Environmental flows and water quality objectives for the River Murray

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Abstract Over the past decade, there intense consideration of managing flows in the River Murray to provide environmental benefits. In 1990 the Murray-Darling Basin Ministerial Council adopted a water quality policy: To maintain and, where necessary, improve existing water quality in the rivers of the Murray-Darling Basin for all beneficial uses – agricultural, environmental, urban, industrial and recreational, and in 1994 a flow policy: To maintain and where necessary improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance 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. In March 1999 the Environmental Flows and Water Quality Objectives for the River Murray Project (the Project) was set up, primarily to establish water quality and environmental flow objectives for the River Murray system. A Flow Management Plan will be developed that aims to achieve a sustainable river environment and water quality, in accordance with community needs, and including an adaptive approach to management and operation of the River. It will lead to objectives for water quality and environmental flows that are feasible, appropriate, have the support of the scientific, management and stakeholder communities, and carry acceptable levels of risk. This paper describes four key aspects of the process being undertaken to determine the objectives, and design the flow options that will meet those objectives: establishment of an appropriate technical, advisory and administrative framework; establishing clear evidence for regulation impacts; undergoing assessment of environmental flow needs; and filling knowledge gaps.

A review of the impacts of flow regulation on the health of the River Murray revealed evidence for decline, but the case for flow regulation as the main cause is circumstantial or uncertain. This is to be expected, because the decline of the River Murray results from many factors acting over a long period. Also, the health of the river varies along its length, from highly degraded to reasonably healthy, so it is clear that different approaches will be needed in the various river zones, with some problems requiring reach or even point scale solutions.

Environmental flow needs have been determined through two major Expert Panel reports that identified the ecological priorities for the river. The next step is to translate these needs into feasible flow management actions that will provide the necessary hydrological conditions. Several investigations are underway to recommend options for flow management. Two important investigations are described in this paper: how to enhance flows to wetlands of national and international significance, and how to physically alter or change the operation of structures (including a dam, weir, lock, regulator, barrage or causeway), to provide significant environmental benefits. Early modelling suggests that the only option which has a positive environmental effect in all zones of the River is a reduction in overall water consumption.

Keywords Environmental flows; flow management; Murray River; water quality objectives

Introduction
The River Murray is a large river with a catchment area of around 1,000,000 km². The River and its catchment have a long history of exploitation and modification, with flow regulation and increased salinity commonly recognised as the two main factors that have impacted (and continue to impact) negatively on the environmental health of the river.

Over the past decade, there have been numerous discussions, investigations and decisions made regarding aspects of managing flows and water quality in the River Murray to...
provide environmental benefits. The Murray-Darling Basin Commission has implemented a number of institutional initiatives and funded several important investigations that address water quality and environmental flow needs of the River.

In 1990, the Murray-Darling Council adopted a water quality policy:

To maintain and, where necessary, improve existing water quality in the rivers of the Murray-Darling Basin for all beneficial uses – agricultural, environmental, urban, industrial and recreational. In the case of those parameters such as salinity and nutrients which are already recognised as causing problems, the policy is to improve existing water quality. In the case of other parameters which may at the moment be well below recognised limits, the policy is to endeavour to ensure that existing quality is not allowed to deteriorate.

In 1992, the Murray-Darling Basin Agreement was amended to include (among other things) a reference to the need for water quality objectives. In 1994, The Murray-Darling Basin Ministerial Council adopted a flow policy. To maintain and where necessary improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance 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 Commission has implemented a number of initiatives addressing aspects of environmental flow management. Some, such as the Cap and its review, address the volumetric aspects of environmental flow needs, others such as the Environmental Flows Decision Support Program provide tools and information to support the management of environmental water, and others are direct flow management operations undertaken by the Commission on the River Murray to deliver specific environmental benefit. Water quality issues have also been addressed through a range of initiatives, such as the Basin-wide Algal Management and Salinity Management strategies, recommendations on proposals referred to the Commission under Clause 46 of the Agreement and under Murray Regional Environmental Plan No. 2, and direct operational actions to mitigate salinity levels and algal blooms. On a State by State basis, the allocation and management of water for environmental needs has been addressed through the policies and programs of the State water management agencies, recognising the sharing arrangement required to gain maximum benefit for River Murray environments.

On a cross-border basis, the Ministerial Council decided in 1993 to allocate 100 GL to water the Barmah-Millewa forest as a single entity. In 1996 more specific environmental flow management opportunities for the Murray were investigated by the establishment of two Scientific Panels which commenced the identification 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 Murray system was recognised by the Commission in 1999. In response it established a high-level Project Board to develop a flow management plan and establish water quality objectives for the River Murray and the Darling River below (and including) Menindee Lakes. In March 1999, the Environmental Flows and Water Quality Objectives for the River Murray Project (the Project) was established. To achieve these objectives, a Flow Management Plan will be developed for the River Murray system. The
Plan will be subject to an adaptive management regime that will include monitoring and reporting against the adopted water quality and environmental flow objectives. The Commission’s Sustainable Rivers Audit will assist with developing an appropriate framework for monitoring and assessing environmental outcomes.

The Commission funds numerous research projects related to gaining an understanding of river processes in an effort to improve management. Some recent projects have been specifically directed towards the issue of environmental flows. Determining objectives for environmental flows for a large, environmentally diverse, politically divided, and heavily regulated river with a large percentage of available water already committed for off-stream use is not a trivial task. It required application of a systematic and detailed process that developed objectives that were feasible, appropriate, had the support of the scientific, management and stakeholder communities, and which carried acceptable levels of risk. This paper summarises progress to date on the Commission’s Environmental Flows and Water Quality Objectives for the River Murray Project. Four key aspects of the process are discussed: establishment of an appropriate technical, advisory and administrative framework; establishing clear evidence for regulation impacts; undergoing assessment of environmental flow needs; and closing knowledge gaps.

**Project organisational structure and objectives**

The Project Board, comprising Commissioners and Deputy Commissioners, has overall responsibility for the completion of the product for the Ministerial Council. It is not a jurisdictional body – its members have clearly defined roles to represent the needs of the executive, users and suppliers of the product. The Board is supported by:

- a Jurisdictional Reference Panel (JRP), responsible for selecting, developing and integrating the new and modified management options for flows in the River Murray system;
- a Community Reference Panel (CRP), responsible for providing the communities’ views and advice on the advantages, disadvantages and future consultation requirements of the options, as well as assisting with the development and assessment of options;
- an Expert Reference Panel (ERP) of internationally recognised experts in the field; and
- a core MDBC project team that supports the above groups and coordinates the development of options within an adaptive management plan framework (Figure 1).

**Objective of the Project**

The objective of the Project is to prepare for the Ministerial Council a Management Plan for future operation of the River Murray system. The Plan will describe actions aimed at achievement of a sustainable river environment and water quality, in accordance with community needs. The Plan will include an adaptive approach to management and operation of the River. Two important secondary products of the Project are a) environmental flow objectives and water quality objectives to provide the basis for ongoing review and modification to management of the River Murray system and b) implementable options for providing flows and water quality which enhance the River Murray riverine environment through achievement of environmentally beneficial outcomes.

**Agreed vision and high level objectives**

A “Vision” developed by the Community Reference Panel, and a number of high level objectives, were adopted by the Ministerial Council in March 2001. The “Vision” has been developed with the intent of bringing communities together and bridging cultural, economic, social and institutional differences – to inspire shared understanding and commitment to
work together towards a common aim: a healthy River Murray system, sustaining communities and preserving unique values.

The agreed high-level objectives related to river health, environmental flows, water quality and the human dimension of river management.

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 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

Figure 1 Organisational structure of the environmental flows and water quality objectives for the River Murray Project
Water quality objectives
- Substantially improve water quality in the Murray system to a level that sustains ecological processes, environmental values and productive capacity
- Manage salinity to minimise impacts on ecological processes and productivity levels
- Manage nutrient levels to reduce the occurrence of blue-green algal blooms
- Minimise the impact of potential pollutants such as sediment and pesticides within riverine environments

Human dimension objectives
- Implement an adaptive approach to the management of the River Murray consistent with the ICM Policy Statement, monitoring ecological outcomes and reviewing operations in the light of new information
- Gather, evaluate and disseminate the community’s living, scientific and intuitive knowledge to optimise environmental flow strategies
- 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
- Recognise the importance of a healthy River Murray to the economic, social and cultural prosperity of communities along the length of the River

The “Vision” and high level objectives for environmental flows and water quality are meant to reflect the needs of various water users and communities, bring about a long-term commitment to address river health and preserve unique values of the River Murray.

Evidence for decline due to regulation
Regulation of flow in the River Murray began with the construction of levees in the 18th century. Commercial navigational use of the river commenced in 1853. In the 1870s, Victoria started to use the river for irrigation in the Kerang Region. At the time, diversion of water for irrigation conflicted with navigation requirements, but by the 1880s the success of railways led to rapid demise of the importance of navigation. Expansion of irrigation was limited to some extent by the variability of flows in the river, and serious droughts in the late 1890s and early 1900s raised the issue of drought protection. The response to this problem was to exert a high level of control over river flow.

Catchment and river diversions have reduced the flow in the lower River Murray (below Euston) to half the natural levels, or less. Inflows from the Darling River do not improve the situation because the current (regulated) average annual discharge is only 57% of the naturalised level (modelled flow time series as if there was no regulation). At the Murray mouth average annual discharge is only 38% of the naturalised level. Flow variability can be defined at various temporal scales, from annual flow variation to the rates of water level variation during flood events. Regulation has generally reduced flow variability. Variation of flow through the year is reduced through the release of relatively constant flow volumes, particularly during the periods of water storage in the major reservoirs (relatively constant low flows are released) and irrigation water supply (relatively constant channel capacity flows are released). Weirs are managed to maintain the water level upstream at a fairly constant level for long periods, and this further reduces natural flow variability.

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 is always 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, but this has now increased to around 20% of the time. The frequencies of peak flood 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 of mid-range flows, or minor-medium floods. Regulation has also reduced the duration of mid-range floods.

One major problem in seeking evidence for environmental decline due to regulation is the difficulty in isolating changes in the aquatic environment that are due to flow regulation from those that are due to changes in other factors such as catchment land use, fishing pressure, introduced species, riparian vegetation cover, large woody debris distribution, and natural variations in flow regime. Another major problem is that regulation of the River Murray occurred progressively over a long period of time, as water resources were developed to meet demands. While availability of data allows the hydrology of the system to be investigated in terms of seven main phases of regulation, the ecological consequences cannot be investigated in such chronological detail. This is partly because collection of suitable data did not begin until the regulated flow regime was well established, but also because ecological responses are complex, often delayed, and can manifest in a location that is distant from the site of the hydrological disturbance.

An example of the difficulty in attributing cause to an observed environmental problem is the case of Murray cod numbers in the River Murray. Various theories have been explored to explain the apparent decline in Murray cod abundance since 1960: reduced larval recruitment due to flow regulation, increased rate of fall in water level downstream of regulating structures, alienation of floodplains, over-fishing, competition and predation from alien fish species, creation of barriers to movement, degradation of in-channel habitat through de-snagging and channelisation, altered water temperatures downstream of dams, and siltation of habitat. While all of these factors have been implicated to some extent in the apparent decline of the Murray cod, scientific studies have emphasised the importance of flow regulation (Rowland, 1989; Walker and Thoms, 1993; McKinnon, 1997).

A review of available information (Gippel and Blackham, 2001) found evidence for decline in the environmental values of the River Murray that could be directly linked to river flow regulation, although other disturbances have also contributed to the decline. Regulation has altered wetland flooding patterns, reversed flow patterns, lowered flow volumes, changed water temperature, and reduced flow variability. Some areas are more affected than others, and there are parts of the system that can be more readily improved through implementation of environmental flow options.

One important outcome of the review by Gippel and Blackham (2001) was identification of the major issues that can potentially be addressed by the Environmental Flows and Water Quality Objectives for the River Murray Project. In fact, the previous Scientific Panel reports prepared for the Murray-Darling Basin Commission (Thoms et al., 2000; Jensen et al., 2000) made numerous recommendations in this regard on the basis of the thorough research and review that was undertaken by the project teams.

Assessing environmental flow needs
The specific impacts of regulation on the River Murray environment are so numerous and complex that they cannot be fully characterised. However, the considerable scientific research effort that has been undertaken has produced a very good understanding of some of the major regulation impacts. Young (2001) undertook the most recent review of scientific knowledge of the interactions between riverine ecology and flow regimes in the Murray Darling Basin. This is a significant piece of work that attempts to develop a comprehensive conceptual model of river function for the major rivers of the Basin. These principles allow qualitative prediction of the impact of regulation across the full range of situations that occur in the River Murray. In other words, these principles allow prediction of the direction of change likely under any particular regulation situation. This model is
an important tool, because some ecological and geomorphic responses are slow, variable or otherwise difficult or expensive to measure directly.

Two important Scientific Panel investigations have been undertaken on the main stem of the River Murray: Thoms et al. (2000) reported on the River Murray from Dartmouth Dam to Wellington, including the Lower Darling River (downstream of Menindee Lakes), and Jensen et al. (2000) reported on the Lower Lakes below Wellington, including the Coorong estuary. The methodology employed by these Expert Panel studies was to collectively pool available data and theoretical knowledge, inspect a range of sites, glean local information, form judgements through workshop interaction, conduct necessary flow modelling, and then make recommendations for priority actions (Thoms et al., 2000, p. 19–21; Jensen et al., 2000, p. 5–6).

In January 2001 the scientific panels were reconvened to consider, evaluate and comment on, in a workshop format, nine flow management options that were derived from recommendations of the original Scientific Panels (Roberts et al., 2001). The deliberations were guided by pre-determined ecological principles and by priorities for each river zone considered, and performance of the options was evaluated against targets set for various desirable hydrological characteristics. The performance of the nine flow options was generally adequate. All except one met, or partly met, their stated target. However, performance of the options was less impressive when non-target effects were considered. Flow options with targets in the lower river rated poorly overall because of negative environmental effects upstream of their target. Delivering flows in a highly regulated system can lead to increasing levels of regulation, thus negating the effects that environmental flows are seeking to achieve. This was less of a problem for flow options implemented in the upper part of the River Murray with options having almost no negative environmental effects on river zones downstream, and almost no positive ones either (larger-scale options tested more recently have shown system-wide benefits).

There is a paradox in that relatively small-scale environmental flows targeting one part of a river system can have negative environmental effects in another. The delivery process is socially constrained and hence results in further regulation rather than less. Of the flow options considered, only one, Reducing the Cap, had a modelled positive effect in all parts of the main-stem River Murray. Its success was attributed to the combination of increases in discharge, and reduced level of diversions. The success of this option is also related to appropriately managing the water retrieved in a manner that reaches environmental thresholds. More recent model runs have attempted to address this issue of “smart” water management.

The major issue, particularly in the upper river, is to re-instate flow variability. Dam translucency options at Hume and Dartmouth Dams were suggested specifically to return some variability to river flows. However, it proved difficult to achieve adequate variability without passing a large percentage of inflows through the dams. As yet it is unclear whether this is an operational issue, a statistical or modelling issue, or whether it reflects the role of the tributaries.

The newly formed Project Expert Reference Panel (Figure 1) is currently reviewing the environmental flow needs of the River Murray in detail. Return to natural flooding frequencies and levels of variability is not an option in such a heavily regulated river, so decisions are required regarding how close hydrological indicators should be to the natural pattern in order to have a high probability of producing a satisfactory environmental benefit. Environmental flows can be delivered by making more water available, by altering the distribution of flows (operational changes) or by altering flow regulating structures (structural changes), or through some combination of these. Given the high current level of water diversion, it makes sense to optimise the way flows are delivered in order to maximise envi-
Closing knowledge gaps

Some issues require investigation before the final options can be formulated. One major challenge is to determine the economic costs and benefits of changing flows in the River Murray. Two other priority issues were identified as requiring urgent investigation:

- review of structural and operational aspects of river infrastructure including major dams and the locks and weirs of the River Murray system, including the lower Darling River,
- opportunities for introducing improved flooding regimes and management of high value wetlands of the River Murray system, including the lower Darling River.

Infrastructure review

The River Murray structures were designed, constructed and operated to suit the circumstances of the time, and according to design standards of the time. Some structures were originally built to provide a reserve of water for stock and domestic supply, others were built to enable transfer of water, others for major irrigation water supply, and others for navigation. Some of these circumstances and design standards may no longer apply, which raises the question of whether some of these structures can be removed, structurally modified, or operated in a different way. This is an especially pertinent question given the increasing realisation that the River Murray aquatic environment has been heavily degraded in some respects and in many places due to the operation of these structures.

The still waters in weir pools are less biologically productive than natural flowing river channels, surrounding vegetation is killed by water-logging, weirs act to trap sediments and contaminants, macroinvertebrate drift is impaired, weir conditions favour development of algal blooms, structures can obstruct fish passage, some alien species can be advantaged by the relatively stable flow conditions, groundwater mounding can occur due to high water levels, channels downstream are starved of sediment because structures interrupt the normal transport of sediment downstream, structures can alter temperature regimes of the river downstream, and the flow regime and total flow volume can be drastically altered.

There is a growing movement in the water industry that recognises the possibilities for, and benefits of, removal or modification of some river regulating structures. If a structure no longer provides benefits, is not functioning properly, has been abandoned or produces fewer benefits than the costs needed to maintain it, a case can be made for its modification, breaching or removal. While this approach may be appropriate in some areas, in highly regulated rivers where the feasibility of radical alteration to major structures may be doubtful in the short-term, it may be more appropriate to build new structures, or modify existing structures, specifically to control water for environmental purposes. An example is the raising of weir pool levels to simulate larger flood conditions.

A project was undertaken to seek out feasible opportunities for removing, modifying or changing the operating procedures of existing river infrastructure where these changes will result in significant environmental benefits. The appropriateness and/or operation of each structure on the River Murray system was reviewed against a set of established criteria, to produce a list of what is feasible at each structure. This list was considered through a process of workshops and review, and narrowed to a short-list for further development. Indicative cost estimates for works to carry out modification of structures were determined. The outcomes of this investigation are now being used to assist in preparation of the Options paper for consideration by the Ministerial Council.
Improved flooding regimes and management of high value wetlands

The dams on the River Murray system, whilst originally constructed for water conservation and water supply purposes, may also act as the main environmental flow control points. Hume Dam is considered to be the highest priority location for achieving environmental benefits downstream for the Upper Murray. Menindee Lakes and Lake Victoria are high priority when considering flows and environmental benefits to the river in South Australia. There are several important wetland/forest areas along the length of the River Murray, with the largest and most well known being the Barmah-Millewa Forest. Much research work has been done on impacts of regulation on the Barmah-Millewa Forest, and proposals have been made on improved water management strategies for this wetland area. Considerable work has also been done on the Coorong, and Chowilla floodplain areas, while other areas have received less attention. No study has previously attempted to investigate opportunities for improved management of flow to important wetlands in an integrated way along the full length of the River. This was the main objective of this investigation.

The importance of wetlands was recognised at three distinct levels: Ramsar listing, Directory of Important Wetlands and those listed by the Murray-Darling Ministerial Council as reference wetlands. The initial priority setting procedure produced a list of 85 wetland sites. This list was reduced to a list of 11 high priority wetlands or wetland systems.

For these high priority wetlands, information was collated on the stage/discharge levels when wetlands commence to flow (i.e. commence inundation). Other information was collected on the volume required for inundation, commence-to-flow levels in any well-defined wetland zones, natural (pre-regulation) inundation timing, frequency and duration, and characteristics of drying phases. Options were explored for achieving the target flow regimes (i.e. sufficient to maintain the wetland’s conservation status). These data are being used in MDBC modelling runs to help formulate flow options.

Conclusion

Most of the environmental flow assessment methods available, and the case studies cited in the literature, apply to relatively simple systems such as reaches of rivers immediately downstream of dams. But even in these cases, environmental flow assessments have proven to be notoriously difficult exercises. Determining objectives for water quality and environmental flows for a very large and complex river system like the River Murray represents an enormous, and perhaps unprecedented, challenge.

The project was justifiable on the grounds of clear evidence for environmental decline caused by flow regulation. There was no single established hydrological or ecological method available that had the capacity to formulate environmental needs for the River Murray. A series of Scientific Panel investigations that drew on a range of techniques, some targeted investigations to fill knowledge gaps, and an Expert Reference Panel were used to determine realistic environmental flow needs of the river.

A number of high level objectives were adopted by the Ministerial Council in March 2001. These concerned river health, environmental flows, water quality, and the human dimension of the issue. Building on these high level objectives, reach by reach objectives for both environmental flows and water quality were developed through a program involving a Project Board and three Panels (community, jurisdictional and expert). Environmental flow options to be presented to the Ministerial Council in October 2001 fall into three main categories: optimising use of existing water using a combination of operational and structural measures, optimise water use but also recover a small but not insignificant volume of the Cap, and optimise water use but also recover the volume of the Cap required to meet the environmental objectives specified by the Expert Reference Panel. A
comprehensive communications strategy and a community consultation process are planned for the next phase of the project, when progressive implementation of the Ministerial Council decisions will begin.

Implementation of agreed options will be carried out under a staged approach, with possible larger interventions, if adopted by Council, phased in over time to facilitate adjustment. The staged implementation approach with ongoing adjustments under an adaptive management regime over many years is important to the success of the project in delivering meaningful improvements to the environmental health of the River Murray system.

References


