gippel and Blackham, 2002) found that regulation of flow has played a major role in the degradation of the river, albeit in many cases that the evidence is circumstantial and there are other potential contributing causes of degradation. Catchment and river diversions have reduced the mean annual flow in the lower River Murray (below Euston) to half the natural levels, or less. The percentage of runoff diverted from the major tributaries varies across the Basin, with several being highly committed (Figure 1).

Inflows from the Darling River do not improve the situation on the River Murray because this river is also highly regulated (Figure 1). Regulation has generally reduced flow variability. Variation of flow through the year is reduced through the release of relatively constant flows during the periods when stored water is increased (relatively constant low flows are released) and irrigation water supply (relatively constant flows near channel capacity are released). Weirs are managed to maintain the water level at a fairly constant level for long periods, and this further reduces natural flow variability. The frequencies of peak flows with recurrence intervals of 20 years or more did not change appreciably with regulation. The major hydrological impact of the construction of storages has been to reduce the frequency of occurrence and duration of mid-range flows, or minor-medium floods. The River Murray flows through a semi-arid environment, so it is not surprising that prior to regulation, during times of extreme drought, it was reduced to a chain of saline ponds. Under regulated conditions, there has always been some flow in the river. Near the Murray Mouth, prior to regulation there was little or no flow for less than 5% of the time. This has now increased to around 20% of the time (Gippel and Blackham, 2002).

An assessment of the River Murray and lower Darling River by Norris et al. (2001) found that overall biological and environmental condition is degraded throughout, with an increasing trend in degradation towards the river Mouth. Although the degraded condition of the River Murray System appears to be the consequence of multiple impacts, the main impacts were thought by Norris et al., (2001) to be related
to the operation of dams and weirs. Unseasonal flooding of wetlands, loss of connection with the floodplain, habitat simplification, water quality and bank erosion were defined as significant issues.

A workshop of experts convened during the development of the Murray-Darling Native Fish Strategy (MDBMC, 2002) ranked environmental flows as the top management intervention that would lead to improved native fish populations (abundance), with habitat restoration a close second (note that the Strategy recommended a holistic approach that combined various interventions, including fishways, control of introduced fish species, correcting cold water pollution and declaring reserves). Without these interventions the experts predicted that over the next 40-50 years, native fish populations would continue to decline from their current abundance of 10% of pre-European settlement levels to 5% (MDBMC, 2002).

The River Murray System has a highly diverse range of aquatic environments. The extensive system of regulation of the river has impacted the hydrology in different ways in different zones of the river, and consequently the environmental impacts have been complex and spatially variable. It is important to recognise that the River Murray System, although degraded, retains environmental values worthy of conservation and rehabilitation, including internationally listed wetland systems, and rare fishes. (Gippel and Blackham, 2002), e.g. the Murray-Darling Basin contains numerous large and significant floodplain wetlands, many of which are located on the River Murray System and the Murrumbidgee and Goulburn Rivers (Figure 2).

2.2 River Murray monitoring

2.2.1 Reviews of previous monitoring

In a major review of the hydrological impact of regulation on the River Murray, Maheshwari et al. (1993) undertook original analysis of hydrological data from eight River Murray gauging stations, and also analysed water level fluctuation data from six Locks. Most of this work was later published as a peer reviewed journal article (Maheshwari et al., 1995).

A River Murray water quality monitoring program was initiated in 1978. The first eight years of its operation were reviewed by Mackay et al. (1988). A more recent review of salinity data was undertaken by Williamson et al. (1997).

There is no ecological equivalent to the structured, detailed and comprehensive hydrological and water quality data collection network. Review of the hydrological data was possible only because of the availability of long-term gauging data (pre- and post- the various phases of regulation), and the existence of a sophisticated hydrological model of the system (the Commission’s MSM model). The water quality data have been collected in a consistent way across the river system. Ecological data are much more diverse, and generally more difficult to collect. Also, there is no integrated program for collection of ecological data. Walker (1985) and Walker (1992) provided excellent reviews of available information regarding the impacts of flow regulation on the ecology of the River Murray. Various chapters in Mackay and Eastburn (1990) detail some biological monitoring programs (plants, phytoplankton, macroinvertebrates, crayfish, mussels, fish and waterbirds), and contain information regarding the impacts of regulation on different aspects of the ecology of the River Murray.
Figure 1. River Murray catchment, showing distribution of, and impact of regulation on, median annual discharge for River Murray and major tributaries (from Gippel et al., 2002).
Figure 2. Large and significant floodplain wetlands in the Murray-Darling Basin (source: MDBMC, 1998).
The reviews of Thoms et al. (1998) and Young (2001) draw on a wide range of literature and data concerning the ecological impacts of regulation. The Cooperative Research Centre for Freshwater Ecology conducts a wide program of fundamental and applied research related to environmental flows (Growns and Gawne, 1998). Also, the Commission has funded a vast program of research through its Natural Resources Management Strategy which began in 1990 (e.g. Banens and Lehane, 1997, Banens and Crabb, 1998) and the Strategic Investigations and Education program (MDBC, 1995; MDBC, 2003f).

It is fair to say that past water monitoring programs have focused more on human use values than ecological processes (i.e. they catered for the main community concerns of the time); the focus was on measuring water quantity and quality, with less emphasis on biological variables.

2.2.2 The Living Murray monitoring

The Commission spends $2.4 million annually directly on water monitoring programs, and has initiatives and statutory responsibilities that rely on the data collected. The overall management of water monitoring data is being advanced within the Commission by two projects:

- **Water Monitoring Project**
  Addresses the what, when, why, how and where of data collection to meet needs and also information sharing - defining how the data are to be made available to users.

- **Data Management Project**
  Covers management of the data once it is acquired i.e. systems for quality assurance, transfer, storage, and access.

*The Living Murray* initiative is just one of the Commission’s programs that has a need for monitoring data (others include river operations, salinity management and management of Cap functions). To date, there is no dedicated monitoring or scientific research program in place for the River Murray System in relation to environmental flows.

Currently, data are gathered through a variety of programs by various agencies and consultants. Data collection and analysis methods are determined as appropriate for each program or investigation, with differing levels of Commission involvement in design of the approach to be taken.

A Water Monitoring Framework has been prepared by the Commission’s Monitoring Review Working Group in an attempt to draw together a process that will coordinate, rationalise and standardise all existing monitoring needs and be able to meet future monitoring needs. Two main forms of monitoring will serve *The Living Murray* initiative:

- Assessing the condition of the River Murray System by measuring the cumulative environmental response to the full range of management interventions (‘system-wide’ surveillance monitoring)

- Detecting and measuring environmental response to specific management interventions (‘campaign’ monitoring)
The development of a monitoring program to assess the condition of the River Murray System by measuring the cumulative environmental response to the full range of management interventions will provide feedback on whether river health is continuing to decline, remaining stable or improving. The Sustainable Rivers Audit (SRA) is a Basin-wide river health monitoring program currently being developed that will report on river health (using 5 environmental themes) at the ‘valley scale’ across the Basin (Wittington et al., 2001). This program will provide information to help direct management actions, and inform the development of targets for river health. The emphasis is on indicators of river condition rather than measuring the variables that cause river health. The SRA will not directly answer why river health might change through time, and will not explain why river health varies across the Basin. Thus, the program cannot be expected to detect local-scale changes to individual variables and relate them to particular improvements in land and river management. For example, one possible scenario is that environmental flow initiatives (particularly associated with small water volumes) will have a positive influence on river health, but that the effect will be only to slow or halt system-scale decline, and not result in a long-term upward trend in river health. This might be due to the negative influences of other problems not corrected by The Living Murray initiative, the inertia of environmental decline set in-train some time ago, or insufficient allocations of environmental water.

‘Campaign monitoring’ serves the need to detect and measure environmental response to specific management interventions. The basis of this type of monitoring is hypothesis testing, with controls and replicates, and detailed consideration of statistical power and analytical methods to be used before monitoring is begun. An example of large-scale monitoring driven by hypothesis testing is the New South Wales Integrated Monitoring of Environmental Flows (IMEF) program (DLWC, 2001a, 2001b).

2.3 Genesis and brief history of The Living Murray initiative

Gippel et al. (2002) documented the history of environmental flow initiatives in the River Murray System. The early 1990s saw the Commission formally adopt water quality and flow policies with the objective of protecting and enhancing the riverine environment. The Audit of Water Use followed in 1995, culminating in the decision of the Ministerial Council to implement an interim cap on new diversions for consumptive use (the Cap) in a bid to halt declining river health. The State water management agencies address their own water allocation and environmental water needs, but they recognise the sharing arrangement required to gain maximum benefit for River Murray environments. In 1996, more specific environmental flow management opportunities for the Murray were investigated by the establishment of two Scientific Panels that commenced the investigation of changes in river operations that would improve the environment while considering the current needs of existing water users. During 1997 to 1999, the Commission also undertook a review of the operation of Hume and Dartmouth Dams and developed a number of operational changes to better address the competing objectives of water supply, environmental enhancement and flood mitigation.

The need to balance competing demands for water through a single integrated approach to managing flows in the River Murray System was recognised by the Commission in 1999 with the establishment of the “Environmental Flows and Water Quality Objectives for the River Murray Project” (Gippel et al., 2002), which was later expanded into “The Living Murray initiative” (MDBC, 2003a). The
Commission, in partnership with the scientific and wider community, has undertaken considerable development work over the past few years, leading to advice being provided to the Ministerial Council (Gippel et al., 2002).

The Ministerial Council has approved in principle a range of measures costing $150 million over 7 years, covering structural and operational changes and investigations that make the best use of the water currently available to the River Murray environment. Also, the Council has directed the Commission to develop a business case for the recovery of 350 GL, 750 GL and 1500 GL per year to the River Murray for environmental benefits. The Living Murray initiative originally applied to the River Murray System (River Murray main stem, including the Mitta Mitta River below Dartmouth, Edward/Wakool system, and lower Darling River below Menindee Lakes). Following the November 2002 Council meeting, it was recently expanded to include the Goulburn River below Eildon Dam and the Murrumbidgee River below Burринjuck Dam (Figure 3).

The process for assessing the three flow recovery scenarios identified by the Ministerial Council is being undertaken over ten river zones by Regional Evaluation Groups using the Murray Flow Assessment Tool (MFAT). MFAT is a set of software tools to describe the impact of different flow scenarios on river and off-river habitat (Young and Cuddy, 2003). Impact is measured by effect on physical habitat condition, especially for native fish, waterbirds and vegetation communities. This model will provide some predictive ability that could be used in the future in adaptive management to develop hypotheses.

2.4 Existing Environmental Water Allocations (EWAs) for the extended River Murray System (including the Goulburn and Murrumbidgee Rivers)

The idea of providing water specifically for environmental benefit is not new in the River Murray System, and implementation of the existing environmental water allocations provides many of the examples of applied environmental flows reviewed in this report (Table 1). Environmental water allocations (EWAs) are volumes of water set aside specifically for environmental benefit. These allocations are also termed ‘allowance’ or ‘account’, and in this report the terms are used interchangeably, and the acronym EWA applies to all three terms (Appendix 1). It is noted that it is possible to have operating rules that provide an allowance to the environment without having an account.

EWAs have rules that govern when, where and how they can be applied. The first EWA in the River Murray System was for the Kerang Lakes in 1968, in an effort to maintain habitat for birds (principally ducks) (Reid and Brooks, 2000). The current EWAs have a broader focus. The EWAs for Victorian River Murray and Goulburn River environments are described in Centre for Environmental Management (1997) and Department of Sustainability and Environment (DSE) (2002). The EWAs for New South Wales River Murray, Lower Darling River and Murrumbidgee River environments are described in Department of Land and Water Conservation (DLWC) (2000a, 2000b, 2002). The EWAs for River Murray environments in South Australia are described in River Murray Catchment Water Management Board (RMCWMB) (2002) (for further details of EWAs, see Appendix 1).
Figure 3. The extended River Murray System that falls within *The Living Murray* initiative.
Table 1. Environmental Water Allocations (EWAs) available in the River Murray System, plus the Murrumbidgee and Goulburn Rivers. EWAs operated by River Murray Water are in shaded rows.

<table>
<thead>
<tr>
<th>Allocation name</th>
<th>Year approved</th>
<th>Volume and main conditions</th>
<th>Main purpose</th>
<th>Key Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barmah-Millewa Forest EWA</td>
<td>1993</td>
<td>100 GL/yr shared by NSW and Victoria (provision to carryover up to 700 GL; can be withheld for up to 4 years)</td>
<td>Wetland watering</td>
<td>RMW operating rules referred to in DLWC (2002)</td>
</tr>
<tr>
<td>Barmah-Millewa Overdraw</td>
<td>2001</td>
<td>50 GL/yr during wetter years (around 80% of years) shared by NSW and Victoria</td>
<td>Wetland watering</td>
<td>RMW operating rules referred to in DLWC (2002)</td>
</tr>
<tr>
<td>Lower Darling River ECA</td>
<td>2002</td>
<td>30 GL/yr (Menindee Lakes must be &gt;480 GL, and have been &gt;640 GL since the last time it was &lt;480 GL)</td>
<td>Flush blue-green algae when at high alert levels</td>
<td>DLWC (2002)</td>
</tr>
<tr>
<td>Murrumbidgee ECA</td>
<td>1998</td>
<td>25 GL/yr (additional volume of 25 GL/yr when allocations are &lt;80%, increasing up to 200 GL for allocations 80% - 100%)</td>
<td>Water quality needs, algal bloom suppression, fish breeding, and forest and wetland watering</td>
<td>DLWC (2000a)</td>
</tr>
<tr>
<td>Gunbower Forest EWA</td>
<td>1997/98</td>
<td>25 GL (one in three years) and 40 GL (one in twelve years)</td>
<td>Top up and extend small to medium sized floods, and cause low-level flooding after two years of being dry</td>
<td>MWEC (1997)</td>
</tr>
<tr>
<td>Goulburn River EWA</td>
<td>1995</td>
<td>80 GL in November in wet years (around 70% of years). Additional 25 GL when inflows to Lake Eildon have been high and the storage is relatively full</td>
<td>Spring flush</td>
<td>DCNR (1995), DSE (2002)</td>
</tr>
<tr>
<td>South Australian Additional Dilution Flows</td>
<td>1987</td>
<td>3,000 ML/d (when storage volumes in the Menindee Lakes exceed nominated trigger points, at the same time the combined storage volume of Hume and Dartmouth Reservoirs also exceed nominated triggers)</td>
<td>Reducing the salinity of water to South Australia (there may be incidental environmental benefits)</td>
<td>RMW operating rules referred to in DLWC (2002)</td>
</tr>
</tbody>
</table>
2.5 Expectations of environmental flows in the River Murray

Broad-focus water management plans have been or are being developed for most rivers and significant wetlands in the Murray-Darling Basin. They have been characterised as having the general aim of mimicking natural (pre-regulation) flooding regimes (Reid and Brooks, 2002). The expert panel process that evaluated the environmental water requirements of the River Murray also followed this philosophy (Gippel et al., 2002).

In March 2001, the Ministerial Council agreed to a vision and set of objectives for the River Murray System to be addressed by the Commission (Appendix 2). The river health and environmental flow objectives were:

**River health objectives**

- Protect and restore key habitat features in the river, riparian zone, floodplain and estuary to enhance ecological processes.
- Protect and restore healthy riverine and estuarine environments and high value floodplain and wetlands of national and international importance.
- Prevent the extinction of native species from the riverine system.
- Overcome barriers to the migration of native fish species.

**Environmental flow objectives**

- Reinstate ecologically significant elements of the natural flow regime.
- Keep the Murray Mouth open to maintain navigation and fish passage and to enhance estuarine conditions in the Coorong.
- Significantly improve connectivity between and within riverine, wetland, floodplain and estuarine environments.

As well as four Water quality objectives, there were four Human dimension objectives (in Appendix 2), with one specifically directing that an adaptive management approach be followed:


In its Corowa Communiqué in April 2002, the Ministerial Council approved in principle, a range of measures costing $150 million over 7 years covering structural and operational changes and investigations, to make the best use of the water currently available to the River Murray environment.

The suite of actions agreed by Council are expected to result in:

- improved floodplain health;
- improved fish management;
- improved management of the Murray Mouth, Coorong and Lower Lakes; and
- the refinement of interim water quality objectives for the River Murray.
The Council’s desire is to focus management of the structures and resources of the River Murray to improve the environment while maintaining the social and economic benefits obtained from resource use. *The Living Murray* initiative refers to this objective as achievement of a ‘healthy working river’ (MDBC, 2003a). The ERP defined ‘healthy working river’ and ‘river health’ as:

“A healthy working river is one that is managed to provide a sustainable compromise, agreed to by the community, between the condition of the river and the level of human use.

A healthy working river will not look like nor will it function in the same way as a pristine river. There is a relationship between the type and level of work we make a river do and its naturalness. In general, the more work the river is made to do the less natural it becomes. By most definitions a loss of naturalness represents a reduction in ecological integrity. For this report, ecological integrity is synonymous with river health.” (Jones et al., 2002).

To improve understanding of the costs and benefits of recovering water for the environment, the Ministerial Council directed the Commission to identify and address key issues such as equity, property rights and water trade through the development of a business case for the recovery of 350 GL, 750 GL and 1500 GL per year to the River Murray. These amounts are currently being used by *The Living Murray* initiative as reference points for further analysis and community consultation, and include the 70 GL to become available from the Snowy River environmental flows process.

*The Living Murray* initiative will identify local as well as system-wide environmental problems and benefits including the issues of the Murray Mouth, the Coorong, the Chowilla floodplain, the Gumbower/Perricoota and Barmah-Millewa forests, and Murray cod. It will also identify costs of various options and strategies to manage the social and economic impacts of measures for improving the health of the River Murray.

The knowledge generated by research scientists, State agencies, the work of the expert panels and the objectives agreed to by the Ministerial Council consistently suggest a set of environmental flow management actions that hold promise for improving river health. These include:

- Varying in-channel flow
- Providing more natural wetland watering and drying regimes, including drawing down of some weir pools to promote drying cycles of wetlands that are typically inundated, and raising of some weir pools to water wetlands that are now typically dry;
- Pulsing flows to disperse blue-green algae
- Flushing flows to move sediment from the Murray Mouth
- Releasing flows from storages to mimic the shape of natural hydrographs
- Managing in-stream structures to allow fish passage

In addition to *The Living Murray* initiative process described above, River Murray Water and other management agencies are already using existing environmental water allocations, and implementing changes to aspects of river flow, to achieve...
environmental outcomes. Review of this work is the main subject of this report. The information was drawn from published and unpublished sources and through targeted requests for information from management agencies and individual researchers. This information is the best currently available: better information may become available in the future as the results of some of the use of environmental water entitlements are analysed and written up more fully.
3 Review of Implemented Environmental Flow Initiatives

Several environmental initiatives have been implemented in the River Murray System (Figure 3) in recent years. The initiatives have taken different forms, addressing issues of in-channel needs, the needs of wetlands, water quality improvement, fish passage and sediment flushing. Many of these initiatives originated from River Murray Water in consultation with partner government agencies and ecologists, and preceded the Living Murray initiative.

The focus of this report is on cases where water management involves delivery of environmental flows through manipulation of River Murray flows or structures, or where specific environmental water allocations are used. The sites where environmental flows have been implemented are located throughout the River Murray System, which can be divided into three main regions, the Riverine Plains (Figure 4), the Sunraysia (Figure 5) and the Riverland (Figure 6).

Figure 4. Riverine Plains region of River Murray, showing sites of environmental flows implementation referred to in this report (map from Mackay and Eastburn, 1990).
Figure 5. Sunraysia region of River Murray, showing sites of environmental flows implementation referred to in this report (map from Mackay and Eastburn, 1990).

Figure 6. Riverland region of River Murray, showing sites of environmental flows implementation referred to in this report (map from Mackay and Eastburn, 1990).
3.1 In-channel variation of flow

3.1.1 Variable flow releases from Dartmouth Dam

Background, aims and methods

Dartmouth Dam (Figure 7) is a large storage that has altered the pattern of low flows, flood flows, as well as seasonal and daily flow variations in the Mitta Mitta River (Figure 3). Accelerated channel erosion has been reported as a problem. Long periods of relatively constant regulated flow appear to be the main cause of this erosion, rather than drawdown, which has long been the conventional wisdom. The flow regime is also reported to adversely impact stream ecology (Gippel and Blackham, 2002).

Figure 7. Dartmouth Dam, Mitta Mitta River (source: David Eastburn). Water is flowing over the spillway.

Flow downstream of the pondage had been maintained throughout Spring 2001 at 4,000 ML/d. From mid-November a small variation in flow was introduced to simulate the response to a rainfall event. The variation was based on a fortnightly cycle, with a short rise over 2 days followed by a recession over 12 days. Flow was varied over the range 3,200 ML/d to 4,800 ML/d, with a mean flow rate of 4,000 ML/d. This corresponded to a variation in river stage of 250 mm (MDBC, 2001).

The flow variation was hypothesised to reduce the potential for bank erosion, provide some wetting and drying of riparian vegetation and biofilms, as well as stimulating fish migration (MDBC, 2001).

A suite of 14 water quality, river productivity and invertebrate indicators were measured on the basis of recommendations by a recognised expert and a member of the SRP (Dr Terry Hillman). The experimental design distinguished between cobble bench environments that were permanently inundated, and those that were newly inundated (those areas inundated during the higher flows). A reference site was used as a control for the experiment.
Results

In general, there was an overall improvement in ecological health of the Mitta Mitta River following the variable flow release pattern, while the data suggested that during the 37-day period of constant flows that followed the trial, river health had begun to decline (Sutherland et al., 2002).

Data suggested that the variable flow regime produced different water quality compared to the monitored period of constant flow that immediately followed the trial. Although the data were not analysed for statistical significance, the variable flows were reported to be lower in electrical conductivity, pH and temperature, and higher in particulate organic matter, total suspended solids and water column chlorophyll a (Sutherland et al., 2002).

Water column extracellular enzyme activity (a measure of productivity) data were analysed using ANOVA statistical techniques. Although very low activity levels were recorded from all sites, the activities of enzymes were significantly higher during the peak discharges. Enzyme activities in the control site were uniformly low. Therefore, the variable releases had a positive effect on the health of the river by increasing the rates of microbial activity for a diverse range of water column bacteria (Sutherland et al., 2002).

Biofilm data were analysed using ANOVA statistical techniques. Scouring of biofilms during the variable release resulted in decreased biomass of biofilms, changed composition of biofilm algal species, and rapid changes in net productivity at all surveyed test sites (Sutherland et al., 2002).

Macroinvertebrate data were analysed using SIGNAL biotic index scores (Chessman, 1995), ANOVA, non-metric multi-dimensional scaling, analysis of similarities and species contributions to similarities. The response of macroinvertebrates was more pronounced at the most upstream site (closer to the dam) than the other sites. There was an increased number of families and an increase in SIGNAL score observed at one site only, however, there were significant changes to community composition at three of the four monitored sites (Sutherland et al., 2002).

Conclusion

Although the Dartmouth Dam variable release event was organised at relatively short notice, a thorough scientific evaluation of the trial was conducted. The monitoring demonstrated that even a modest 250 mm controlled stage variation over a two-week duration was able to produce statistically significant positive environmental benefits in the Mitta Mitta River.

3.1.2 Variable flow release to South Australia

Background, aims and methods

In November 2001 the pattern of flows to South Australia (Figure 3) were varied to provide a short pulse rather than a constant flow. Since 1 November flows had been constant at around 7,000 ML/d. From 8 November releases from Lake Victoria (Figure 6) were increased over 4 days to achieve a peak flow to South Australia of 13,000 ML/d, followed by a reduction to 6,000 ML/d over the following week. The intention was to provide the hypothesised environmental benefits of variable flow rather than constant flow, and also to provide a wetting and drying cycle to the littoral zone downstream of the Locks and Weirs (RMW et al., 2001).
Scott Nichols (Australian Landscape Trust, Renmark, pers. comm. 12 March 2003) is undertaking a fish research project in the Riverland of South Australia, investigating the effects of flow control structures on fish movement into and out of managed and unmanaged wetlands. He took the opportunity to monitor fish movement on three occasions around the time of the November 2001 variable flow release (on 9 November, 13-14 November, and 19-20 November). The sampling was done at Ral Creek adjacent temporary and permanent inlets to Lake Merreti, located in the South Australian Riverland area (Figure 2, Figure 6).

Results

The temporary inlets to the lake did not flow during this period. Very few fish were caught (Scott Nichols, Australian Landscape Trust, Renmark, pers. comm., 12 March 2003). There does not appear to have been any other monitoring undertaken during this flow release.

Conclusion

Scott Nichols (Australian Landscape Trust, Renmark, pers. comm., 12 March 2003) was of the opinion that the experimental variable flow release of one-week duration was not significant for fish in the lower Murray, because it did not allow sufficient time for fish to react. However, this release was not comprehensively monitored for other organisms, so it is not possible to ascertain its effectiveness.

3.2 Wetland watering using specific flood event or allocation

3.2.1 Trial watering of wetlands on private land within the MIL area

Background, aims and methods

In late-2001 the MWWG initiated a pilot project to increase wetland diversity within the operation area of Murray Irrigation Limited (MIL) (Figure 4). This was part of the MWWG’s objective to develop and implement scientifically defensible, technically sound and community endorsed local wetland management programs, while at the same time developing a strategic Murray and Lower Darling regional approach. The MIL area of operations covers an elevated floodplain area in central NSW that would have been inundated only in times of high floods. Due to changes in land management and river hydrology, the depressions in this area are rarely inundated. Towns in this region include Deniliquin, Berrigan, Finley and Wakool, and the main waterways are the River Murray, Edward River, Wakool River and Niemur River (Figure 4) (Nias et al., 2002).

The trial aimed to increase wetland health, and to test the level of landholder interest in wetland management. Vegetation community composition, tree vigour and bird composition were selected as the indicator variables to benchmark pre-watering conditions, and to test for changes after intervention. Surface water salinity and electrical conductivity were also monitored.

Eleven sites on private land, incorporating 250 ha, were selected using a process that involved cooperation of MIL (MWWG, 2002a). Landholders responded to an advertised Expression of Interest for Environmental Water, and the potential sites were assessed for suitability using MIL and MWWG criteria. The selected sites included areas of black-box depression, prior streams and lignum swamps. The Regional Director, Murray Region DLWC, approved a bulk temporary transfer of 800 ML from the NSW Murray Wetlands EWA to the MIL licence. Water was
delivered to the wetlands using MIL’s channel system. Landholders began filling their wetlands by October 2001. The landholders were not permitted to use the water for consumptive purposes. MWWG Project Officers and one MIL contract employee conducted monitoring for six months, until April 2002. Ten of the sites were dry prior to watering, with the other being a semi-permanent wetland.

The vegetation monitoring used the methods of photopoints (every three weeks), transects of vegetation profile (every 2-3 months) and quadrat analysis of community composition (five randomly selected quadrats repeatedly measured every three weeks). At the conclusion of the watering trial the wetlands were allowed to dry, and nine weeks after drying a final measurement of the indicators was undertaken. Birds were surveyed using standard 20-minute and 1-hour searches, incorporating all available habitat types.

Results

After nine weeks of the trial, five of the eleven wetlands in the trial were no longer inundated, and after twelve weeks another one had drained. This related to underestimation of the volume of water required to fill some of the wetlands. Some wetlands used less water than allocated, so that only 569 ML of the allocated 741 ML was used. Salinity was below 400 $\mu$$\text{Scm}^{-1}$ for the duration of the trial, which is regarded as within the tolerance limits of freshwater species (Nias et al., 2002).

All sites displayed a positive growth in both wetland plants and terrestrial plants after receiving water (Figure 8, Figure 9, Figure 10). Emergence of wetland plants not seen prior to watering indicated that these species were still present in the seed bank, despite years of grazing and being mainly dry for 20-30 years. Inundation of terrestrial grasses allowed native wetland plants to colonise, in some places achieving 100% coverage. As the duration of inundation increased, the percentage of wetland species increased, and the percentage of introduced species declined, although Nias et al. (2002) did not report tests for statistical significance for these differences (Figure 11). Although the total number of species present declined from 59 (pre-watering) to 25 (12 weeks post watering), the percentages that were wetland plants increased from 19% to 48%. This was achieved through a reduction in introduced species (Figure 11). Field observations indicated that plants were able to germinate, flower, and seed within a 12-week inundation period (Nias et al., 2002).

Figure 8. Redgum/lignum swamp near Jerilderie site before watering (left) and 5 weeks after inundation, 2000-2001 season (source: Deb Nias, MWWG).
Figure 9. Open wetland site with mostly fringing lignum/blackbox before watering (left) and 15 weeks after inundation, 2000-2001 season (source: Deb Nias, MWWG).

Figure 10. Blackbox wetland site before watering (left) and 10 weeks after inundation. The watering promoted new growth on the trees as well as prolific establishment of wetland plants, 2001-2002 season (source: Deb Nias, MWWG).

Figure 11. Percentage of introduced, native terrestrial and wetland plant species, and total number of plant species observed, in quadrat analysis, pre-treatment, and for three periods post-watering of wetlands (data from Nias et al., 2002).
Bird diversity increased from 93 (pre-watering) to 142 (post-watering). Nine species considered threatened under NSW legislation, and eight migratory species were observed (these were mutually exclusive sets). As expected, there was a large increase in the number of waterbird species present after the wetlands were inundated. Diversity of waterbird species at the individual sites increased from 0-3 (pre-watering) to 0-11 (post-watering), with six sites having at least five species present post-watering (Figure 12). Nias et al. (2002) did not report tests for statistical significance. However, it is likely that the differences were significant.

Figure 12. Mean number of waterbird species recorded per 1-hour search prior to watering and after watering. Storage dams or nearby waterbodies explain the presence of birds at five sites prior to watering. One (semi-permanent) site not included (data from Nias et al., 2002).

Landholders were reported to be pleased at the improvement in health of trees in the wetlands, and surprised at the diversity of plants that emerged from the soil (Nias et al., 2002).

The trial watering established short-term responses to wetland inundation. A longer program of monitoring is required to fully assess the long-term implications of this management policy. Some relatively minor and inconsequential operational difficulties were experienced (Nias et al., 2002). It was noted that the resources required for monitoring were “substantial” (Nias et al., 2002).

Valuable lessons were learned from the trial watering, leading to management recommendations to improve on-going watering events. These recommendations included starting the trial earlier in the season to maximise ecological benefits, allowing for delivery of additional water to sites where the volume required was underestimated, dividing wetlands into three monitoring groups (i.e. in each, measure trees, wetland vegetation or waterbirds, rather than all three), planting of additional understorey, encouraging fencing and weed removal, and encouraging on-going
monitoring by landholders (Nias et al., 2002). It was also recommended that the idea be progressed from trial status to being considered a normal part of wetland management.

**On-going progress**

The success of the 2001/02 wetland-watering project led to expansion of the project in 2002/03 (MWWG, 2002b). The number of landholders participating increased from ten in 2001/02 to twenty-seven in 2002/03. The expanded project involved 43 wetland sites, encompassing 572 ha, and delivery of 3,975 ML of water. Although the extent of watering expanded, the monitoring program was rationalised, with only nine sites being measured.

The recommendations from the 2001/02 project were implemented, with the water delivered earlier in the year. Early monitoring results confirmed the increased bird numbers and vegetation changes that were observed in the previous year. However, a greater bird response was expected due to the regional drought conditions (MWWG, 2002b).

**Conclusion**

The Watering of Wetlands on Private Land project established that such a management policy was politically, socially and technically feasible. The project conducted targeted monitoring, using a before and after design. The project design was limited to some extent by the single pre-intervention measurement, and lack of controls. Replication was in the form of some of the sites being similar, or having similar habitat types. The project report (Nias et al., 2002) did not test for statistical significance of differences, but the changes were so marked that they would appear to be unequivocal. Despite the lack of control sites, it is almost certain that the experimental inundation was responsible for the response, because the experiment was conducted during drought conditions.

Some lessons learned during the first trial were used to improve the second trial. The well-planned objectives, high level of community approval, agency support, and scientifically (although not statistically) demonstrated success of the first trial were major factors that encouraged the expansion of this management policy in the following year. This project demonstrated that long-dry and grazed floodplain wetlands can be rejuvenated (at least in the short-term) in terms of plants and waterbirds through artificial watering. The project also demonstrated that the local community is willing to support and become actively involved in this form of management action. It is worth noting that the MWWG were finalists in the Thiess National Riverprize Awards 2002 for their work in wetland restoration.

**3.2.2 Enhanced flooding of the Barmah-Millewa Forest**

**Background, aims and methods**

One well-recognised impact of regulation of the River Murray has been reduction in the frequency of ecologically important spring medium-sized flood events in the Barmah-Millewa Forest (Figure 4). The objectives of the Water Management Strategy (Barmah-Millewa Forum, 2000) are: to optimise use of river flows to enhance water management of the forest environment; to monitor, record and evaluate scientific information required for adaptive management, and; to increase knowledge that will aid adaptive management.
The Barmah Millewa Forest EWA was first used in 1998 when 97 GL was provided to supplement a minor flood in the Forest caused by high flows in the Ovens and Kiewa Rivers (Maunsell McIntyre Pty Ltd, 1999). From October 2000 to January 2001, a total of 341 GL from environmental accounts was released in three parcels (Figure 13) to supplement a 1 in 5 year flood event that was naturally occurring in the Barmah-Millewa Forest (Barmah-Millewa Forum, 2001; Leslie and Ward, 2002). The environmental water provided to the Forest comprised 200 GL of accrued allocation (from carryover) from the Barmah-Millewa Forest EWA, 50 GL of allocation loaned to irrigators in the 1997/98 season and since paid back, 50 GL of advanced draw against the 2001/02 season, 15 GL from the Victorian Murray Wetlands EWA, and 26 GL from the New South Wales Murray Wetlands EWA.

![Figure 13. Yarrawonga Weir releases and Barmah-Millewa Forest Account, Jun 2000 - Jan 2001. Actual releases, simulated releases without environmental releases, estimated natural flow downstream of Yarrawonga, and cumulative use of environmental flow account.](image)

**Results**

Release of the 1998 allocation was intended to fill in some of the gaps in the natural hydrograph lost due to flow regulation and irrigation extractions. The flood inundated lower parts of the floodplain for 4 weeks, primarily in the eastern (upstream) end of the Forest. Blanch (1999) reported that while many floodplain plant and bird species reacted favourably to the 1998 flood enhancement, the period of inundation was of insufficient duration and depth to achieve all the desired ecological outcomes. For example, no colonial nesting waterbirds were observed to breed, and initiation of flowering in Moira grass also failed. Similarly, flooding was too brief to establish wetland plant species that are being replaced by redgums, which prefer less frequent inundation (Blanch, 1999). Most native fish require water temperatures of at least 20°C to spawn (Young, 2001). Temperatures were below this until mid-December, which was well after floodwaters had receded. In contrast, carp benefited from the
environmental allocation (Blanch, 2001). Also, some frog breeding was observed (Blanch, 1999).

Use of the allocation in the 2000/01 flood enhancement involved a much greater volume of water than that used in the smaller 1998 flood event. At 341 GL, this is the largest allocation of environmental water yet made in Australia (Leslie and Ward, 2002). By way of comparison, the high-profile 1996 controlled flood of the Colorado River in the Grand Canyon involved release of 110 200 ML/day for 8 days (Konieczki et al., 1997), which equates to a total release of 881 GL. This release did not enhance a natural flood; it was an entirely artificial flood.

The bulk of the water released to the River Murray in the 2000/01 flood was used to slow the recessions of the October and November floods (to mimic unregulated recession rates), mainly to maintain conditions suitable for bird breeding. Other ecological benefits were also expected. To put the environmental flow release into perspective, the total flow passing downstream of Yarrawonga from September 2000 to January 2001 inclusive was 4,426 GL, of which only 8% was contributed by the environmental water allocation (Barmah-Millewa Forum, 2001).

Although there was some inconvenience flooding in limited areas during the 2000/01 flood, general community response was positive in view of the significant environmental benefits arising from the event. A report on the impact of the flood (Barmah-Millewa Forum, 2001) revealed that bird breeding success was ranked at least a 1 in 10 year event in terms of number of species, and total bird numbers. The Great, Intermediate and Little Egrets (all endangered species in Victoria) bred in the Forest for the first time since 1993, 1992 and 1975 respectively (Leslie and Ward, 2002). Because the breeding events reached completion (at least 15,000 breeding pairs of 20 or more species), a large population of birds became available for future breeding events. Without the environmental flow, Leslie and Ward (2002) estimated that about 3,000 nests would have been abandoned by mid-December. A survey of frogs indicated nine species of newly hatched tadpoles throughout key breeding areas of the forest (Ward, 2001). While recruitment of some native fish species occurred during the flood, introduced nuisance fish species also showed widespread breeding success (Barmah-Millewa Forum, 2001).

It is quite natural for floods to cause rapid oxygen depletion on a large scale during flooding of the Barmah-Millewa Forest, and re-entry of this water to the river has been associated with fish kills and emergence of Murray crayfish *en masse* from the river (McKinnon, 1997). When floodwaters become heavily coloured with dissolved organic acids they are commonly referred to as “blackwater”, and in most cases fish could be expected to actively avoid such water (Gehrke et al., 1993). The 2000/01 flood did result in a period of lowered dissolved oxygen downstream of Picnic Point throughout December 2000. However, this was a natural and expected process, and Barmah-Millewa Forum (2001) concluded that the environmental flow enhancement would have lessened this effect through flow dilution.

**Conclusion**

The 1998 allocation of 97 GL, which helped flood the forest for 4 weeks, provided negligible environmental benefit (Maunsell Pty Ltd et al., 1992; Leslie and Ward, 2002). This experience confirmed the growing scientific knowledge that long duration events are critical to successful bird breeding. In contrast, supplementation of the
2000/01 flood with a larger allocation of 341 GL produced demonstrated environmental benefits.

Implementation of environmental flows in the Barmah-Millewa Forest confirmed the research and modelling that provided the scientific basis for development of the flow rules. Provided a suitable natural flood occurs, and provided a large enough allocation is made to supplement that flood, enhanced flooding can provide real ecological benefits to the Barmah-Millewa Forest floodplain wetlands.

3.2.3 Werai Forest watering

Background, aims and methods

Werai Forest is a 12,000 ha floodplain Ramsar listed wetland located 40 km northwest of Deniliquin at the intersection of the Edward River, Colligen Creek and Niemur River (Figure 4). The wetlands are fed by water from the Edward River via Tummudgery Creek. Flow records suggest that river regulation and construction of regulators in the Werai Forest have significantly reduced the frequency and duration of flooding in these wetlands (Green, 2001a). It is thought that increased frequency of flooding is required in order to maintain the natural wetland diversity within the forest.

In November 2001 a 3-week trial flooding of wetlands along the Tummudgery Creek, using water from the NSW Murray Wetlands EWA, was undertaken by the Murray Wetland Working Group in conjunction with the State Forests of NSW and the Commission (RMW 2001e). The main aims of the project were to identify the area of wetlands inundated when the Edward River is at various levels, to determine the volume of water required for wetland flooding, and to identify the management complexities of providing water to these wetlands. The trial aimed to inundate 150 ha of the Forest wetland. These results were used to assist in the development of a water management plan, and to refine environmental flow rules (Green, 2001a).

DLWC hydrographers gauged the discharge into the forest and back into Colligen Creek (the outlet). MWWG project officers monitored water quality, measured the movement and distribution of water through the forest, and estimated the total amount of water used. The project also identified social, environmental and economic implications of implementing the trial. Vegetation surveys were conducted on two occasions after the trial watering. A single bird survey was conducted at the conclusion of the trial watering.

Results

A relationship was established between flow in the Edward River and extent of flooding in Werai Forest. The costs of transferring the water were also determined.

The flooding impacted an area of approximately 137 ha. A series of flood runners 0.4-0.8 m deep flowed between partially inundated reed beds. The growth of Moira Grass and Water Milfoil in these flood runners was thought to be initiated by the flooding (although there was no pre-treatment vegetation survey) (Green, 2001a). The bird survey identified 41 species in the vicinity of the wetlands, but control data, or pre-treatment data, were not collected for comparison. Qualitative field observation suggested that the trial initiated frog breeding (Green, 2001a).

The turbidity of the water leaving the wetland declined during the trial from 32 NTU to 9 NTU, and it was less turbid than that entering the wetland (which dropped from...
100 NTU to 65 NTU during the course of the trial). The salinity of the water increased slightly as it passed through the wetland, and was always less than 132 µS/cm. Water pH was slightly acidic (within expected range) throughout the trial (Green, 2001a). The dissolved oxygen monitoring was inadequate to characterise the effects of the trial on this variable.

Most of the water dried up within 1 month of the watering. A total of 3,261 ML was debited from the EWA (Green, 2001a). The fee for delivery of water via Mulwala Canal was approximately $12,000. The trial watering was well received by the local aboriginal community and there were no complaints from neighbouring landholders (Green, 2001a).

Conclusion

This was mainly a hydrological trial, although some ecological monitoring was also conducted. The ecological monitoring suggested that the trial produced positive results. However, the sampling was too limited to allow confident conclusions to be drawn. The hydrological monitoring was adequate to establish relationships between river discharge and wetland inundation that can be used in future forest-watering exercises. The project outcomes were linked to future management through input to the development of a Water Management Plan for the Werai Forest. This project is an example of cooperation between a non-government community based group (like the MWWG) and government agencies to achieve a common goal (MWWG, 2001b).

3.2.4 Wanganella Swamp watering

Background, aims and methods

Wanganella Swamp is located 30 km north of Deniliquin on the Forest Creek (Figure 4). The area is actually one swamp divided into two sections by the Cobb Highway. Cumbungi and sedges dominate the swamps. Although comparatively small in area, the swamps are considered to support significant waterbird populations (Roberts and Pasma, 1993). Under the proposed Forest Creek Management Plan (Glazebrook, 2000) an environmental flow for the swamp has been requested in years when certain ‘triggers’ are met. The triggers are a flow >400 ML/d at Warriston Weir gauge for more than 40 consecutive days between mid-August and mid-October, and the initiation of waterbird breeding in the swamp (Green, 2001b).

The Management Plan identified an ‘ideal’ environmental flow regime at Warriston Weir that would be implemented when the triggers were met. This gradually declining Forest Creek hydrograph was hypothesised to supply sufficient water to Wanganella Swamp to provide an opportunity for numerous species of waterbirds to complete their breeding cycle. The ‘ideal’ regime was provided as a guide for the water managers to follow (Damian Green, MDBC, pers. comm., 20 March 2003).

An opportunistic field survey on 7 December 2000 (on the recession limb of a natural flood event) counted approximately 7,000 adult birds and 15,000 dependent young. It was noticed that water levels were receding, and there was evidence of nest abandonment and some of the more cryptic species (birds that are secretive, shy, keep out of full sunlight and most likely to be revealed by their call or accidental flushing) had already left the Swamp (Green, 2001b). Although the Forest Creek flow condition trigger for an environmental flow allocation had not been met (Figure 14), the initiation of a breeding event warranted provision of the allocation to the Swamp. A volume of 1,500 ML was supplied from the Moira Lakes Savings (managed by the
MWWG), and 1,000 ML was made available from the Murrumbidgee Environmental Contingency Allowance, which is controlled by the Murrumbidgee River Management Committee (note that Forest Creek is supplied by both the River Murray and the Murrumbidgee River) (Green, 2001b).

In accordance with the proposed Forest Creek Management Plan, an extra 60 ML/d was supplied from 15 December 2000 for three weeks, followed by an extra 20 ML/d until the end of January (Figure 14). With the cooperation of MIL and DLWC, water was supplied via the Finley Channel and the Billabong Creek. The operation required restrictions on pumpers on the Billabong Creek system (Green, 2001b).

![Figure 14. Flow in Forest Creek recorded at Warriston Weir, spring/summer of 2000/2001. The hydrograph is lagged 8 days to simulate the travel time to Wanganella Swamp (source: Green, 2001b). The target environmental flow is the “ideal” pattern given in the Management Plan to guide water managers.](image)

Results

During the lag period between the initial natural flood inundation and the enhancement by the environmental allocation there was a temporary reduction in water levels (Figure 14). This did not appear to have affected ibis breeding, but could have been detrimental to other species. Substantial populations of birds (mostly ibis spp. and Royal spoonbills) with young were successfully fledged from Wanganella Swamp (MWWG, 2001a).

Although the 2000/01 watering achieved a level of success, experience from the project suggested that improvements could be made in the future. It was recommended that rather than relying on opportunistic field surveys to report breeding events, a more formal monitoring program was required (Green, 2001b). Also, during the period when the flow allocations are being applied, site visits should be made to observe water levels, species present and breeding success (Green, 2001b).

Conclusion

At the time of this first release of an environmental water allocation to Wanganella Swamp there was no formal monitoring evaluation plan in place. The decision to
release the environmental allocation relied solely on a fortunate visit to the site by a
team of scientists at a critical time when birds were starting to abandon their nests.
With advance warning, the allocation could have been made earlier, which may have
enabled maintenance of water levels, and prevention of nest abandonment. This is
important at this site because of the long travel times (in the order of 30 days)
between the wetland and the point where river flow is regulated.

Although the Management Plan identified an ‘ideal’ environmental flow pattern for
Wanganella Swamp, the timing of the request for an allocation, the level of water
abstraction at the time, the dampening of flood pulses, and rain events mean that the
‘ideal’ flow may be difficult to achieve in practice (Damian Green, MDBC, pers.
comm., 20 March 2003).

Observations of bird breeding made during the 2000/01 event suggest that the
management action may have had a positive benefit for ibis. The opportunistic nature
of the monitoring means that it is not possible to evaluate the relative success of the
flow enhancement.

3.2.5 Enhanced flows and weir surcharge to inundate South Australian
wetlands

Background, aims and methods

Weirs on the River Murray are known to have had an overall negative impact on the
natural environment, largely through the way they reduce the seasonal variation in
stage (Gippel and Blackham, 2002). River management agencies have an interest in
finding ways of ameliorating these impacts while retaining some, if not all, of the
utilitarian services they provide to the wider community.

Ohlmeyer (1991) considered the feasibility of increasing the area of wetland
inundation through manipulating water levels between Locks 1 to 10, and concluded
that the options were perhaps limited to raising the level in Pool 8, which is distant
from most river users. Blanch et al. (1996) responded to this recommendation in 1995
with a trial of controlled surcharge at Weir 8 (the planned drawdown was abandoned
due to natural floods). This trial concluded that deep flooding followed by slow
recession stimulated the greatest ecological responses. However, a modest water level
rise of 0.45 m produced significant plant responses.

Sharley and Huggan (1995) detailed plans for enhancing River Murray flow peaks,
through releases from Lake Victoria, to extend the area and frequency of floodplain
vegetation watered on the Chowilla wetlands (Figure 6). Considerable research had
determined the area flooded for different flow rates, likely environmental benefits,
and possible negative impacts.

Jensen (1997) indicated the appropriate environmental flow management actions for
the South Australian River Murray for different flow classes. The October and
December 2000 natural floods provided opportunities to enhance flows for the
purpose of increasing the area of floodplain inundation in South Australia, and
thereby stimulating growth in floodplain ecosystems (RMW and SA Water, 2000;
RMW, 2000b). This was the first time that the Commission agreed to operate works
to increase the peak flow to South Australia. Monitoring of environmental,
community and infrastructure impacts was conducted by South Australian agencies
(RMW and SA Water, 2000; RMW et al., 2000b).
During the October 2000 event, the flow to South Australia was enhanced by about 8,000 ML/d by appropriately timed releases from Lake Victoria, so that flow at the South Australian border reached a peak near 40,000 ML/d (RMW, 2000). More widespread inundation was achieved by surcharging of the upstream pool level of Lock 5 near Renmark (Figure 6) by about 0.5 m using stop logs on the weir. The peak enhanced flow at this location was 32,000 ML/d, but the weir surcharging produced a river stage that was equivalent to about 70,000 ML/d (Department of Water, Land and Biodiversity Conservation, 2002a). To ensure the stability of the weir at Lock 5 during the trial, it was necessary to also surcharge Lock 4 weir pool, by about 0.4 m, thereby raising the water levels downstream of Lock 5 and maintaining a safe upstream to downstream head difference (Department of Water, Land and Biodiversity Conservation, 2002a).

The Berri Office of the Department of Water, Land and Biodiversity Conservation conducted a monitoring program during the October 2000 trial with a focus on the response of groundwater and surface water to the changed river operating conditions. The main objectives were to determine the extent of water level rise in the river channel and floodplain, and to determine the salinity change in the river, wetlands and backwaters. Fish movement, plant growth and reaction from the local community were also monitored (Department of Water, Land and Biodiversity Conservation, 2002a).

In the larger December 2000 event, the Commission agreed to enhance the peak to South Australia by about 9,000 ML/day to achieve a peak of 63,400 ML/d on 17-18 December (RMW, 2000d; RMW et al., 2000b). This peak discharge included a contribution of about 11,000 ML/d from the Darling River resulting from flood operation of Menindee Lakes.

Results

As a result of the October 2000 event, the area of floodplain that was inundated (between Lock 7 and Lock 1, which covers most of the River Murray in South Australia) (Figure 6) was increased by about 10%, increasing the area flooded by about 2,400 ha. At the time, this was reported to have achieved unspecified environmental benefits to wetlands upstream of Lock 5 (RMW, 2000b).

Department of Water, Land and Biodiversity Conservation (2002a) found that from a groundwater perspective, there were no environmental costs, with groundwater electrical conductivity being lowered in the short-term in response to raising the pool level. There were some concerns about the possible consequences of longer-term raising of weir pool levels. No adult fish were recorded attempting to move into the inundated wetlands. The plant study, undertaken by The University of Adelaide, indicated that there was no response of aquatic plants, suggesting low seedbank viability. There was a change in the floristic composition in ground dwelling species as a consequence of the enhanced flood, with a shift towards a more amphibious species. However, these species accounted for less than 1.4% of the abundance and cover. It was assumed that the duration of the enhanced flow was inadequate to generate a response from aquatic plants (Department of Water, Land and Biodiversity Conservation, 2002a). In general the local community were supportive of the trial (Department of Water, Land and Biodiversity Conservation, 2002a).
The enhancement of flow during the December event increased the area of floodplain inundated on the Chowilla wetlands (Figure 6) from 13% to 25% of the total area, inundating about 4,000 ha (RMW, 2000d). Unfortunately, on this occasion there were insufficient arrangements in place to provide additional floodplain inundation by surcharging of upstream pool level at Lock 5 and other weirs.

Conclusion

In general, the project demonstrated that increasing floodplain inundation through flow enhancement and weir surcharging created environmental benefits, and few if any environmental costs. In contrast to the wetland flooding experiments undertaken in the middle-Murray (which produced a flourish of aquatic plants), here the seedbank did not respond, possibly because the duration of inundation was too short.

3.2.6 Victorian Murray Wetlands hydrological management

Introduction

The Victorian Murray Wetlands EWA is an allocation of 27.6 GL per year of high security water committed for flora and fauna conservation in the Victorian Murray Wetlands (Figure 2). In 1999 the Victorian Murray Wetlands EWA was converted to Bulk Entitlement through the Murray River Bulk Water Entitlement process, which resulted in the EWA becoming a defined entitlement for the environment.

Recommendations on the development of the works program are made by the Environmental Water Allocation Committee. Current membership includes local stakeholders such as Field & Game Australia, Parks Victoria, Goulburn-Murray Water, Sunraysia Rural Water Authority, DSE Victoria, Torrumbarry Water Services Committee, Loddon Implementation Committee, and with input from the four northern Catchment Management Authorities.

The process of determining the distribution of the EWA in each season involves use of seven main criteria, a decision flowchart, and consideration of other factors such as hydrological requirements, ecological requirements and seasonal conditions (DNRE, 2002a).

Application of the EWA in the 2001/2002 season

In the 2001/02 season, allocations were made to McDonalds Swamp, Hird Swamp, Johnsons Swamp, Lake Murphy, Round Lake and Cardross Lake (DNRE, 2001) (Figure 4, Figure 5).

Part of the EWA was used to enable excessive Cumbungi and Phragmites growth within the Hird Swamp (Figure 4) to be effectively managed. Prior to spraying, the Cumbungi and Phragmites needed to be in an unstressed, active growth state to maximise the effectiveness of the spray. This was ensured by delivery of 2,025 ML of water to the Swamp in Nov-Dec 2001. Consultants recommended that the water be held in the Swamp for a minimum of 6 weeks to allow for plant growth (in practice, water was held in the Swamp for 10½ weeks). Vegetation monitoring was conducted by the Applied Science Business Unit of the Bendigo Regional Institute of TAFE, a bird survey methodology was established and two surveys were conducted (on 20 December 2001 and 13 February 2002), and comprehensive water quality testing was undertaken by Thiess Environmental Services (DNRE, 2001).
Due to the dry conditions in 2001/02, Lake Murphy (Figure 4) was provided with 1,590 ML so it could act as a drought refuge for a range of waterfowl, including wading species (DNRE, 2001).

Round Lake (Figure 4) is a significant wetland due to the presence of the Flora and Fauna Guarantee listed fish species Murray hardyhead (*Craterocephalus fluviatilis*). Round Lake is one of 5 lakes within northern Victoria that displays this species, and as such it is critical to ensure salinity levels of the lake do not reach life-threatening levels (DNRE, 2001). In the 2001/02, 100 ML was allocated to Round Lake to ensure salinity levels did not increase 40,000 EC. The application was guided by monthly salinity monitoring of Round Lake (DNRE, 2001).

Cardross Lakes (Figure 5) are significant habitat for a diverse aquatic fauna community, including Murray hardyhead. The area surrounding Cardross Lakes also supports a number of native vegetation communities, including the threatened belah woodland (DNRE, 2001). Since 1996, aquatic habitat had been maintained at the Lake mostly by the annual input of about 1,000 ML of the EWA, but during 2000/01 the EWA was not used there and water levels dropped by around one metre. In the 2001/02 season 1,100 ML from the EWA was delivered to the wetland, which subsequently stabilised the water levels (DNRE, 2001).

In dry years, it may be more beneficial to the ecology of many wetlands to not add water and allow drying or partial drying. In those years, a proportion of the EWA has been temporarily traded on the open market. Trading of the allocation has only occurred after all identified environmental targets have been met. Temporary trading of the allocation between 1994/95 and 2001/02 seasons has generated over $1.2 million in funds to meet service delivery costs and to undertake on-ground works for wetland management (DNRE, 2001).

**Results**

The EWA is applied on the basis of the assumption that implementing a watering regime that is closer to the natural regime will improve wetland health. While anecdotal evidence of a wetland’s response to environmental water may be of some value, it is recognised that objective scientifically based monitoring of the EWA is required (DNRE, 2001).

Within Victoria, two major monitoring programs relate to wetlands management: salinity trend monitoring, and mandatory monitoring. The primary purpose of the mandatory monitoring program is to identify and detect changes in the environmental conditions of wetland and remnant vegetation ecosystems as a result of salinity and salinity mitigation works (DNRE, 2002a).

Monthly monitoring of Kerang Lakes wetlands (Figure 4) includes parameters such as surface and groundwater salinity, depth to groundwater and nitrogen and phosphorous. Many operational plans contain recommendations for monitoring. There has been difficulty in obtaining agreement between stakeholders regarding the level of monitoring that should be undertaken for the EWA (DNRE, 2001) given the cost and resources required.

**Conclusion**
The process for implementing the Victorian Murray Wetland EWA is well developed, and utilises various criteria to make decisions about how the allocation is distributed from year-to-year, including monitoring results. It is recognised by DNRE (2001) that the monitoring program will involve interpretation over the short-term for year-to-year management, and over the longer-term (5 years plus) to determine trends in wetland health. While it appears that the EWA process achieves its year-to-year management goals, the longer-term interpretation of wetland health trends is not yet available.

3.2.7 Barmah-Millewa Forest hydrological management

Introduction

While volumes of 97 GL and 341 GL have been provided to the Barmah-Millewa Forest (Figure 4) for environmental purposes during two flood events (described previously), the hydrology of the Barmah-Millewa Forest is also managed on a more regular basis with smaller volumes of water (Barmah-Millewa Forum, 2000). Recommendations for water management may arise from investigations, such as bird monitoring, vegetation sampling, or frog monitoring (Ward, 2001; 2002). This form of water management may involve use of the Barmah-Millewa Forest EWA or any other relevant environmental water allocation. For example, the Victorian Murray Wetlands EWA is often used for Kerang Lakes. However, 3000 ML from this account was used for waterbird breeding in Barmah during January-February 2003. In other cases, the EWA is not used, and management involves directing natural flooding or managing ‘rain rejection events’ to achieve environmental objectives. The Barmah-Millewa Water Management Strategy has established a process for decision-making regarding management of the Forest (Barmah-Millewa Forum, 2000).

Decision making process

The decision-making process was explained from the perspective of an on-ground resource manager by Keith Ward (North East Catchment Management Authority, pers. comm., 18 March 2003):

a) The Barmah-Millewa Forum develop an Annual Operating Plan for water management that outlines Water Management Areas requiring flooding in preference to others that may have been flooded in previous years. Some areas are then managed to be watered by natural seasonal flooding and rain-rejection events. Various triggers for use of the Barmah-Millewa Forest EWA are also considered, such as accumulated resource in light of the number of years that the forest has been dry. However, bird-breeding events usually dictate use of the EWA [an opinion supported by Reid and Brooks (2000) and David Leslie, State Forests of NSW, pers. comm. 12 March 2003]. This is partly because they are readily visible species with high public appeal, with known conservation status, and they respond directly to appropriate water management. The case for providing water for bird breeding is compelling, and includes documented evidence of severe declines in certain bird species, the modelled risks to breeding associated with river regulation, and habitat alteration.

b) Once an identifiable need is demonstrated, the water order is placed by the State agencies and managed in the Forest by the relevant State agency. Close liaison is held between the State agencies to ensure appropriate water management is being achieved (mainly ensuring that the correct combination
of regulators are operated so as not to starve or overly influence a regulator on the other side of the River Murray).

c) Monitoring programs may be intensified based on the specific management objective, with adjustments made as appropriate. For example, the frog monitoring program (Ward, 2002), upon finding a significant species (e.g. Inland Bull Frog or Growling Grass Frog), or observing mass strandings of near developed tadpoles of other species that would obviously benefit from an extension of the duration of flooding, would influence water management decisions. These manipulations to ‘assist’ breeding are justified on the grounds that the biota has been harmed through river regulation impacts.

d) An Annual Report is produced at the conclusion of the season to document water management activities.

Conclusion

The process for managing the hydrology of the Barmah-Millewa Forest is adaptive, with management responding to short- and long-term monitoring results. The relative health of the Barmah-Millewa Forest, and changes in Forest health over time, have not been documented in such a way as to allow evaluation of the response of Forest health to management initiatives. The monitoring is not necessarily hypothesis driven, so it may take some time before it is possible to unequivocally link water management policies to improved health of the Forest.

There is an emphasis on delivery of readily observable outcomes (such as waterbird breeding) with less emphasis on the ecological functions that underpin such outcomes (David Leslie, State Forests of NSW, pers. comm. 12 March 2003). The work of Reid and Brooks (1998; 2000) and Reid et al. (2001) concluded that it is unlikely that birds will be useful indicators of short-term changes in wetland ecosystems in response to hydrological management; however, they may prove to be valuable indicators of longer-term changes. Aquatic macrophytes were the preferred indicator, with macroinvertebrates also recommended. Reid and Brooks (2000) concluded that the significance of frogs to the structure and function of wetland ecosystems has yet to be properly established. However, they suggested further investigation before discarding frogs as possible indicators of changing wetland health. In this respect, the frog study of Ward (2002) should provide useful information.

3.3 Restoration of natural wetland hydrological regimes

3.3.1 Restoration of Lake Merreti and Gurra Gurra Lakes Wetland Complex hydrological regimes

Background, aims and methods

Jensen (2002a, 2002b) reported on the application of an adaptive management approach to the problem of restoring the hydrology of privately and publicly owned floodplain wetlands South Australian Riverland (Figure 3, Figure 6). While these wetlands are impacted by regulation of River Murray flows, they had other problems such as blocked floodplain flowpaths, inappropriate local regulation of their wetting and drying regimes, and impacts of introduced exotic fish, particularly carp. The work reported in Jensen (2002a; 2002b) has established a strong set of adaptive management experiments, based around the key objective of maximising aquatic plant diversity (Jensen, 2002a). The hydrological restoration does not involve use of
EWAs; rather, it involves better use of currently available water. However, the project would have produced water savings for the River Murray through reduced evaporative loss (by introduction of wetland drying cycles).

The Lower Murray Wetland Research and Monitoring Program by the Australian Landscape Trust is producing best practice guidelines for wetland management, based on scientific monitoring of the response of indicator variables to management regimes in nine wetlands (Tucker et al., 2002). Other research is investigating dynamics of Carp, role of wetting and drying cycles, response of native vegetation, and native fish access to wetlands, with full reports not yet published (Jensen, 2002a).

Prior to regulation, Lake Merreti was a large semi-permanent wetland supporting a high level of biodiversity. Until a drying cycle was introduced in 1995, the wetland was managed as a permanent lake since 1927. The Lake supported intermittent breeding by straw-necked and sacred ibis, but the success of the colony was compromised by rapid flood recessions (causing mass nest abandonment) driven by irrigation management needs (Jensen, 2002a). Installation of a flow regulator in 1982 for water quality management purposes also created the opportunity for control of the water regime to more closely mimic the natural cycle. After a trial partial drying in 1991, Lake Merreti has been dried three times since 1995, and the ecological response monitored intensively (Tucker, in press).

A wetland management plan has been prepared for the Gurra Gurra Lakes Wetland Complex in the South Australian Riverland area (Jensen et al., 1999). Six wetlands are being monitored by the Australian Landscape Trust (Jensen, 2002b). The rehabilitation demonstration sites at the Complex comprise Little Duck Lagoon, Old Loxton Road Lagoon and Causeway Lagoon. The main cause of environmental decline was blocked flow paths across the Gurra floodplain. The restoration project corrected this problem by constructing culverts on major roads and causeways. Also, flow control structures were used to restore natural drying and wetting cycles (Jensen, 2002a). Old Loxton Road Lagoon required lowering the inlet sill to increase the flood frequency. Ecological response has been intensively monitored (Jensen, 2002a).

**Results**

Hydrological and ecological monitoring of the wetlands to date has demonstrated a positive response to the restored water regimes. The results supported the idea that maintaining a diverse plant community also supports a diverse range of macroinvertebrates and small native fish. At Lake Merreti the third wet phase produced a flourish of aquatic plants. Water turbidity was reduced following the drying phases due to bed consolidation and increased coverage by plants.

A generic annual flow regime that follows from the work of Pressey (1987) was initially implemented at Little Duck Lagoon. This involved annual spring filling, followed by autumn/winter drying. The response to hydrological management at Little Duck Lagoon was similar to that at Lake Merreti, except that episodes of high nutrient concentrations, and low dissolved oxygen were recorded during re-filling. The diversity and abundance of aquatic plants was clearly linked to the duration the dry phase. The dry phase community was found to be dominant, and determined the community composition in the wet phase. Vegetation species diversity increased with distance from the wetland inlet, and was inversely related to turbidity. Prolonged flooding (exceeding 14 months) led to reduced macroinvertebrate abundance.
Numbers of native fish relative to introduced fish declined after 12 months of filling (Jensen, 2002a).

Consideration of the results at Little Duck Lagoon led to the formulation of a modified watering regime, with a longer wetting cycle of up to 14 months, and a reduced drying cycle of 6 months. This regime is designed to maximise the diversity of macroinvertebrate and macrophyte communities during the flooding cycle. The limited drying cycle is aimed at minimising accumulation of plant matter that might cause ‘blackwater’ (low dissolved oxygen) during subsequent re-filling (Jensen, 2002b).

After 5 months of hydrological management of Causeway Lagoon the salinity was reduced from over 45,000 EC to under 5,000 EC (the upper limit of freshwater range). However, following a drying phase, it increased to 25,000 EC due to seepage of saline groundwater. Waterbird use of the lagoon for feeding and roosting has increased. Hardhead duck was reported for the first time in 15 years (Jensen, 2002a).

The salinity of Old Loxton Road Lagoon was initially high as it filled, reached the salinity of river water when it was full, and then increased in salinity due to evaporation and saline inflows. Raptors and fish-eating birds were attracted by the plentiful food supply. There was no significant growth of aquatic plants, possibly due to high salinities and loss of soil structure in the bed (Jensen, 2002a).

Jensen (2002a) warned that it is important to allow adequate time between obtaining monitoring results and implementing altered management strategies. In the case of wetlands, several seasons may be required before plant communities adjust to the new regime. Some of the short-term changes that occurred in response to altered regimes in these SA Riverland wetlands could have been interpreted as negative, with retreat being a possible management response. However, Jensen (2002a) stressed that such temporary changes must be identified and overlooked if long-term goals are to be achieved.

Conclusion

The adaptive management projects at Lake Merreti and the Gurra Gurra Lakes Wetland Complex are aiming to achieve improved local wetland management and also to improve understanding of fundamental ecological process. The adaptive nature of the project was grounded on an admission of scientific uncertainty about the details of ecological functions within wetlands. Management actions have resulted in overall demonstrated improvements in wetland health.

Jensen (2002a) found that on-ground adaptive management works well at the local scale of the hydrological unit. The opportunities to manage at this local scale are determined by management of the hydrology by Regional and State agencies at the floodplain and river reach scale.

3.3.2 Restoration of Moira Lake hydrological regime

Background, aims and methods

Moira Lake is a shallow freshwater lake 800 ha in area, immediately adjacent to the River Murray, within the Moira State Forest, 15 km south of Mathoura in Southern NSW (Figure 4). It is the largest open water wetland within the Barmah-Millewa
Forest (Figure 4). The forest ecosystem has become degraded as a result of hydrological alteration of the River Murray (NSW EPA, 2001). Regulation reduced winter-spring flooding, and regular summer drying ceased. This hydrological change reduced Moira Lake’s ability to support many native plant and animal species whose lifecycles depended on flooding and drying, and created ideal conditions for alien species (such as carp) and native opportunist species such as Giant Rush (State Forests of NSW, undated).

The management response was to prepare a Hydrological Management Plan in 1994 with the aim of completely drying the system for 3 months in 2 out of every 3 years, flood the system during the Spring breeding season, provide gradually receding water levels at the end of the breeding season, provide unrestricted access for fish during spawning and juvenile development periods, and to minimise disruption to consumptive users (Leslie and Lugg, 1994).

The Plan was implemented in stages and overseen by the NSW Murray Wetlands Working Group. Approximately $0.5 million was invested in civil engineering works to reinstate a more natural water regime. Stage III, which was subjected to formal environmental impact assessment, included construction and utilisation of Moira Lake Regulator and syphon, a drainage channel through Algeboia Plain, and Algeboia Regulator and fishway (Gutteridge Haskins and Davey Pty Ltd, 2003).

A range of management actions complemented the civil engineering works. For example, a 4 km long fence was constructed along the northern perimeter of the Lake to exclude cattle grazing, and carp were removed from the lake rather than allowing them to return to the Murray. Fire was tested as a tool to manage the beds of giant rush (Leslie, 1999). The Lake experienced a three-month drying period in 1998 (the first time in 60 years) and again in 1999 (Figure 15). The flood mode is nominally operative during the months May-November inclusive when seasonal flooding of the River is more likely. The Lake is filled by river surpluses (i.e. flooding) and no control over flood heights or distribution is exercised (Gutteridge Haskins and Davey Pty Ltd, 2003). During the irrigation season, the regulators are used to either beneficially maintain water in the Lake and floodplains (following premature flood recession in spring) or to beneficially allow the Lake and floodplains to drain and dry (during summer and autumn) (Gutteridge Haskins and Davey Pty Ltd, 2003).

A range of research projects have been undertaken to monitor and assess changes to fish, vegetation, waterbird and micro-invertebrate assemblages involving NSW Fisheries, Monash University, the CRC for Freshwater Ecology and the Barmah-Millewa Forum (Leslie, 1999).

Results

In 1998, during the first 3-month drying stage (the first for 60 years), thousands of carp perished on the drying lake bed (MWWG, 2001a). In the following year, the drying period allowed a commercial operator to harvest 10 tonnes of carp (Leslie, 1999). Chester (2002) reported that by 2002, in excess of 100 tonnes of Carp had been removed from Moira Lake using a fishing method designed to protect native fish (Figure 16).
Figure 15. Moira Lake after draining for drying phase (source: David Leslie, State Forests of NSW).

Figure 16. Carp, which perished during managed lake drying, being harvested from Moira Lake (source: David Leslie, State Forests of NSW).
In addition to the rehabilitation of the lake environment, keeping water out of the lake over summer (when it would be dry under natural river flow conditions) has also prevented evaporative loss from the lake surface of water meant for downstream irrigation. In effect, less water now needs to be released from Hume Dam for water supply over summer because less is lost in transit. The net water saving from rehabilitating Moira Lake is 2,200 ML per year. These water savings are from regulated flows, not from any environmental allocation (MWWG, 2000).

Chester (2001; 2002) reported that since the simulated natural flooding and drying patterns were implemented, many species of waterbirds are breeding in Moira Lake for the first time in 25 years. Birds like the threatened brown bittern have made an appearance along with others such as the great egret, intermediate egret, black swan, nankeen night heron, cormorants and ibises (Figure 17).

![Figure 17. Number of waterbirds (bars) and number of species (line) observed at Moira Lake 1994-1999 (source: State Forests of NSW, no date).](image)

**Conclusion**

The Moira Lake Hydrological Management Plan has been successful in restoring a more natural hydrological regime. To date the biological response information, while positive, is largely descriptive. There has been an emphasis on delivering readily observable outcomes (such as waterbird breeding and carp removal), with less regard for the ecological functions that underpin such outcomes (David Leslie, State Forests of NSW, pers. comm., 12 March, 2003).

One important outcome of the project was the achievement of an annual 2,027 ML of water savings.

It is worth noting that work in restoring environmental flows and wetland values by State Forests of NSW (which included the Moira Lake hydrological restoration...
Mildura Weir drawdown

Background, aims and methods

It has been suggested that a sustained drawdown with controlled rates of rise and fall may ameliorate some of the detrimental impacts of weir operation and provide significant ecological benefits to the river (McCarthy et al., 2001). Ohlmeyer (1991) monitored a number of trial drawdowns, including Weir 3 by 0.5 m (May 1989) and Weirs 1–6 by 0.3 m (July 1990). The re-introduction of stage variability that mimics in some way the natural flow/water level regime of a particular stream may achieve broad ecological benefits (McCarthy et al., 2001).

The pools on Weirs 1-11 on the River Murray rarely fall below their base level, and generally fluctuate within a narrow range, so any type of manipulation that provides some variability to the water level in these weirs would be expected to provide ecological benefits (McCarthy et al., 2001). Many weirs currently undergo an annual drawdown in their normal operation. For example, until 1998 (i.e. before the old Weir was replaced), Torrumbarry Weir (Figure 4) pool underwent an annual early winter drawdown of 1-5 m for maintenance purposes (unpublished headwater level data supplied by MDBC; MDBC, 2003b). One adaptive management approach would be to monitor the ecological response to such drawdowns and relate the results to other weirs for which drawdown might be proposed. The other approach is to conduct a dedicated drawdown investigation that aims to maximise scientific rigour in terms of controls, replicates, and minimisation of confounding influences.

McCarthy et al. (2001) reviewed the literature on the physical, environmental, economic, social, political, cultural, and management implications of weir pool drawdowns in the River Murray System. They determined that Mildura and Wentworth Weir (Figure 5) pools were most suited to scientifically monitored drawdown trials.

In May 2001 and May-June 2002 the Mildura Weir (Figure 5) pool (Figure 18) was fully drawn down to allow for maintenance work to be conducted on the Mildura Weir (Weir No. 11) (Figure 19). The opportunity was taken to monitor these relatively short drawdowns, with a focus on salinity impacts. In both years the monitoring was conducted on three occasions prior to drawdown, three occasions during re-filling, and three occasions after re-filling (thus, the experiment involved replication). Three sites were monitored, one within the weir pool (the experimental point), one at a free flowing section of river upstream of the weir pool (control point), and another downstream of the weir pool (point impacted by drawdown). This experiment also measured the same variables at Euston Weir, where no drawdown was undertaken, as a control site.
Results

Results of monitoring of the 2001 and 2002 Mildura Weir drawdowns will be reported as part of MDBC SI&E Project R10010. Bernard McCarthy (Murray Darling Freshwater Research Centre, Lower Basin Laboratory, Mildura) provided some preliminary results, and the major findings are reported here.

The May 2001 drawdown resulted in a drop in water level of 3.43 m over 10 days, followed by an 11 day rise period. As the water level fell, electrical conductivity of water downstream of the weir pool increased from a baseline of 200 μScm\(^{-1}\) to a peak of 525 μScm\(^{-1}\). Electrical conductivity at the upstream control point and the control
site (Euston Weir) did not vary to the same extent or in a similar way, so the changes at Mildura Weir were almost certainly due to the manipulation. This increase in salinity is thought to be due to decreased hydraulic pressure on the groundwater system and resultant inflow of saline groundwater into the weir pool.

Turbidity increased in the weir pool as the drawdown progressed, and this was thought to be due to re-suspension of bottom sediments by the faster flowing shallower water. Total phosphorus followed the same pattern as turbidity (as much of the phosphorus is adsorbed onto the surface of fine particulate matter). Nitrogen concentrations did not appear to change with the drawdown. Bioavailable nitrogen and phosphorus concentrations remained low throughout the drawdown.

The May-June 2002 drawdown was similar to the 2001 event. However, in this case flows increased throughout the drawdown, adding a degree of difficulty to interpretation of the monitoring results. Despite this, it was clear that turbidity and electrical conductivity increased during the drawdown, as was observed in the 2001 event. The apparent acceptance of the Mildura Weir pool drawdowns by the community is most likely explained by the recognition that it was done for weir maintenance reasons, and for a short duration.

**Conclusion**

The monitoring of Mildura Weir drawdown focussed on water quality, because fears over a poor water quality response (i.e. increased salinity of the water) was thought to be one of the likely reasons why some stakeholders may object to a drawdown for environmental purposes. Thus, the monitoring did not measure the environmental benefits of drawdown. Salinity increases during these drawdowns were not high. This may have been because river flow at the time was moderate and assisted in diluting increased salt inputs. With longer duration drawdowns that correspond with lower river flows, high salinity impacts can be expected, and this aspect will need to be taken into consideration.

### 3.5 Operation of Barrages to scour sand from the Murray Mouth

**Background, aims and methods**

Increasing frequency and duration of periods of very low flow have contributed greatly to sedimentation at the Murray Mouth and nearby channels (Figure 3). The sediment regime has also been impacted by the restriction of flow by the Barrages causing a shift towards a more strongly depositional regime. While closure of the Mouth is an extremely rare event, the regulated regime presents conditions that are more conducive to closure than prior to regulation (Gippel and Blackham, 2002; Walker, 2002). Closure of the Mouth occurred for the first time in recorded history in April 1981 (Figure 20), and bulldozers were used to dredge an opening. Observations at the time suggested that flows of 25,000-30,000 ML/d were required to expand and maintain the opening (Walker, 2002).

The Mouth was again approaching closure during the protracted drought conditions beginning in 1998. While it is natural for estuaries to occasionally close, it is so rare on the Murray that it would cause considerable disruption to some stakeholders, and potentially disrupt the ecology of the Ramsar listed Coorong. Local stakeholders and management agencies are committed to maintaining the Mouth in an open condition, and the Ministerial Council also supports this objective.
Walker (2002) developed a model to predict Mouth opening based on the degree of opening in the previous month and river flows two months previously. This model is being used to help develop management strategies that will maintain the Mouth in an open condition. Two alternative policies are being explored, namely, an annual flushing flow using additional water temporarily stored in the lower Lakes, and additional flows delivered through the Mouth each month. Early results suggest that both could be effective, but the monthly flow increase option appears to offer lower risks of Mouth closure (Walker, 2002).

In late 2000 an opportunity arose to trial the use of a flushing flow to scour sediment from the Mouth. During September 2000, surcharging of the lower Lakes began, using increased flows from the River Murray (RMW 2000e). By October 2000 it was reported that the period of naturally increased flow had reduced the extent of accumulated sand at the Mouth (RMW, 2000b). In December 2000, the flood peak to South Australia was increased by an appropriately timed release from Lake Victoria in an attempt to scour accumulated sand (RMW 2000d). Mundoo Barrage was opened fully (for the first time since 1996) in the belief that its proximity to the Mouth would offer the most effective means of moving sediment from the Mouth (Brindal, 2000).

The flood peak upstream of the Barrages was about 40,000 ML/day. The flood was of a short duration and had a rapid rate of recession. Water surcharged in the lower Lakes was utilised, in conjunction with the arrival of the River Murray flood peak, to
produce a short-term flow of about 11,000 ML/day from Mundoo Barrage for about 16 days.

Results
The flushing operation did not scour a significant volume of sand from the Mouth, probably because the flow rates were not sufficiently high.

Fears of Mouth closure during 2002 prompted a $2 million dredging operation that began in mid-October 2002 (Department for Water, Land and Biodiversity Conservation, 2002b), with a 690 m long channel opened to the sea on 22 November 2002. This was recognised as a short-term emergency measure, while awaiting a longer-term solution based on increasing flows through the Mouth.

Conclusion
Although the flushing experiment did not achieve its objective, the operation provided useful information for the development of strategies for management of the Mouth (i.e. it is known that any future sediment flushing flows must be higher than those used in the late-2000 experiment).

3.6 Flows for dispersal and suppression of algal blooms on the lower Murray and lower Darling Rivers

Background, aims and methods
In January 2001, following a period of high temperatures, high diversion demand and high river losses, conditions were conducive to blue-green algal growth in the lower River Murray (Figure 3). Air temperatures were above 30°C for 40 days and flow was down to around 3,500 ML/d. Stratification of the Mildura weir pool and significant blue-green algal counts were recorded in the River Murray between Euston and Wentworth (in the Mildura and Wentworth Weir pools) (Figure 5) in late January and early February 2001 (Bernard McCarthy, Murray Darling Freshwater Research Centre, Lower Basin Laboratory, Mildura, unpublished data). On 22 January 2001 blue-green algal counts reached almost 8,000 cells mL$^{-1}$, and an anoxic layer had formed at the bottom of the Mildura weir pool (dissolved oxygen was as low as 2 mgL$^{-1}$). The blue-green algal counts during the month prior to the bloom were <1000 cells mL$^{-1}$, which is regarded as within the low range for risk of bloom (NSW Murray Regional Algal Coordinating Committee, 2002). Surface layer dissolved oxygen was within an acceptable range of 6.5-9.0 mgL$^{-1}$.

Significant headwater rainfall in January 2001 produced a rain rejection event (increased river flows contributed by water that is ordered by irrigators but not used because rain falls before the order is fulfilled) in the River Murray and Murrumbidgee River in the last week of January. By 7 February, flow at Euston (Figure 5) had reached 5,100 ML/d and by 9 February it was 8,000 ML/d (RMW 2001a). Flows continued to increase, and when the peak flow occurred on 16 February the Euston Weir Pool level was temporarily lowered to boost the peak to 13,000 ML/d to assist in dispersal and suppression of blue-green algal blooms downstream (RMW 2001b). Prior to and during this pulse, the DLWC measured velocity profiles, and the Lower Basin Laboratory measured algal counts in the vicinity of Mildura Weir pool.
During this period, high counts of blue-green algae were also measured in the lower Darling River (Figure 3). In anticipation of the arrival of additional inflows to the Menindee Lakes, by 21 February 2001 the release from Menindee had been increased from 4,500 ML/d to 8,000 ML/day. This increase was made specifically to assist dispersal of downstream algal blooms (RMW, 2001b).

**Results**

By 28 February 2001, at Burtundy on the lower Darling River, blue-green algal counts had reduced from a peak of 19,000 cells mL\(^{-1}\) to about 1,000 cells mL\(^{-1}\) (RMW, 2001c). By this date at Mildura Weir, blue-green algal counts had fallen below the ‘no alert’ level of 500 cells mL\(^{-1}\), and the weir pool had de-stratified (Bernard McCarthy, Murray Darling Freshwater Research Centre, Lower Basin Laboratory, Mildura, unpublished data). The high blue-green algal counts in both the River Murray at Mildura and the lower Darling River were dispersed and growth was suppressed, but it was not clear whether this was due to the flow pulse, or the change to cooler, windier weather that happened to accompany the pulse (Bernard McCarthy, pers. comm., 12 March 2003, RMW, 2001c).

**Conclusion**

In early 2001 high blue-green algal cell counts were recorded in the lower River Murray and lower Darling River due to conditions of low flows and high temperatures, and at the same time rainfall had occurred in the upper catchment, creating an opportunity to boost flows to the lower river. Although the cell counts declined at the time of the increased flows, it cannot be certain that this was a response to the increased flows, because weather conditions also became less favourable for algal growth. When conducting field-scale management experiments there is always a chance that unexpected factors will confound interpretation of the results. The data collected during this experiment have not yet been formally documented.

### 3.7 Use of the Murrumbidgee River ECA

**Introduction**

The Murrumbidgee Region contains a diverse range of wetlands, including extensive floodplains and billabongs in the lower area; several wetlands (e.g. Lowbigee Wetlands) are classified as being of National Importance (Figure 2, Figure 4) (DLWC, 2000a). Over the last 100 years the Murrumbidgee River and associated wetlands and floodplains have changed significantly from their natural state with the use of water for agriculture, recreation, industry and domestic needs (DLWC, 2000a). In late 1997, a River Management Committee (RMC) was established by the NSW Government for the Murrumbidgee River. A set of Environmental Flow Rules (EFR) were agreed to by the Committee, endorsed by the Government and introduced in the Murrumbidgee Valley for the first time in the 1998/99 water year. Since then, the Committee has reviewed the rules on an annual basis (DLWC, 2000a).

Rule 3 of the EFR relates to translucent releases and the protection of winter flow and variability, while Rule 4 provides for water contingencies (the Murrumbidgee ECA), which is a 25 GL annual allocation to meet water quality needs and algal bloom suppression, fish breeding and forest and wetland watering. The Murrumbidgee RMC considered the River Flow Objectives (a list of general objectives used to guide...
general community discussion on specific valley objectives) (DLWC, 2001a) and the specific local and regional circumstances, and designed the environmental flow rules to address specific issues (DLWC, 2000a).

Sound scientific assessment of the response of the riverine ecosystems to the environmental flow rules was regarded as essential (DLWC, 2001a). The NSW Government established a major scientific program to address this need, known as the Integrated Monitoring of Environmental Flows (IMEF). The IMEF involves the collection of biological, physical and/or chemical data from river sites and wetland sites within sections of the river that are affected by the flow rules (DLWC, 2001a,b). The IMEF program is underway in the Murrumbidgee River Valley.

**Results**

Environmental releases in the Murrumbidgee in September 1998 resulted in wetlands filling as far downstream as Hay, a distance of 800 km of river. It was estimated that over 30 wetlands were inundated as a result of a major environmental release, some for the first time in over two years. Approximately 250 GL was delivered to the main channel and wetlands of the Murrumbidgee River (DLWC, 2000a). The wetlands were reported to have responded almost instantly to inundation with an increase in wetland vegetation as well as frogs, tortoises, waterbirds and other animals. These data have not yet been publicly reported (DLWC, 2000a). Rule 4 was not triggered during the 1999/2000 season (DLWC, 2000a).

The IMEF program has published two reports that examine river condition prior to implementation of the environmental water allocation (DLWC, 2001a,b). Information on how the river and wetland ecosystems of the Murrumbidgee are responding to the environmental flow rules has not yet been published.

**Conclusion**

The Murrumbidgee River Environmental Contingency Allowance has been applied ostensibly to meet water quality needs and algal bloom suppression, fish breeding and forest and wetland watering. The monitoring of this allocation has been detailed and scientifically sound, being hypothesis driven. Information on how the river and wetland ecosystems of the Murrumbidgee are responding to the environmental flow rules has not yet been published.

3.8 Other initiatives (not experimentally monitored)

3.8.1 Stevens Weir drawdown

**Background, aims and methods**

Stevens Weir is the largest regulating structure in the Edward-Wakool system and is located 28 km downstream of Deniliquin (Figure 4, Figure 21). The Weir provides regulated flows to over 300 private pumpers and the Wakool Irrigation District (Green, 2001c). The Edward River is also used to supply part of the entitlement flow to South Australia during the irrigation season, effectively bypassing the Barmah Choke. This pattern of management means that the Stevens Weir pool is maintained at a high level throughout the irrigation season. Green (2001c) recommended lowering the Stevens Weir pool during the non-irrigation season to reduce the water level in the river upstream, thereby allowing water to drain from over 90 ha of riparian wetlands.
RMW (2001, 2002) reported that Green’s (2001c) recommendation was adopted, and drawdown of the Stevens Weir pool is now an annual event, beginning at the end of May (DLWC, 2002; RMW, 2001, 2002). The objective of the drawdown is to allow vegetation on the banks of the Edward River upstream to dry out before high water levels in the next irrigation season (RMW, 2001d). Refilling normally begins late in July, allowing for 2 months of drying (RMW, 2002). Also, the Weir gates are fully raised to allow for unimpeded fish passage. Another objective of the first drawdown was to identify any inflows of saline groundwater at low water levels over time (David Harriss, DLWC, pers. comm., 5 March 2003).

Monitoring of Stevens Weir drawdown has not been undertaken. Cameron Lay (NSW Fisheries, pers. comm., 19 March 2003) is of the opinion that the timing of the drawdown is such that it would appear to be of marginal benefit to native fish. Torrumbarry fishway on the Murray occupies a similar ecological niche, and surveys show that during the winter months there is virtually no upstream movement through the fishway (Mallen-Cooper et al., 1995, p. 74). This would suggest a similar lack of movement in the Edward River. There may be a benefit for downstream migrants. There is a well-documented accumulation of migrants below Stevens Weir during the summer, suggesting that an associated downstream migration must take place. However it more likely takes place soon after the upstream movement, and not during winter (Cameron Lay, NSW Fisheries, pers. comm., 19 March 2003). A properly designed fish passage experiment at Stevens Weir could help to reduce this uncertainty.

3.8.2 Manipulation of Euston Weir pool aimed at filling of Hattah Lakes

Hattah Lakes, south of the River Murray downstream of Euston Weir (Figure 5), are periodically filled when flow in the River Murray exceeds 37,000 ML/day. River regulation in accordance with the current operating rules has reduced the frequency of filling (Figure 22). In the first River Murray flood of October 2000, an attempt was
made to partly inundate Hattah Lakes (Figure 5) by enhancing the river flow with a small release achieved through drawdown of Euston Weir pool (RMW, 2000a). However, this flow was insufficient to achieve filling of the Lakes. In the December 2000 flood that followed, the River Murray flow peak was sufficient to inundate Hattah Lakes without the need to augment flow by operation of Euston Weir (RMW, 2000c). Although not used successfully in 2000, the strategy is now in place for potential future utilisation.

Figure 22. Hattah Lakes, in a dry condition (left) and wet condition (right) (source: Ted Lawton).

3.8.3 Operation of Menindee Lakes to mimic the shape of natural hydrographs in the Lower Darling River

In accordance with the recommendations of Jenkins (1999), flood operation of Menindee Lakes (Figure 3) over recent years has been aimed at mimicking the shape of the natural flood hydrograph in the lower Darling River, while at the same time remaining consistent with other management objectives. The rules for flow releases are given in DLWC (2002, Appendix 6). During the Darling River flood of late-2000, the shape of the flow hydrograph downstream of Menindee Lakes was tailored to produce a relatively sharp peak of 20,000 ML/d. Commencing 21 December, the flow at Weir 32 was gradually reduced by about 500 ML/d each day until it reached about 9,000 ML/d (RMW, 2000d). Maximum natural rates of fall of river level were followed in order to reduce the impact of a steep recession on stream banks.

Routine monitoring of the lower Darling River has been undertaken by the DLWC for more than 10 years. The variables include flow, nutrients, salinity, and blue-green algae counts. These data may be able to provide an indication of the effects of flow releases that mimic the natural hydrograph (Shaun Meredith, Murray Darling Freshwater Research Centre, pers. comm., 19 March 2003).

3.8.4 Opening of gates at Torrumbarry Weir during high river stage

On 16 November 2000, the opportunity was taken during a period of high flows to raise and fully open all gates of Torrumbarry Weir (Figure 4) to assist with clearing of timber accumulated near the structure (Figure 23). Opening of the gates provided a 12-day period of ‘open river’, which enabled unrestricted passage for biota through the weir, although fish passage was the stated major objective (RMW, 2000f). This
management action was opportunistic, and biological assessment of the ‘open river’ conditions was not undertaken. However, the Spring timing of the event coincided with a period when several native species are known to migrate upstream. These species include silver perch, golden perch, bony herring, Australian smelt, short-headed lampreys and Murray cod (Mallen-Cooper et al., 1995, p. 74).

Figure 23. Torrumbarry Weir with radial gates in the normal ‘down’ position (left) and fully raised and open during a high flow event in Nov 2000 (right) [source: John Baker (left) and Terry Holt (right)].

3.8.5 Pulsing of flows downstream of Euston Weir

From the late 1990s, it was observed that increased weekend pumping from the River between Euston and Mildura Weirs significantly reduced the flow downstream of Mildura Weir during some days of the week. This was particularly true during periods of low regulated flow in summer and autumn, the seasons when blue-green algal blooms tend to occur. Based on the assumption that very low flows increase the risk of elevated blue-green algal counts in the Mildura and Wentworth weir pools, River Murray Water initiated a change in operational practice.

The change in operational practice involves pulsing the flow downstream of Euston Weir by up to 1,000 ML/day for two days and balancing this with a corresponding reduction in flow over the remaining five days of the week, so that the total weekly flow downstream of Euston Weir is unchanged. Flow measurements by River Murray Water indicate that the risk of very low flow downstream of Mildura Weir has been significantly reduced by this practice. This operation also creates more variability in the water level of the Euston Weir pool within a week (generally in the order of 0.2 to 0.3 m), and greater variability of flows downstream of Euston Weir within a week. The assumption that this operational practice reduces the risk of high blue-green algal counts in the Mildura and Wentworth Weir pools is based on best available information, but is yet to be tested scientifically.
4 The New Standard - Adaptive Management

4.1 Definition of adaptive management

Adaptive management (AM) has its roots in “adaptive environmental assessment and management” (AEAM), a structured approach to the evaluation and solution of environmental management problems developed by Holling and several colleagues at the University of British Columbia's Institute of Resource Ecology, Vancouver, Canada in the late 1960s. Some of the principles and methods of AM are similar to the “Deming” management method, and the related “Total Quality Management” method, which are used in the business world (Forest Service, British Columbia, 1997; Walton, 1986).

Adaptive management in the context of environmental flows can also mean having flexible legislative requirements that allow for re-allocation of environmental water on the basis of periodic reviews (Dyson, 2002). Although relevant and important to the debate, this aspect lies beyond the scope of this report. The focus here is at the scale of on-groundwater management decisions, which can be altered on the basis of improved knowledge, whether or not the total annual allocation varies.

Three definitions of AM are:

"a process which integrates environmental with economic and social understanding at the very beginning of the design process, in a sequence of steps during the design phase and after implementation" (Holling 1978).

"a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies" (Walters 1997).

"(a process) combining democratic principles, scientific analysis, education, and institutional learning to increase our understanding of ecosystem processes and the consequences of management interventions, and to improve the quality of data upon which decisions must be made" (The Ecological Society of America 1996).

Some river managers might argue that they have always practiced AM, through implementing works and then trying different approaches if problems arise. However, this is a superficial understanding of AM. Adaptive management explicitly recognises uncertainty, so policies (and resultant on-ground actions) are seen as experiments that, if carefully designed and monitored, can provide information about the system. Under an AM philosophy, management is involved in development of best-practice, rather than passively adopting new technologies when they become available.

Adaptive management has been used in resource management for around 30 years, and there is a high level of awareness of AM among management agencies and stakeholders responsible for the River Murray (e.g. MDBMC, 1998; Reid and Brooks, 1998; Barmah-Millewa Forum, 2000; Jensen, 2002; Tucker et al., 2002; DAMPSC, 2002, p. 73; Field & Game Australia Inc., 2003). Reid and Brooks (2000, p. 480) described the monitoring requirements for adaptive management of wetlands of the Murray-Darling Basin, as: “The key to the long-term success of these ‘environmental water allocations’ (EWAs) is a well-established monitoring programme; monitoring must involve ecological indicators that are sensitive to hydrological variation, whose selection has been based on scientific criteria”.

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The Ministerial Council directed that adaptive management be used for the River Murray in March 2001. Although there was an awareness of AM among managers prior to this announcement, most of the environmental flows initiatives undertaken so far cannot be expected to have followed a rigid adaptive management framework. There is currently a high level of enthusiasm for adaptive management among the management (and wider) community. To date, no examples could be found where a formal AM framework (as described by Holling, Walters and others) has been explicitly followed from inception to implementation and adjustment. This is not to say that the river and floodplain management work described in this report does not fall within the realm of AM. The Barmah-Millewa Forest Water Management Strategy (Barmah-Millewa Forum, 2000) appears to be a working example of adaptive management, and so does the work on managing wetlands in South Australia (Jensen, 2002a, 2002b). The success of these projects as exercises in adaptive management, and how well they achieve their environmental objectives, can be evaluated in the future through a review process.

Experience in the United States has revealed that individuals and groups involved in AM projects can hold widely differing and competing views on what constitutes AM (Stankey, 2002). This is understandable, given the heterogeneity of stakeholder groups in terms of motivations, objectives, fears, and knowledge of and previous involvement with management, science and AM. There is also ongoing discussion and debate among AM practitioners regarding the core concepts and definitions of AM (Institute for Agriculture and Trade Policy, 2003). This report evaluates the implemented River Murray System environmental flow projects in a broad sense, comparing the projects’ structure with that of basic adaptive management principles. This is meant to be a constructive criticism that informs future projects aiming to follow AM principles (as directed by the Ministerial Council resolution).

4.2 Adaptive management learning cycle

The procedure for AM can be conceptualised as comprising several interrelated components (Boswell, 2000) that Nyberg (1999a; 1999b) depicted as a cycle (Figure 24), similar to the adaptive management learning cycle of Walters and Holling (1990). The components of Nyberg’s (1999b) model are:

- **Problem assessment** is often done in stakeholder workshop situations, making use of conceptual models and developing numerical simulation models. It is important to involve those who will implement, monitor and be affected by the plans, as well as managers, scientists and technicians. The models are used to set objectives, screen potential management policies, make explicit forecasts about the likely environmental response to management actions, and to identify information gaps and uncertainties.

- **Design** of the management plan considers a number of management options, and generates management experiments that have appropriate monitoring programs. The plan includes selection of indicators, consideration of the statistical aspects of the design, statement of how management actions will be adjusted, and statement of how results will be communicated.

- **Implementation** is the act of following the plan, and where necessary to deviate from the original plan. It is important to document all actions.
• **Monitoring** allows assessment of how actions affect the indicators. Monitoring is required for compliance (was the plan implemented?), effectiveness (did the plan meet the objectives?), and validation of model parameters and relationships (which hypotheses are supported?). Monitoring usually involves a small number of key indicators.

• **Evaluation** compares outcomes to the forecasts made in the problem assessment phase. Evaluation is concerned with explaining the results, and includes recommendations for future action. Explanation of results, and the level of confidence in the recommendations is strongly dependent on the quality and appropriateness of the experimental design. Documentation is important, to enable others to learn from the experiences.

• **Adjustment** is the process of using the information to verify or update the system models, adjust management actions as necessary, and re-evaluate objectives. New predictions can be made, and new experiments designed, to test new hypotheses.

![Adaptive management cycle figure](image)

**Figure 24. Adaptive management cycle (from Nyberg, 1999a; 1999b).**

### 4.3 Science and adaptive management

Adaptive management is clearly based on science. How does the science in AM differ from traditional independent research science? Research science usually aims to tightly control variables and minimise confounding influences, so that relationships can be sought within a reasonable time-frame and budget. Much ecological river research has been intentionally conducted away from places where the complexities of human disturbance and management actions confound the natural processes of interest. Other research has necessarily been done at the local site-scale, or has examined relationships between a small number of variables (this reflects the complexity of the system). Such research has vastly improved our knowledge of river processes. Examples of environmental flow related research science are listed in Growns and Gawne (1998).
The science used in adaptive management can be quite different from independent research science (Table 2), although they share some common elements (e.g., hypothesis-testing, experimental design, data collection and analysis) and there are no clean boundaries between the two. Science is often openly contested in the environmental management arena, partly because scientists may appear to be cautious and uncertain (uncertainty is a fundamental tenant of science), partly because science may have failed to address the main concerns of managers and stakeholders, and partly because the science has been undertaken without the involvement of stakeholders (so they may not understand it, and may not trust it). Also, environmental river management problems cannot be reduced to ecological, hydrological, chemical and geomorphological issues – they also have social, political, economic and cultural dimensions.

Table 2. Comparison of characteristics of science as applied in the research and adaptive management spheres (adapted from Nyberg and Taylor, 1995 and Nyberg, 1999).

<table>
<thead>
<tr>
<th>Issue</th>
<th>Adaptive Management</th>
<th>Research Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who leads the projects?</td>
<td>Managers, supported by scientists</td>
<td>Scientists, perhaps funded or supported by managers</td>
</tr>
<tr>
<td>Scale of application</td>
<td>Routine operations in the field</td>
<td>Precise experimentation in laboratories or small plots</td>
</tr>
<tr>
<td>Rigour of design</td>
<td>Projects are often less tightly controlled, experimental conditions “messy”</td>
<td>Tight controls and replication</td>
</tr>
<tr>
<td>Intensity of measurements</td>
<td>Measures small set of key management/response indicators</td>
<td>Many researchers measuring many variables intensively</td>
</tr>
<tr>
<td>Outputs</td>
<td>Increases understanding and produces goods or services</td>
<td>Increases understanding</td>
</tr>
</tbody>
</table>

4.4 Different forms of adaptive management

Johnson (1999) defined five decision-making approaches used in resource management. Four of these he regarded as traditional approaches and the fifth was adaptive management:

- Political/social approach – main concerns are public and political response to a decision.
- Conventional wisdom approach – use an historical method or rule-of-thumb.
- Best-current data approach – use scientifically collected data to choose best option for implementation (no monitoring).
Monitor and modify approach – the selected best option is implemented and monitored, with periodic modifications intended to hone (not challenge or overhaul) the accepted policy that is assumed to be best practice.

Adaptive management approach – follows the AM learning cycle (Figure 24).

Walters and Holling (1990) accepted that the traditional approaches (which they termed evolutionary or ‘trial and error’) could still be adaptive in some sense, and they distinguished between two true-forms of adaptive management - passive and active. Hilborn (1992) distinguished between reactive adaptive management and pro-active (passive and active) adaptive management:

1. *Evolutionary* or ‘trial and error’ approach

Management policies may be based on anecdotes, or ‘conventional wisdom’ (Johnson, 1999) built up from experience with haphazardly applied and narrowly evaluated actions. This approach is uncritical and unreliable, and can easily lead to widespread acceptance of management ‘myths’ (Nyberg, 1998a).

2. *Reactive adaptive* approach

Like Johnson’s (1999) ‘political/social’ approach, change is driven by external stimuli, such as political decrees, legal requirements, public relations, and research findings. Feedback occurs and adjustments are made, although not necessarily in response to scientific monitoring (also, ‘do nothing’ or ‘delay action’ may be common outcomes). Problems arise when different stimuli conflict, and the rate of change outstrips the rate of learning. Crisis management tends to emerge, and maintaining a long-term strategy becomes difficult (Bormann, 1996). This category also encompasses Johnson’s (1999) ‘best-current data’ approach, whereby management reacts to external scientific developments (i.e. not through planned scientific monitoring of the specific and local management action in question).

3. *Passive adaptive* approach

Like Johnson’s (1999) ‘monitor and modify’ approach, this approach uses historical data to construct a single best estimate or model for response, and the management decision is based on an assumption that this model is correct. By designing management actions as experiments, stronger inferences can be drawn from their outcomes, reducing the chance of generating false notions (Nyberg, 1998a). Specific monitoring is undertaken, but if the commitment to monitoring wanes, the strategy can revert to a reactive one (Bormann, 1996). Management may follow a cyclic pattern, whereby the agreed ‘best practice’ is tweaked from time to time according to the results of monitoring, until a new form of ‘best practice’ is adopted. This approach requires patience to allow sufficient time for learning, and environmental improvements may take a long time to achieve.

4. *Active adaptive* approach

This approach embraces uncertainty by designing management interventions that seek to test two or more plausible actions (i.e. the policies that might otherwise be deemed through uncertain methods to run a close ‘second-best’ or ‘third-best’ etc. are not discarded). An active approach seeks to learn more rapidly than under reactive or passive strategies by designing suites of policies...
that can be directly compared in management experiments. Because an active approach simultaneously compares alternative policies, learning is more rapid than a passive approach that compares different policies sequentially through time (Bormann, 1996).

Most river management in Australia has traditionally followed a ‘trial and error’ or reactive model (1. or 2. above). In more recent times, as scientific knowledge has expanded, communication between scientists and managers has improved, and awareness of adaptive management has increased, management has begun to use the passive adaptive model (3. above), whereby reviews by consultants or expert panels direct the best course for management. Monitoring of specific management actions (as opposed to descriptive surveillance monitoring) is relatively new, and although its value is widely recognised, it is yet to be routinely implemented. The Victorian River Health Strategy is an exception, having established an adaptive management framework for stream management (DNRE, 2002b). The framework sets out how to manage the State’s rivers using an adaptive process, but does not provide details of how individual management experiments should be conducted in an adaptive way.

The active adaptive process (4. above) involves experimentation with multiple management practices, and has rarely been applied to river management. Lee (1993, 57) stated that: "Although virtually all policy designs take into account feedback from action, the idea of using a deliberately experimental design, paying attention to the choice of controls and the statistical power needed to test hypotheses, is rarely articulated and still more rarely implemented." This is generally true of river management in Australia to date, including management of the River Murray, although there are some exceptions.

4.5 Statistics in adaptive management

For reasons of scale, expense, and practical limitations, experiments in adaptive management will not always include controls, replication, multiple treatments, randomisation, or other features commonly expected of traditional experimental design and frequentist (classical) statistical methods. In large rivers like the River Murray, it maybe impossible to find controls, and replicates are problematic given that potential sites along a river are connected longitudinally. Despite these limitations, practicality needs to be balanced with statistical rigour. Statistical analyses allow managers to detect change due to management, and to distinguish it from background variation and sampling errors. The statistical methods to be used in analysis of data must be agreed as part of the experimental design process, i.e. before any measurements are made (Nyberg, 1998).

One limitation of classical statistical methods such as ANOVA and regression analysis in adaptive management is that they are not designed to answer management questions, such as “What is the probability of a 50% increase in Murray cod abundance after allocating an extra 350 GL/yr to the River Murray?” (example modified after that given in Nyberg, 1998). When classical methods are not appropriate, there are alternative options for statistical analysis (Sit and Taylor, 1998).

Bayesian statistics directly analyses the probability of a hypothesis being true, allowing scientists to formally update their beliefs in a variety of experimental and non-experimental situations. Bayesian analysis can assign intermediate degrees of belief or probability to hypotheses, unlike the all-or-nothing inferences ‘reject/retain
the hypothesis’ (Anderson, 1998). The Bayesian approach provides a way of incorporating prior knowledge with new knowledge (Bergerud and Reed, 1998).

Reid et al., (2001) developed a model for measuring the effectiveness of environmental water allocations to wetlands within the Barmah-Millewa Forest. The method follows a modified “Before-After/Control-Impact” (BACI) design. The results of their pilot study supported the notion of Reid and Brooks (2000) that aquatic macrophytes are the indicator group best suited to the task of detecting ecological responses to hydrological changes. There was some evidence to suggest that macroinvertebrates are also sufficiently sensitive to hydrological cues. However, this was inconclusive due to confounding driven by short-term changes. The need to maximise statistical power, and problems with distinguishing between treatment and controls sites highlighted the need to include multiple wetlands in any future or on-going monitoring (Reid et al., 2001).

Mallen-Cooper et al. (1995) used some fishway data to illustrate an important difference between what they termed ‘assessment’ (understanding process using well-structured experimental design and analysis) and ‘monitoring’ (counting or describing). The first fishway on a Commission structure was installed as an experiment at Euston Weir (Figure 5) in 1938, using a North American design intended for salmon. A monitoring survey at the fishway between 1938 and 1942 (55 months) counted 16,000 native fish at the top of the fishway, which was later reported by Petts (1984) in an internationally recognised text as ‘large numbers’ in the context of an effective fishway. However, a later assessment of the fishway by Mallen-Cooper and Brand (1992) found that there were 100 times more golden perch at the bottom of the fishway compared to the top. This assessment of the fishway was able to put the ‘large numbers’ observed through monitoring into perspective, and exposed the performance of the fishway as inadequate. The management response is to modify the fishway in an attempt to make it more compatible with the swimming abilities and behaviour of Australian native fish. This is an example of management responding to new information that could only be provided by proper scientific investigation.
5 Assessment of Environmental Flow Initiatives with Respect to Adaptive Management Principles

5.1 Risk of failure in pursuing an adaptive management approach to management of flows in the River Murray

Adaptive management (AM) is frequently mentioned in documents relating to management of flows in the River Murray System. To date, a framework for AM, or a set of principles or guidelines, have yet to be defined. This is a potentially serious problem, because adaptive management can be implemented in various forms, from the simple ‘trial-and-error’ approach to the full-scale ‘active adaptive’ approach. Without a framework, or set of policy guidelines, assertions that management should be, or is being, conducted according to adaptive management principles is no guarantee that such principles are being followed. The MDBC is commencing work on this framework.

Experience in other countries has demonstrated that without a concerted effort to assist its adoption and avoid its pitfalls, adaptive management is likely to fail (Stankey, 2002; Ladson and Argent, 2002). Stankey (2002) asked “If the concept of adaptive management is compelling and intuitively appealing, why has it proven so resistant to successful implementation?” This was in response to troubling comments by Walters and Lee, two of the most influential pioneers of adaptive management:

“I have participated in 25 planning exercises for adaptive management of riparian and coastal ecosystems over the last 20 years; only seven of these have resulted in relatively large-scale management experiments, and only two of these experiments would be considered well planned in terms of statistical design.” Walters (1997, p. 2-3)

“adaptive management has been more influential, so far, as an idea than as a practical means of gaining insight into the behavior of ecosystems utilized and inhabited by humans.” Lee (1999, p. 1)

According to Stankey (2002), the problems are grounded in a complex web of inadequate institutional structures and processes, organizational norms and belief systems, and internal and external sanctions. Collectively, these forces interact to stymie efforts to experiment, learn, and innovate.

Based on its overseas track record, it appears that AM has a high chance of failure. However, the reasons for failure have been identified and articulated, so it should be possible to avoid repeating these mistakes in Australia. The main caution in the literature seems to be that AM is not worth attempting unless it is well resourced and taken seriously from the outset.

Ladson and Argent (2002) reviewed adaptive management projects in three large North American rivers and considered how these experiences relate to the application of AM to environmental flows in the River Murray. The three case studies were for the Columbia, Colorado and Mississippi Rivers in North America. These rivers have all been developed for irrigation, hydropower or navigation, and AM was used to explore flow changes proposed for environmental reasons while recognising the trade-off with production values. Ladson and Argent (2002) found that of the three AM
case studies considered, the Colorado River was the most successful. Reasons for this success included:

- few jurisdictional issues (river lies solely with the State of Arizona)
- few points of intervention (controlled only by the operation of Glen Canyon Dam)
- credible science (all proposals and reports were subject to peer review)
- an appropriate level of modelling (there was recognition that building a more complex model would draw resources from other activities, and that further model building would be subject to diminishing returns)
- early success of experimental management (the effect size of artificial flooding was large enough that the response was detectable amongst the noise of natural variation)
- a sense of community amongst stakeholders (established from the outset)
- barriers to stakeholders leaving the adaptive management process (there were no alternative forums, and the process had support at the Federal level)

Being mindful of the characteristics of successful projects can reduce the risk of failure of AM in the River Murray System.

5.2 Key characteristics of an adaptive management approach

There are two key characteristics that distinguish adaptive management from traditional management:

1. management actions are a response to uncertainty about the system being managed; and
2. management actions are designed, at least in part, to provide new information about the system.

Other characteristics can and should vary according to the system being managed and its political context (Williams, 1998). However, there are some other attributes that are typical of successful adaptive management programs:

- The full adaptive management learning cycle (Figure 24) is undertaken.
- Adaptive management is recognised to be more than just surveillance monitoring. There are too many variables that could possibly be measured, so some form of hypothesis testing should guide it.
- Active adaptive management involves testing of various alternative policies at the same time, while passive adaptive management is slower, testing alternative policies sequentially. Reactive adaptive and trial-and-error approaches are less critical of the status quo, and take much longer to develop revised policies.
• Managers lead the project, supported by scientists and other stakeholders.

• The initial process of setting objectives, filtering potential management policies, and developing a numerical-spatial physical/chemical/ecological model of the system is undertaken with a range of representative stakeholders. The model is relatively simple, with its heuristic (learning) value to stakeholders being more important than its predictive ability.

• The science involves evaluation of field-scale management actions, rather than plot-scale or laboratory-based studies.

• A small set of key indicator variables are strategically measured, as opposed to intensive measurement of a vast suite of variables.

• Management does not stop and wait for research science to provide low-risk guidance.

• Project design may not satisfy the requirements of frequentist (classical) statistics, so alternative methods such as Bayesian analysis may be more appropriate.

• The management agency has a program of staff training and education in adaptive management principles and practice, supported with reference materials such as guidelines.

5.3 Evaluation of River Murray flow initiatives against adaptive management principles

Most of the environmental flow projects reviewed here did not explicitly set out to follow an active adaptive management model. This is not surprising, given that most of the initiatives pre-date the Ministerial Council’s directive to follow an adaptive management approach, and the Commission does not yet have a framework to provide advice on how best to implement adaptive management in the River Murray System. State agencies, while generally supporting the concept of AM, do not all formally insist on its adoption. The recently developed Victorian River Health Strategy (VRHS) has adopted an adaptive management framework for river management that separates ‘monitoring’ and ‘research’ (DNRE, 2002b). The ‘monitoring’ component explicitly involves community engagement and involvement, while the ‘research’ will be undertaken through “partnership between government research institutions, universities and Cooperative Research Centres” (p. 137). To be adaptive according to the principles of Holling and others (the originators of the concept), the research component also needs to include the non-scientific and non-management stakeholders. The model appears to be a passive adaptive one, based on “best available scientific information and will be adaptive” (p. 137). The VRHS embraces uncertainty, and specifically identifies the need for basic research on understanding the effect of environmental flows on river health.

There are some practical difficulties with implementing adaptive management in the River Murray setting, such as the lack of available sites to choose as controls and replicates, and limited ability to operate the river according to several different flow rules at the same time.
No truly active adaptive management (testing of multiple hypotheses) environmental flow projects have been undertaken on the River Murray System, with most of the projects falling into the passive adaptive or trial-and-error categories. However, the wetland rehabilitation work in the Riverland area of South Australia (Jensen, 2002a; 2002b) is a good example of adaptive management. Given the practical difficulties of employing active adaptive management in river situations, this may be the most sophisticated form of AM possible for the River Murray System. Although the same fundamental management action is being tested at each wetland, local site differences mean that each wetland is a different case, in a sense creating a de facto multiple hypothesis-testing situation.

The passive adaptive approach has its roots in the traditional expectation that scientists can deliver low-risk ‘best management practice’ or recommendations grounded in ‘defensible science’. While most individual scientists working on River Murray management problems would embrace uncertainty as an accepted tenant of their daily working life, many in the non-scientific community may not. There is a tradition in the non-scientific community to highly regard a scientific process that confidently recommends specific management options, while being naturally cautious of tentative, ambiguous or uncertain recommendations. While it is accepted that managers have to make decisions irrespective of uncertainty, it is another matter to disregard or fail to acknowledge that uncertainty. In the adaptively managed wetland rehabilitation work in the Riverland area of South Australia, the ‘best practice’ model of wetland water regime derived from science was found to be less than ideal, leading to adjustments in the management policy. This case illustrates the value of embracing uncertainty about scientific knowledge.

Management does appear to be well informed of the current scientific thinking, as evidenced by the rapid transferral of research science findings and recommendations in Expert Panel reports and Management Plans into on-ground actions (for example, Stevens Weir drawdown, introduction of variable flow releases, and an emphasis on restoration of wetland hydrology). Most of the scientifically based management advice provided to the Commission does not associate the recommended actions with a probability that they will achieve a given level of improvement in river health [the Living Murray initiative SRP report by Jones et al., (2002) to the Ministerial Council is a notable exception].

Management decisions may well be made with awareness of the uncertainty of the science, but this is rarely explicitly acknowledged. There is a simplistic appeal in the idea that if managers are going to act then they might as well act on the ‘best’ available advice. However, in many cases the idea of a single ‘best’ piece of advice may be an illusion, with the reality being that there exists one or more alternative ideas that may have an effectively equal chance of being the ‘best’. A focus on policies and actions as hypotheses subject to critical analysis is the hallmark of an adaptive approach. In Gunderson’s (1999, p. 35) view, an adaptive approach views policies as “questions masquerading as answers”.

Some River Murray management actions, such as drawdown of Stevens Weir, opening of gates of Torrumbarry Weir during high flow events, and operation of Menindee Lakes to mimic the shape of natural hydrographs, are undertaken in the belief that they will produce the environmental outcomes promised by the independent scientific investigations. Such management strategies are not yet being
challenged or refined on the basis of critical and challenging experiments (at least in the short-term).

It could be argued that there are insufficient resources available for rigorous monitoring and testing of every management action. It would seem an inefficient use of resources to repeat experiments when little gain in knowledge is expected. Once a certain management action is known to achieve the desired objectives within acceptable limits of probability, there is no need to keep testing it. The expected long-term improvements in river health should be detectable by the system-wide scale Sustainable Rivers Audit. AM should focus on developing and testing new management actions. Coordination of AM efforts over the River Murray System will avoid unnecessary repetition of experiments, and allow transfer of results across the System.

The in-channel flow variability and wetland watering projects reviewed here all possess elements that are characteristic of adaptive management. There was a general weakness apparent in experimental design and statistical evaluation of results. None of the studies reviewed here reported development of a simple numerical-spatial system model with stakeholders. The early practitioners of adaptive management regarded this as a necessary feature. In contrast, it is now recognised that an over-emphasis on modelling can stifle the AM process (Ladson and Argent, 2002).

An example of an AM-type system model is a GIS-based model that is under development for wetlands of the Kanyapella Basin, Victoria (Figure 4) (Robertson and James, 2002) (Figure 3). The model is being developed collaboratively with a stakeholder steering committee formed in 1999 with representatives of Field & Game Australia Inc., Deakin University, Koyuga-Kanyapella Landcare Group, Parks Victoria, Goulburn-Broken Catchment Management Authority, the Shire of Campaspe and Goulburn-Murray Water. Local schools have also expressed an interest in the project (Bird Observers Club of Australia, Echuca and District Branch, 2003). Field & Game Australia Inc., which was instrumental in initiating and funding research on the rehabilitation project, support development of “an adaptive management strategy and implementation plan for the basin” (Field & Game Australia Inc., 2003). The GIS-model is incorporating physical, ecological and water quality data, plus oral history information, to create a tool that will guide policies for provision (and monitoring) of environmental water to the Basin (MMWG, 2001a; Robertson and James, 2002). The work has helped resolve issues of how to inundate the wetland so that wildlife and the Black Box forest community will benefit without damaging the crops of nearby landholders (Bird Observers Club of Australia, Echuca and District Branch, 2003). The Kanyapella Basin Management Plan was presented to the stakeholders early in 2003.

One deficiency of adaptive management, as practiced on the River Murray System, is the lack of a framework to guide practitioners. To be effective, such a framework would have to be supported by forums (e.g. MacDonald et al., 1999), training courses (e.g. British Columbia Forest Service, 1999), resources such as manuals (e.g. Ontario Ministry of Natural Resources, 2001), and reviews by technical panels (e.g. AMFSTP, 2001). Cooperation between stakeholders, managers and scientists would be helped if they had a common conception of what constitutes an adaptive management approach. The MDBC is commencing work on developing this framework.
6 Have Environmental Flows Improved River Health?

Scientists believe that properly implemented environmental water allocations will lead to measurable improvements in the health of the River Murray. The findings from this review support this belief. However, full testing of this assumption awaits scientific research and adaptive management. Some environmental responses may take decades.

One difficult problem is trying to attribute changes in river health to environmental flow initiatives, as opposed to habitat rehabilitation, or structural and operational changes (or natural variations in river health through time). Resolution of this problem will require careful experimental design. For now, a review of initiatives already undertaken generally supports the belief that environmental flows can be implemented, and can lead to measurable improvements in river health (Table 3).

Table 3. River Murray environmental flow management actions that have been trialed. All actions were justified on the basis of ‘best available knowledge’, and may have produced improvements in river health; this table evaluates whether such improvements were demonstrated as part of the implementation process.

<table>
<thead>
<tr>
<th>Environmental Flow action</th>
<th>Successful implementation?</th>
<th>Scientifically demonstrated improvement in river health?</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-channel variation of flow system</td>
<td>Applied on the upper and lower river system</td>
<td>Demonstrated ecological benefit on the Mitta Mitta River.</td>
</tr>
<tr>
<td>Wetland watering through delivering allocations, and enhancing natural floods</td>
<td>Applied on private and public wetlands. Environmental allocations achieved.</td>
<td>Demonstrated ecological benefit on private wetlands within the MIL area, the Barmah-Millewa Forest, Moira Lake, Werai Forest, Wanganella Swamp, and Victorian Murray wetlands.</td>
</tr>
<tr>
<td>Restoration of wetland hydrological regime using local structural and operational manipulation</td>
<td>Applied on Moira Lake and SA Riverland wetlands</td>
<td>Demonstrated short-term ecological benefits; overall long-term improvements in ecological health not yet evaluated.</td>
</tr>
<tr>
<td>Flows to disperse blue-green algae</td>
<td>Applied on lower Murray and Darling Rivers</td>
<td>Some limited evidence of ecological benefit.</td>
</tr>
<tr>
<td>Weir pool drawdown</td>
<td>Applied from time to time for maintenance at several weirs, and annually for environmental reasons on Stevens Weir; some resistance to experimental environmental drawdown elsewhere</td>
<td>Salinity impacts within tolerable range at Mildura for short drawdown. Salinity impacts may be significant if river flows are low or if drawdown is for an extended period. Ecological benefits not yet demonstrated at Mildura Weir or at Stevens Weir</td>
</tr>
<tr>
<td>Weir pool surcharging associated with flood enhancement</td>
<td>Applied on the lower River Murray (Lock 5)</td>
<td>Demonstrated ecological benefit</td>
</tr>
<tr>
<td>Sediment flushing flows</td>
<td>Applied at the Murray Mouth</td>
<td>Applied flow insufficient capacity, so sediment flushing not yet demonstrated</td>
</tr>
<tr>
<td>Mimic shape of natural hydrographs</td>
<td>Applied on the lower Darling River</td>
<td>Not monitored.</td>
</tr>
<tr>
<td>Temporarily open weir gates to allow fish passage</td>
<td>Applied at Torrumbarry Weir and Stevens Weir</td>
<td>Open passage demonstrated; overall significance to fish movement not measured</td>
</tr>
</tbody>
</table>
7 Conclusion

This report reviewed efforts to date on improving the health of the River Murray through environmental flow actions. Some conclusions from this investigation are:

- Environmental water has been allocated and implemented in the River Murray System. The review presented in this report provides ample evidence that environmental flows implementation has been based on science and that it can lead to improvements in river health.

- Management agencies and stakeholders across the River Murray System have demonstrated willingness to experiment with environmental flow implementation. Most efforts to date have been limited to the local scale. Collectively these interventions may have a regional impact. Also, some individual actions (such as mimicking natural flows in the Lower Darling) have regional impacts.

- Environmental flow actions have generally involved some form of monitoring, although this has been undertaken using various levels of scientific rigour. Monitoring and reporting of biotic data are needed for accountability. The Sustainable Rivers Audit will provide the right kind of data to examine long-term changes at the system-scale, but more detailed programs will be required to assess the effectiveness of individual environmental flow actions at the local and regional-scale.

- Environmental flow actions have generally demonstrated or suggested positive impacts on river health at the local scale. It must be remembered that most environmental flow actions have only been implemented fairly recently on the River Murray (within the past 2-4 years). For some initiatives, effective implementation and collection of statistically reliable evidence regarding impacts on river health may require a 5-10 year time frame.

- Adaptive management can range from unreliable trial and error, to active adaptive management, which involves simultaneous testing of multiple actions. Implementation of environmental flows in the River Murray System has not followed a consistent approach, with most of the projects being passive adaptive or trial-and-error. While the learning process is potentially faster under active adaptive management, there may be intractable barriers to applying this approach in its purest sense on the River Murray.

- Simple numerical-spatial system modelling with stakeholders at the start of the project (a characteristic of the classic AM approach) has generally not been undertaken.

- In general, managers appear to be well informed regarding ‘best management practice’, and there is a high level of interest in learning more about adaptive management and how to implement it on the River Murray System, consistent with the Ministerial Council resolution.

- In wetland management there appears to be an emphasis on managing for, and publicising, waterbird breeding. This is understandable given the strong...
community concern for birds. While bird surveys are valuable, it appears that aquatic vegetation and macroinvertebrates may be more reliable indicators of changes in wetland health.

• Given the lack of an adaptive management framework to date, there is likely to be a wide range of views present among managers, scientists and stakeholders regarding what constitutes adaptive management. There is a need for clarity regarding the most appropriate ways of adaptively managing implementation of environmental flow initiatives on the River Murray System.
8 Recommendations and concluding remarks

Some recommendations regarding future implementation of environmental flow actions within the River Murray System follow from this review:

- The Living Murray initiative rightly adopts a system-wide approach to developing environmental flow policies. However, evidence from elsewhere suggests that implementation and monitoring of environmental flows is best reduced to local- or regional-scale problems that involve relatively simple interventions, few jurisdictional issues and potential to build a strong sense of community ownership. Ten river zones are currently being used by the Regional Evaluation Groups for modelling environmental flow benefits using MFAT. These zones are also appropriate in size and geographical coverage for creating opportunities for environmental flows. Smaller, local-scale hydrological units may be required for successful on-ground implementation and monitoring of environmental flows.

- A high level of community participation should be encouraged from the very earliest stages of projects (including formulation of policies to be tested). Acceptance of community involvement in the process is a hallmark of adaptive management. In some cases there may be a level of resistance by landholders to become involved in a ‘trial’, because of the negative ‘guinea pig’ connotation. The Commission should remain mindful of this issue, as it can potentially de-rail the adaptive management process.

- Managers may rightly feel uncomfortable about bold hypothesis testing in areas where threatened species legislation and Ramsar responsibilities apply. However, these areas are high priority in terms of environmental protection, and an ostensibly cautious ‘do-nothing’ or ‘delay’ management approach is not necessarily less risky than prudently implementing interventions. While caution is needed, positive adaptive management of high priority species and areas is recommended.

- Where applicable, simple numerical system models with graphical map-based output should be developed with stakeholders when an environmental flow action is to be implemented using adaptive management principles. Most AM models are modest GIS-based spatial models that do not pretend to be deterministic representations of the entire physical, chemical and ecological system. Rather, their main value is as a tool for learning and evaluating policy options. An example of this approach can be found in the Kanyapella Basin wetland management study (Robertson and James, 2002).

- Monitoring needs to be tailored for each project, and managers are encouraged to seek professional statistical and scientific advice regarding experimental design and statistical testing. Some stakeholders may not be familiar with, or see the need for, rigorous scientific monitoring, and this will have to be overcome in the modelling phase. The recommendations of Reid and Brooks (1998; 2000) and Reid et al. (2001) should be followed when monitoring the effects of environmental water allocations to wetlands. Adjustment of management regimes should normally be made at the 2-3 year time-frame or
longer, as some initial and temporary adjustments of the system could be viewed as negative in a seasonal context.

- This review documented the implemented environmental flow work in the River Murray System (as covered by the Living Murray initiative). The findings of this work were provided as reported by the individual projects; no attempt was made to analyse the data to determine if ecological health had changed in response to water management. It is recommended that, as well as utilising monitoring data for regular year-to-year management, projects should also carry out periodic reviews of data that examine medium to long-term changes in ecological health with respect to water management policies.

- Given limited resources available for monitoring, it is necessary to establish criteria for prioritising projects according to the quality and usefulness of the knowledge likely to be gained. High priority projects should be well-resourced adaptive management interventions, with lower priority projects either not monitored, or monitored using a very limited number of indicator variables.

- Consistent with the Ministerial Council’s expectations on adaptive management for the Living Murray initiative, the Commission has initiated establishment of an adaptive management framework. This framework needs to be tailored to suit the physical, ecological, social, economic and political conditions that prevail in the River Murray System. When developed, the Commission should actively encourage adoption and maintenance of the framework.
9 References


Mallen-Cooper, M. and Brand, D. 1992. Assessment of Two Fishways on the River Murray at Euston (Lock 15) and Murtho (Lock 6). Fisheries Research Institute, New South Wales Department of Fisheries, Cronulla.


Appendix 1

Description of Environmental Water Allocations (EWAs) active in the extended River Murray System, including the Murrumbidgee River and Goulburn River

The NSW Water Sharing Plan for the Murray and Lower Darling (DLWC, 2002) defines three categories of environmental water provisions: Environmental Health Water (EHW), Supplementary Environmental Water (SEW), and Adaptive Environmental Water (AEW) [see IRN and NCC (2003) for critique]. EHW is the volume in excess of the long-term extraction limits established. SEW comprises the half-share of the Barmah-Millewa Forest Allocation (50 GL/yr), the half-share of the Barmah-Millewa Overdraw (25 GL/yr conditional), and the Lower Darling River Environmental Contingency Allowance (ECA) (30 GL/yr conditional). AEW comprises the NSW Murray Wetlands Environmental Water Account (30 GL/yr) and the Moira Lake Savings (2,027 ML/yr). A set of Environmental Flow Rules were introduced in the Murrumbidgee Valley for the first time in the 1998/99 water year, establishing the Murrumbidgee River Contingency Allowance (ECA) (25 GL/yr, plus 25 GL/yr provisional).

Victoria has three categories of EWA: the half-share of the Barmah-Millewa Forest Allocation (50 GL/yr), the half-share of the Barmah-Millewa Overdraw (25 GL/yr conditional), and the Victorian Murray Wetlands Environmental Water Account (27.6 GL/yr).


Barmah-Millewa Forest EWA

In 1993, the Murray-Darling Ministerial Council approved the allocation of 100 GL/year from which the environmental water needs of the Barmah-Millewa Forest could be met, with NSW and Victoria contributing equal shares of this water (Barmah-Millewa Forum, 2000). This is known as the Barmah-Millewa Forest EWA. The allocation was based principally on the assumed needs of waterbirds (David Leslie, State Forests of NSW, pers. comm. 14 March, 2003).

It is recognised that the EWA is, by itself, insufficient to meet the environmental needs of the Forest (Maunsell Pty Ltd et al., 1992), so the EWA is intended for use as a supplement to natural floods that would otherwise have deficiencies as far as ecological requirements are concerned. The various conditions associated with the EWA, and triggers for its use, are set out in DLWC (2002). These conditions include a provision to carryover up to 700 GL, and during dry periods there can be up to 4 years with no water release.

Flows that are provided for flooding to the Barmah Millewa Forests under the Barmah-Millewa EWA, and which are diverted through the Edward/Wakool system, are to be managed to provide flood flows to the Werai Forest below Stevens Weir where possible (DLWC, 2002).

Barmah-Millewa Overdraw

In the late 1990s, David Leslie (State Forests of NSW) developed a decision support model based on requirements of colonially-nesting waterbirds (Leslie, 2001) which revealed that the 100 GL/yr EWA was insufficient to achieve the flow targets in about
50% of the years in which the flow rules were activated. In its *Sharing the Murray* report (MWEC, 1997), the Murray Water Entitlement Committee recommended an increase in the allocation. In 2001 The Barmah-Millewa Overdraw was approved by the Ministerial Council to allow an additional 50 GL/yr to be added to the 100 GL/yr Barmah-Millewa EWA during 'wet' years (or around 80% of years). The Overdraw is shared equally between Victoria and NSW for use in the Barmah-Forest. The various conditions associated with the EWA, and triggers for its use, are set out in DLWC (2002).

**Lower Darling River ECA**

The Lower Darling ECA is 30 GL/yr, dependent on the volume of water in Menindee Lakes being above 480 GL, and having risen above 640 GL since the last time it was below 480 GL. Releases from the Lower Darling ECA may occur whenever a high blue green algal alert level, as set out in the Sunraysia Regional Algal Contingency Strategy, is announced by the Minister in the Lower Darling Water Source (DLWC, 2002).

**NSW Murray Wetlands EWA**

The NSW Water Administration Ministerial Corporation holds licences committed as adaptive environmental water, subject to conditions set out in the NSW Water Sharing Plan for the Murray and Lower Darling. This allows a regulated river (conveyance) access licence with a share component of 30 GL/yr, known as the NSW Murray Wetlands EWA (DLWC, 2002). The NSW Murray Wetlands Working Group (MWWG) manages (for a 3-year trial period which began in 2000) this EWA on behalf of the Ministerial Corporation (MWWG, 2002a).

**Moira Lakes Savings**

The net water saving from rehabilitating Moira Lake is 2,200 ML per year (achieved through reduced evaporation loss). These Savings are from regulated flows, not from any environmental allocation (MWWG, 2000). From these Savings, the NSW Water Administration Ministerial Corporation allows 2,027 ML/yr to be used as adaptive environmental water for a regulated river (high security) access licence. The MWWG administers the Savings, 50% of which can be sold each year, with the remainder directed to wetlands needing increased inundation (MWWG, 2000).

**Murrumbidgee ECA**

Rule 4 of the Murrumbidgee Valley Environmental Flow Rules concerns the Murrumbidgee Environmental Contingency Allowance, which provides for water contingencies and has been designed to specifically target the wetlands of the Murrumbidgee River valley. A reservation of 25 GL/yr is made annually to provide water to meet water quality needs and algal bloom suppression, fish breeding and forest and wetland watering. Water is also reserved to buffer the impact of environmental releases on irrigators during sequences of dry years and to ensure environmental allocations will be available. This additional volume is 25 GL/yr when allocations are below 80% and will increase from 25 GL to 200 GL for allocations between 80% and 100% (DLWC, 2000a).

**Victorian Murray Wetlands EWA**

In 1987 the Natural Resource and Environment Committee of Cabinet committed an allocation of 27.6 GL/yr of environmental water supplied from Hume and Dartmouth reservoir, known as the Victorian Murray Wetlands EWA. DSE is responsible for its...
management and distribution within the Murray system. Of this allocation, 2,600 ML/yr has been allocated to Hird and Johnsons Swamps (DSE, 2002).

Each year the Environmental Water Allocation Committee (EWAC) makes recommendations on the development of the works program (e.g. Kelly 1997; DNRE, 2002a). Historically, the allocation has been used within the Kerang Lakes area to maximise the environmental values of the wetlands and to reduce salinity impacts (Centre for Environmental Management, 1997; Reid and Brooks, 2000). However, the allocation can be used for other wetlands along the Murray River system (Centre for Environmental Management, 1997; DNRE, 2001; 2002a).

**Gunbower Forest EWA**

The Murray Water Entitlement Committee (MWEC, 1997) proposed two allocations of environmental water to be used for Gunbower Forest (Cooling et al., 2002). The first, 25 GL used on average one in three years, is designed to top up and extend small to medium sized floods. The second is an additional 40 GL, used about one in twelve years to cause low-level flooding when the forest has been dry for two years. It is proposed that the EWA is derived from surplus flows that cannot be used to meet other entitlements and cannot be stored, so it is not a secure allocation. A plan for the use of the Gunbower Forest EWA is being managed by the North Central Catchment Management Authority. While the emphasis is on using the EWA at high river flows to achieve extensive flooding, Cooling *et al.* (2002) suggested that the restoration of small, regular flows is also critical, and this will require a secure allocation or creative use of rain-rejections flows.

**Goulburn River EWA**

The Goulburn River is so highly regulated that opportunities for allocations for environmental purposes are limited. At present there is an allocation of 80 GL for a spring flush to be provided in November in wet years (on average seven out of ten years) with a flow rate not exceeding 185 m$^3$/s (DCNR, 1995; DSE, 2002). Further, when inflows to Lake Eildon have been high and the storage is relatively full, 25 GL has been allocated for environmental purposes over spring. However, re-regulation of the water at Nagambie prevents this allocation reaching the lower Goulburn River (DSE, 2002). There may be potential to use some of the Victorian Murray Wetlands EWA sourced from Lake Dartmouth on the Goulburn River system, particularly on the lower river (DSE, 2002).

**South Australian Additional Dilution Flows**

As part of the Murray-Darling Basin Agreement, South Australia receives an Entitlement Flow of 1,850 GL per year. This is a very secure entitlement provided jointly by NSW and Victoria and under all but the most extreme and prolonged dry period (i.e. 1 in 100 years). Although South Australia receives only entitlement flow in very dry periods, such as from December 2001, the average flow to the State is normally much higher, averaging approximately 6,000 GL/yr in November (RMW *et al.*, 2001).

In 1987, as part of the Commission’s Salinity and Drainage Strategy, it was agreed that South Australia would be entitled to additional water to mitigate the impacts of surface water salinity. This volume, known as ‘additional dilution flow’, is only provided when the storage volumes in the Menindee Lakes exceed nominated trigger points, at the same time the combined storage volume of Hume and Dartmouth Reservoirs also exceed nominated triggers. When these trigger volumes are exceeded,
South Australia is entitled to an additional flow of 3,000 ML/d (DLWC, 2002). These flows are principally for reducing the salinity of water to South Australia, although there may be other incidental environmental benefits.

South Australian Murray Wetlands EWA

Until mid-2002 there was no water allocation for wetlands in South Australia, but the practice of drying wetlands (for environmental benefits) had been employed in some places (Jensen, 2002a, 2002b). This would have generated water savings for the River Murray through reduced evaporative losses.

With the introduction of the Water Allocation Plan for the River Murray in mid-2002 in SA (RMCWMB, 2002) provision has now become available for allocating water for permanent wetlands. The allocation of 200 GL/yr was calculated according to the amount of water that could be saved by drying out permanent wetlands, and comes out of South Australia’s entitlement flow (it is not new or additional water). There is no maximum volume identified for allocations to temporary wetlands, and this allocation is in addition to the 200 GL/yr allocated for permanent wetlands (RMCWMB, 2002).

Under the Water Allocation Plan, in order for wetland managers to fill wetlands they will require a water licence, and a range of requirements are attached to that water licence (e.g. the development of a management plan to a set standard and salinity impacts assessment). This is a new process that is currently being implemented by the DWLBC (DWLBC) (Prue Tucker, DWLBC, pers. comm. 18 March 2003).
Appendix 2

Ministerial Council Vision and Objectives

The Ministerial Council has provided a clear basis for a principled approach to address the issue of environmental flows in the River Murray System. In March 2001, Council agreed to a vision and set of objectives for the River Murray System to be addressed by the Commission. The vision and objectives for River Murray environmental flows adopted by Ministerial Council in March 2001 are as follows:

Vision:
“… a healthy River Murray System, sustaining communities and preserving unique values.”

Objectives:

River health objectives
1. Protect and restore key habitat features in the river, riparian zone, floodplain and estuary to enhance ecological processes.
2. Protect and restore healthy riverine and estuarine environments and high value floodplain and wetlands of national and international importance.
3. Prevent the extinction of native species from the riverine system.
4. Overcome barriers to the migration of native fish species.

Environmental flow objectives
5. Reinstate ecologically significant elements of the natural flow regime.
6. Keep the Murray Mouth open to maintain navigation and fish passage and to enhance estuarine conditions in the Coorong.
7. Significantly improve connectivity between and within riverine, wetland, floodplain and estuarine environments.

Water quality objectives
8. Substantially improve water quality in the Murray system to a level that sustains ecological processes, environmental values and productive capacity.
9. Manage salinity to minimise impacts on ecological processes and productivity levels.
10. Manage nutrient levels to reduce the occurrence of blue-green algal blooms.
11. Minimise the impact of potential pollutants such as sediment and pesticides within riverine environments.

Human dimension objectives
12. Implement an adaptive approach to the management of the River Murray consistent with the Integrated Catchment Management Policy Statement,
monitoring ecological outcomes and reviewing operations in the light of new information.

13. Gather, evaluate and disseminate the community's living, scientific and intuitive knowledge to optimise environmental flow strategies.

14. Ensure participation of the entire community by recognising the cultural and historical relationship to the river, its landscape and its people and acknowledging the past to effect the future.

15. Recognise the importance of a healthy River Murray to the economic, social and cultural prosperity of communities along the length of the River.