the murray mouth

Exploring the implications of closure or restricted flow

MURRAY-DARLING BASIN COMMISSION

The Department of Water, Land and Biodiversity Conservation

Government of South Australia

The Murray Mouth

Exploring the implications of
closure or restricted flow

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The land and waters is a living body.

We the Ngarrindjeri people are a part of its existence.

The land and waters must be healthy for the

Ngarrindjeri people to be healthy.

We are hurting for our country.

The Land is dying,

the River is dying,

the Kurangk (Coorong) is dying

and the Murray Mouth is closing.

What does the future hold for us?

Tom Trevorrow, Ngarrindjeri elder, Camp Coorong, 2002

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Foreword

In the 1930s the Government made the decision to construct barrages at the Mouth of the River Murray to prevent salt water intrusion into the Lower Lakes. This was in response to demand for increased freshwater diversions from the Lakes themselves and upstream users. As a consequence, reduced flows and barrage construction has altered the morphology of the Murray estuary and Mouth, increasing the threat of Murray Mouth closure. This has significantly impacted on the environmental, social and economic values of the region, including the Coorong.

Over the last sixty years, we have worked with this modified River system and are now trying to address the challenges that arise from the altered flow regime. This compilation of papers presents the complexity of the issues faced by a closure of the Murray Mouth - social, economic and environmental impacts, as seen through the eyes of community members and scientists. The papers are intended to inform the debate leading to better management of, not only this reach of the River, but more generally throughout the Murray-Darling system.

The Murray-Darling Basin Commission, together with South Australian agencies, is investing significant resources to increase our understanding of the broad range of issues facing the Murray Mouth. In 2001, The Murray-Darling Basin Ministerial Council adopted 15 objectives to attain a healthy River Murray. Keeping the Murray Mouth open to maintain navigation and fish passage and to enhance estuarine conditions in the Coorong is one of these objectives. The papers in this compilation provide a comprehensive springboard for future projects and management possibilities to achieve this objective.

Don Blackmore
Murray-Darling Basin Commission

Authors

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Summary

While a build-up of sand inside the Murray Mouth and reduced tidal flows is not a new phenomenon, the current situation is set apart by the duration and degree of sand build up, which is greater than ever previously reported. The ongoing threat of closure highlights the need to understand the potential impacts of this changed flow regime on the ecological health of the Coorong and Lower Lakes.

This compilation seeks to explore these implications from a range of perspectives, and bring together current knowledge and concerns to inform and guide future management decisions.

Common Ground

While each paper reflects a different perspective and area of interest or expertise, some common views have emerged:

- The accumulation of sediment at the Murray Mouth reflects the vastly altered hydrology of the River Murray and is symptomatic of the condition of the entire Murray-Darling Basin.
- The implications of closure depend on its duration, timing and frequency – that is, the period for which the Mouth stays closed, the time of year when this happens and the interval between closures.
- Short-term closure, when the Mouth is reopened before water quality is seriously degraded, is likely to have minimal impacts. However, such impacts would escalate if closure occurred during the warmer months.
- Currently, the risk of long-term closure is greater than ever before due to the condition of the River Murray– that is, negligible River flows reaching the Mouth, and a major reduction in ‘big flood’ events.
- Long-term closure would have serious deleterious, and in some cases irreversible, impacts on the ecology of the area and those who depend on it.
- South Australia has an international obligation to protect the ecosystems of the Coorong and Lower Lakes.
- All stakeholders recognise the special ecological value of the area and the need to stop further degradation.
- Any solution needs to be considered in the context of the total River Murray system.

Perspectives

Ngarrindjeri Culture

The Murray Mouth is an important cultural and spiritual place for the Ngarrindjeri people. The growing environmental degradation of the Murray-Darling Basin and the threatened, continuing closure of the Murray Mouth, has already, and will continue to place enormous pressure and cultural trauma on the Ngarrindjeri community.

> *The sense of feeling, sense of belonging, sense of responsibility for the River, Lakes and Coorong experienced by Ngarrindjeri people has survived occupation, dispersal and attempted assimilation. It continues to exist irrespective of where Ngarrindjeri people currently live. The link with the land lies at the heart and soul of Ngarrindjeri culture. A proper relationship and role in management of the land is a fundamental platform in building and maintaining Ngarrindjeri culture and Ngarrindjeri self respect. Ngarrindjeri believe that their future involvement in the management of the land would be positive and beneficial to all members of the community, not just Ngarrindjeri. It would represent a significant step in the process of reconciliation and co-existence. The strengthening of Ngarrindjeri people and their culture requires a serious involvement in the managing of their traditional lands* (NRWG 1999).

Fishing Industry

If the passage for fish between the sea, Lower Lakes and estuary is prevented by closure of the Murray Mouth, several economically important fish species will decline.

Many species depend on movement from the ocean into the estuary and freshwater Lower Lakes for reproduction and recruitment. Key species are Mulloway (*Argyrosomus japonicus*), Goolwa Cockles (*Donax deltoides*), Black Bream (*Acanthopagrus butcheri*), Greenback Flounder (*Rhombosolea taparina*) and Yellow-Eye Mullet (*Aldrichetta forsteri*).

If Mouth closure occurs over the warmer months, there is potential for fish kills as a result of low oxygen levels and algal blooms associated with warm, still, high nutrient water. Long periods (more than two weeks) of hot weather would increase the probability of oxygen levels declining below survival levels of 1-2ppm. Closure therefore has the potential to make the existing commercial fishery uneconomic and reduce recreational fishing.

Tourism and Recreation

The ecology of the Coorong and Lower Lakes area is the basis of its tourism and recreation value.

The Murray Mouth and the Coorong are unique, iconic sites and serve to differentiate South Australia from other tourist destinations. Mouth closure would seriously undermine this tourism asset. Mouth closure and its associated impacts would also adversely affect a range of recreational uses, particularly fishing, boating and bird watching.

Water Quality

The major water quality impacts, which may eventuate from Murray Mouth closure, represent a risk to stakeholders because they degrade habitat for aquatic organisms or present a health risk to recreational users.

The two major factors which will impact water quality at the Murray Mouth region are the quality of the water arriving from upstream (source water) and density stratification. Closure or restriction of the Murray Mouth would result in the development of stratification which is a necessary physical condition for many hazards to eventuate, including blooms of toxic cyanobacteria, anoxia in the deepest water layer (hypolimnion) and nutrient release from sediment. Mouth closure is also likely to increase salinity, particularly in the Northern Lagoon, which is strongly influenced by source water from the River Murray.

Fish and Invertebrates

Mouth closure would have multiple effects on the plants and animals of the Coorong and Murray estuary. Not only would it largely prevent fish and other organisms from migrating between the Coorong and the sea (thereby affecting lifecycle processes), but sand deposited inside the Mouth would also smother the productive mudflats in the local area of the Mouth (affecting food resources and water quality for birds and fish).

Further, secondary consequences of Mouth closure relate to elevated salinities and possible reduced dissolved oxygen concentration in the Coorong. There would be reduced food availability and, with less suitable habitat for all species, predator-prey interactions would increase. The most severe effect would be seen if the Mouth remains closed for longer than a year.

Migratory Waders

There is sufficient evidence to show that under the current management regime the estuarine habitats in the Murray Mouth region are declining in area and quality, particularly as habitat for migratory waders.

Lack of adequate flows through the Murray Mouth leads to a series of changes, all of which erode the quality of the estuarine habitats for waders. For example, lack of flows allows coarse marine sands to be pushed into the estuary and these can interfere with the birds' foraging. Also, lack of flows leads to reductions in the intertidal zone around the shoreline, limiting suitable habitat which is then more likely to become eroded as birds concentrate and feed in a smaller area. Reductions in the volumes and changes in the frequency, timing and duration of releases of

Summary

water over the barrages clearly have the potential to erode habitat quality and feeding efficiency for migratory waders and other shorebirds.

Continuing to allow these estuarine habitats to deteriorate contravenes Australia's obligations under a series of international agreements, including the Ramsar Convention, JAMBA and CAMBA. Knowledge of natural systems remains limited, and this impedes management decisions, but there is adequate information to know that complete closure of the Murray Mouth will exacerbate the degradation.

Aquatic Plant Communities

Prior to River regulation, a rich diversity of plants was distributed across the floodplain, temporary wetlands and main channel. However, with the increase in water turbidity the aquatic flora is now restricted to the littoral zone. The lack of inundation of the floodplain, coupled with grazing and clearing, has also impacted upon plant biodiversity.

A consequence is severely depleted flora, weed invasion and a loss of biodiversity. If the Murray Mouth closed there would be an undesirable impact on plant communities allowing depauperate conditions to further reduce plant biodiversity.

Coastal Processes

Historically, the Mouth was mobile, moving along the coast depending on the wave, current and River flow climate. It is likely that sand accumulated in the Mouth during periods of low River flow, but that periodic flooding would have ejected significant quantities of sediment from the Mouth into the coastal zone.

The Murray Mouth is currently significantly restricted and is acting as a sink for sand which enters the Mouth from the coastal littoral system. The restriction in the supply of sand to the downdrift side of the Mouth, the Sir Richard Peninsula, is causing the Peninsula to erode and the Mouth to move steadily north-west.

If the Mouth became blocked with sand and closed, it would cease to absorb sand from the beach system and the littoral drift would continue along the beach uninterrupted. The scour and erosion-induced movement of Sir Richard Peninsula would stop, although aeolian (wind-blown) movement of sand would obviously continue, especially given that the erosion has exposed large areas of unvegetated dune to the elements.

What is Possible: Hydrology and Morphology

Low flows and their effect on the Murray Mouth are not recent phenomena. What has changed is the frequency at which the low flow events occur.

Techniques are available to estimate size and position of the Murray Mouth, and predict the likely pattern of future restriction.

To determine whether flows from the Lower Lakes over the barrages can be manipulated to optimise Mouth opening, two strategies have been evaluated:

1. an annual concentrated discharge designed to flush out excess material that has built up on the flood tidal delta over the previous 12 months, and
2. additional flows to lift the month by month releases in an attempt to prevent the influx of sediment through the Mouth.

Early results indicate that although both strategies should be effective, the option that attempts to maintain some outflow throughout the whole year appears more effective (based on the model developed by Walker to describe Mouth opening). This may be due to the fact that any flow from the River would tip the balance in the Mouth to a net outward flow that would assist in preventing sediment entering the inlet during a rising tide and assist in flushing during the ebb flows.

It can therefore be seen that options exist for maintaining flows over the barrages to prevent Mouth closure. The final solution, however, is likely to depend to a large extent on determining a viable pattern of releases from the Lower Lakes taking into account the health of the total River system.

Introduction

The Murray Mouth at the River Murray's end is a significant site to all Australians. The restriction at the Mouth and threat of complete closure continues with little understanding of the possible impacts. Recognising this, the Murray-Darling Basin Commission and the South Australian Department of Water, Land and Biodiversity Conservation commissioned papers from a range of experts and interests to explore the implications that Murray Mouth closure would have on:

- *o vegetation*
- *o fish and invertebrates*
- *o migratory waders*
- *o hydrology and morphology*
- *o the commercial fishing industry*
- *o water quality*
- *o coastal processes*
- *o indigenous culture*
- *o recreation and ecotourism*

Whilst these topics are not exhaustive, they go some way toward appreciating the range of perspectives and complexity of issues involved, and begin to highlight some imperatives and options for future management.

"Too much water has been diverted from the river system and not enough water now reaches the Lakes and Coorong. The quality of the water has also fallen. The water is cloudy, polluted and not fit for drinking. The Murray, the Lakes and the Coorong are no longer environmentally healthy and this is partly why the Ngarrindjeri people are not healthy. The Ngarrindjeri know that the Coorong, Lakes and River are dying."

Ngarrindjeri Ramsar Working Group (1999) 'Ngarrindjeri perspectives on Ramsar Issues' in Draft Coorong and Lakes Alexandrina and Albert Ramsar Management Plan, SA Department for Environment and Heritage.

The Murray

The River Murray terminates at the Southern Ocean, saving its most circuitous route to the very end of its journey where it passes through Lakes Alexandrina and Albert, the Murray estuary, the Coorong – a hypersaline coastal lagoon and, finally, the Murray Mouth (see page 86). This, in large part, accounts for both its unique ecological qualities, recognised internationally[1] , and the challenges it presents to those involved in managing the area.

However, current challenges have been further heightened by the way the Murray-Darling Basin has been managed over the past 100 years. River regulation and water diversions have dramatically reduced River flows and flood frequency, with flows at the Mouth down to 27% of the natural median flow. Since 1940, diversions from the River system have increased from approximately 3000GL per year to over 10 000GL per year. Also, barrages constructed at the Mouth to separate marine and freshwater habitats decreased the size of the estuary by 660km^2 and further interrupted tidal flows through the Mouth.

The accumulation of sediment at the Murray Mouth can therefore be seen as symptomatic of the condition of the entire Murray-Darling Basin.

The Mouth

The Murray Mouth is essentially a tidal inlet restricted by the accumulation of dune material on the flanking spits of Sir Richard Peninsula and Younghusband Peninsula (Bourman and Harvey 1983). It is located in a high-energy environment and is extremely dynamic.

The location, size and shape of the Mouth and the adjacent estuarine area are dictated by a combination of River flows, tidal flows and coastal and ocean processes. The Mouth has migrated in an east-west direction as a result of River droughts and floods and coastal events. Archaeological evidence indicates that the Mouth has travelled over a 6-8km width during the past 3000 years. Since recorded history, the Mouth has oscillated over a 2km stretch of beach. The rate of change can be dramatic – a single storm event in the early 1980s removed 800 000m^3 of sand from Sir Richard Peninsula.

However, the subtle changes are probably more important in the long-term. Large volumes of sand are continually being moved through the Mouth by daily tidal flows. Consequently, only a small change in the

[1] The Coorong Lagoon is listed as a RAMSAR wetland, and is protection under the Japan-Australia and China-Australia Migratory Agreements (Edyvane and Carvalho 1995).

Introduction

balance of the net amount of sand entering and remaining inside the Mouth can result in a substantial accumulation of sediment over time.

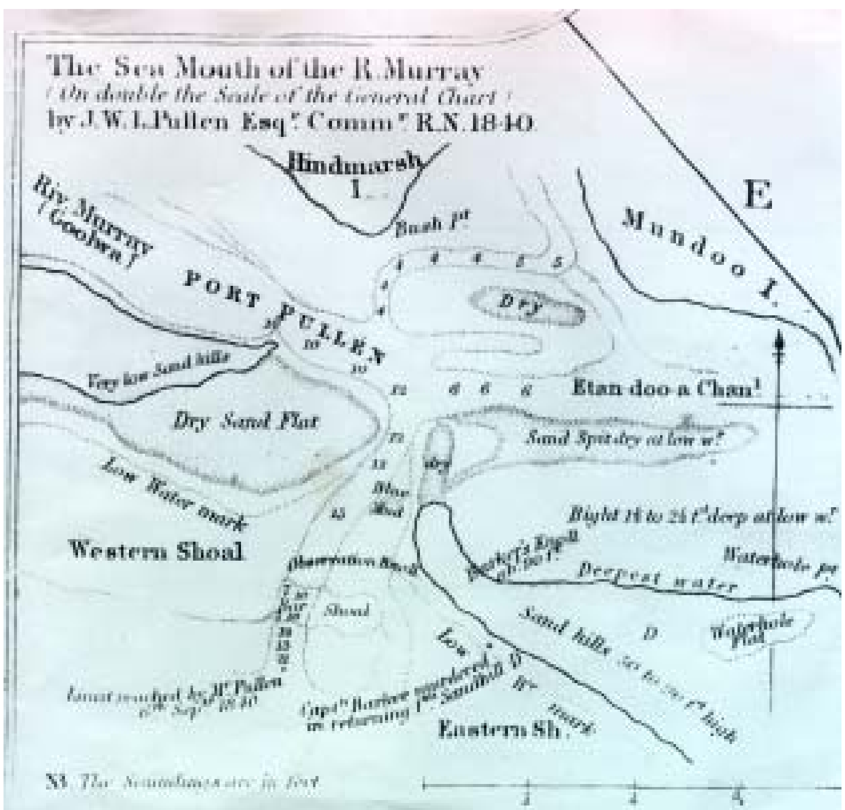
The capacity of the tidal flow to transport sand is dependent on two main factors - tidal velocity and wind and wave action in the immediate vicinity of the Mouth. Tidal velocity is determined by the tidal range, River flow over the barrages, and the existing water level in the estuary. Since the capacity of the tidal flow to transport sediment is a power function of the tidal velocity, even reasonably small River flows counteracting an incoming tide may result in a significant reduction in the sediment load carried.

There are now more frequent and longer periods of zero or very low River flows at the barrages. This flow is insufficient to counteract the incoming tidal flow, and is a significant factor in 'tipping the balance' towards increased deposition inside the Mouth, as has been evident over the past four years.

A Modest History

The River Murray Mouth has always been a dynamic and at times restricted opening into the Southern Ocean, with severe constrictions reported in 1914, during the 1920s and in 1939. Neither Flinders nor Baudin identified the Mouth when anchored in Encounter Bay in April 1802, presumably at a time when River flow was low. In February 1830, at the end of his trip down the River, Captain Charles Sturt commented that he was disappointed at the size of the Mouth.

During the years of River transport (1850s to 1920s), conditions at the Mouth were often not conducive to navigation, with shallow water, strong currents and large seas making boat passage difficult and dangerous. As early as 1856, Goyder (then Deputy Surveyor General) proposed modifications to improve navigability of the River Mouth. He recognised that the most direct route to the Mouth would maximise the possibility of scouring and suggested dredging and straightening Mundoo channel.



The Murray Mouth - 1840

Towards the end of an exceptionally dry period (1911 to 1914), it is understood that the Mouth became shallow enough to walk across. Local folklore suggests that the Mouth closed and was opened on the next high-tide by local fishermen using shovels. A similar story is told about the Mouth during the 1938-1939 drought. In 1981, the Murray Mouth closed for the first time in recorded history. A rapid accumulation of sediment at this time was attributed to unusually calm sea

Map supplied by MAPLAND, Environmental and Geographic Information, Department for Environment and Heritage.

conditions, a period of low high-tides and a lack of fluvial action (Bourman and Harvey 1983). On 6 May 1981, the Mouth was partially reopened by a high tide, but completely closed again by 14 May 1981. The additional flows required to open the Mouth were greater than the recorded 1956 flood flow levels (1.43m Lake level). The Mouth was artificially opened on the 15 July 1981 by the excavation of two channels (Bourman and Harvey 1983). Since this closure, concerns about restriction and possible closure of the Murray Mouth have been raised on a number of occasions.

Clearly, if earlier closures did occur, they were unlike the 1981 event when the sand bar that evolved across the Mouth was too large to remove with shovels. Differences between the rumoured 1914 and 1939 events and the closure in 1981 are to be expected.

Putting Current Conditions in Perspective

While a build-up of sand inside the Murray Mouth and reduced tidal flows is not a new phenomenon, the current situation is set apart by the duration and degree of sand build up, which is greater than ever previously reported. From analysis of the predicted flow conditions for the Mouth, it is evident that periods of severe constriction in the River estuary are likely to persist unless there is some deliberate intervention. Options for intervention are being investigated.

The ongoing threat of closure highlights the need to understand the potential impacts of this changed flow regime on the ecological health of the Coorong. This compilation seeks to explore these implications from a range of perspectives, and bring together current knowledge and concerns to inform and guide future management decisions.

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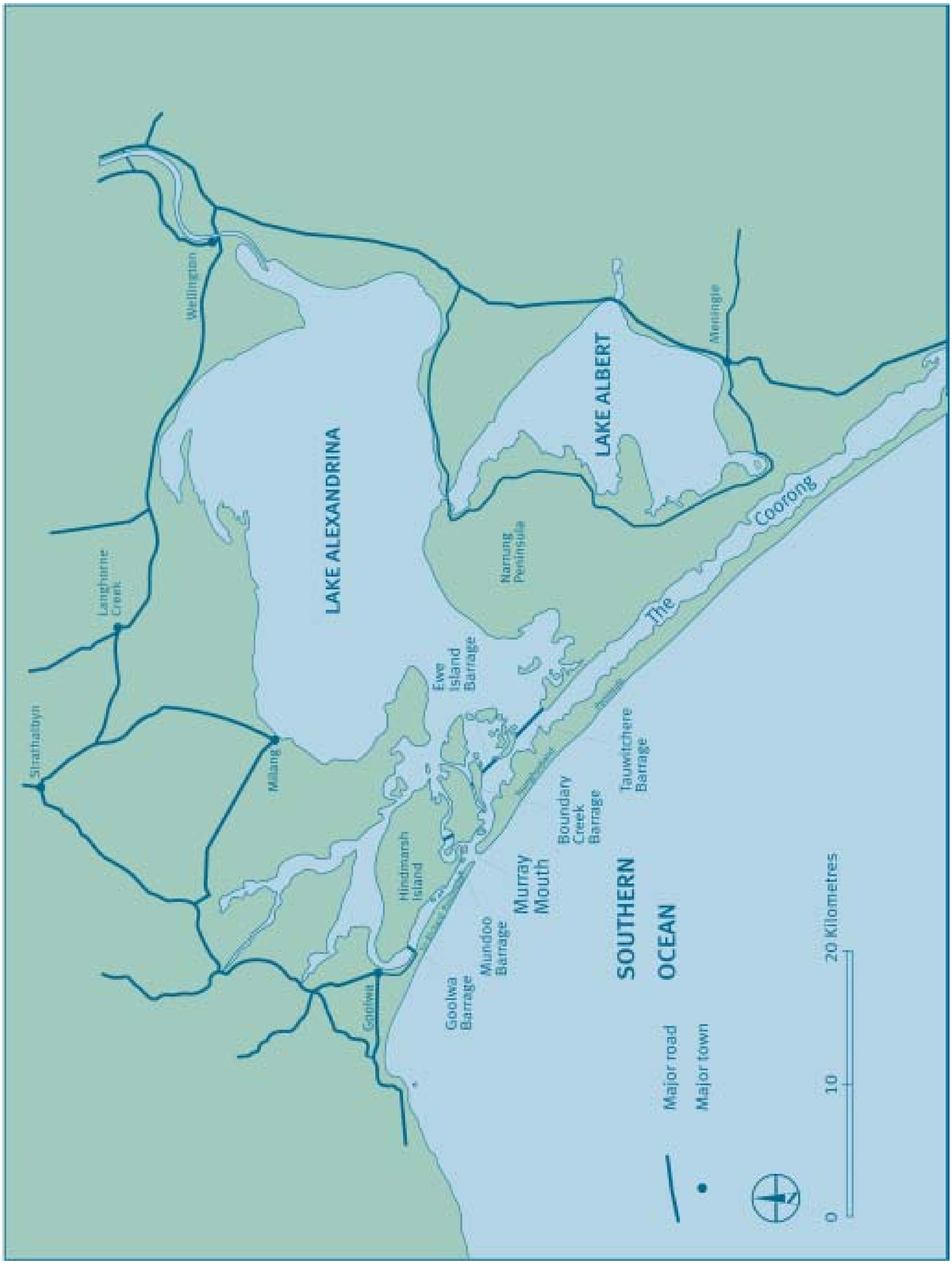
The Lower Lakes & Coorong



"The land and waters must be healthy for the Ngarrindjeri people to be healthy. We are hurting for our country…"

Steve Hemming, Australian Studies, Flinders University
Tom Trevorrow, Acting Chair, Ngarrindjeri Heritage Committee and Ngarrindjeri Land and Progress Association
Matt Rigney, Chair, Ngarrindjeri Native Title Management Committee

Ngarrindjeri Culture

STEVE HEMMING Australian Studies, Flinders University
TOM TREVORROW Acting Chair, Ngarrindjeri Heritage Committee and Ngarrindjeri Land and Progress Association
MATT RIGNEY Chair, Ngarrindjeri Native Title Management Committee

This chapter provides a preliminary Ngarrindjeri perspective on the effect that the closure of the Murray Mouth will have on the Ngarrindjeri people of the Lower Murray, Coorong and Lower Lakes area of South Australia. It is not a community perspective, but provides the views of two senior Ngarrindjeri men and includes relevant material that illustrates broader Ngarrindjeri community perspectives. In particular, it calls for a new, negotiated partnership to steer the management of this invaluable part of Ngarrindjeri country into the future and to ensure Ngarrindjeri survival on their lands.

Introduction

The Ngarrindjeri authors of this chapter strongly believe that a formal partnership should be established between the Ngarrindjeri people and the Murray-Darling Basin Commission (MDBC). This would be a major step on the path towards a future in which the Murray Mouth area remains healthy and the Lower Murray, Lower Lakes and Coorong continue to sustain and nurture the Ngarrindjeri people and their culture. As Tom Trevorrow points out at the beginning of this report, the closure of the Murray Mouth is an indicator that Ngarrindjeri survival is at stake.

Please note, this is not an exhaustive report and the reader's attention is drawn to the following chapter development discussion.

Chapter development discussion

Due to the restricted time-frame available for the development of this report, Tom Trevorrow and Matt Rigney, as senior Ngarrindjeri people and experienced leaders in their community, have made the decision to work with Steve Hemming (non-Indigenous researcher) to produce a preliminary discussion of the implications of the closure of the Murray Mouth for the Ngarrindjeri. They believe that it is vital that a statement introducing Ngarrindjeri perspectives be submitted to the next Murray-Darling Basin Ministerial Council meeting. Along with the views of Tom Trevorrow and Matt Rigney, this chapter also includes some reference to several key reports and publications providing Ngarrindjeri knowledge and perspectives relevant to this issue. In particular, the Ngarrindjeri Ramsar Working Group's

Photograph: Department of Water, Land and Biodiversity Conservation

Ngarrindjeri Culture

(NRWG) paper 'Ngarrindjeri perspective on Ramsar Issues', developed for the Coorong, Lake Alexandrina and Lake Albert Ramsar Management Plan, is considered of central importance (NRWG 1999). Importantly, this extended discussion of issues relevant to the closure of the Murray Mouth has Ngarrindjeri community endorsement.

The Ngarrindjeri authors of this report consider that their expertise in Ngarrindjeri cultural and political affairs, combined with the positions that they presently occupy, provide them with the responsibility to take this opportunity to identify a set of preliminary recommendations for the consideration of the Murray-Darling Basin Ministerial Council. They do not wish to discuss in any detail what are often defined as the 'cultural heritage' implications (often misunderstood by non-Indigenous people as relating only to the past) for the Ngarrindjeri. For example, this would include impacts on Dreaming sites and middens, or the spiritual significance of damage to the land and waters (see for example: Fergie 1994 and Bell 1998). Such a report would take considerable time and broad Ngarrindjeri community discussion. After their experiences with the Kumarangk (Hindmarsh Island) issue, the Ngarrindjeri authors believe that these issues are Ngarrindjeri business and should not be the starting point and basis of a public discussion of the implication of the closure of the Murray Mouth for Ngarrindjeri people.

Of course, Ngarrindjeri people support the sharing of their knowledge with non-Indigenous people, but this must be on Indigenous terms. Camp Coorong's Race Relations and Cultural Education Centre, near Meningie on the shores of Lake Albert, was established in the 1980s by the Ngarrindjeri Land and Progress Association (NLPA) to help perform this function (see Hemming 1993).

The recommendations provided in this report contain a request for sufficient resources to enable the Ngarrindjeri to stage appropriate community meetings to discuss the implications of the closure of the Murray Mouth and develop a detailed and thoughtful position. This is a complex problem for the Ngarrindjeri and it has a range of inter-related implications relating to political, economic, cultural and social issues. Ngarrindjeri interests in an area such as the Murray Mouth cannot be reduced to what is often called 'heritage'. The importance of the Ngarrindjeri relationship to the land and waters is made very clear by Tom Trevorrow at the beginning of this chapter.

Finally, as mentioned above, it should be recognised that this is by no means an exhaustive report: it seeks predominantly to draw the attention of the relevant Government Ministers to the urgent need for a new, negotiated, partnership between the Ngarrindjeri and the MDBC in the development of a long-term approach to the sustainable management of the Murray-Darling Basin.

Background

It has only been since the 1980s that the views and participation of Ngarrindjeri people have been considered important by State Government agencies in the planning and management of places such as national parks. The passing of the South Australian *Aboriginal Heritage Act 1988* was a turning point in the involvement of South Australian Indigenous people in issues associated with development, natural resource management and regional planning.

Ngarrindjeri organisations such as the Lower Murray and Ngarrindjeri Heritage Associations, the Lower Murray Nungas Club, the Raukkan Council and the Ngarrindjeri Land and Progress Association have worked with Government and private interests on a broad range of issues and projects. Unfortunately, the serious conflict over the building of a bridge to Kumarangk

(Hindmarsh Island) has in many ways adversely affected the positive relations that were built up between the Ngarrindjeri and the non-Indigenous community. The two Ngarrindjeri authors of this paper opposed the building of the bridge and continue to advocate the establishment of a ferry service to Kumarangk to provide alternative access to the Island for Ngarrindjeri people.

The Ngarrindjeri manage their country and its 'natural resources' in the ways taught to them by their old people. For example, fishing, hunting, the gathering of medicine plants and the harvesting of sedges for basket making are all governed by Ngarrindjeri tradition (Hemming *et al.* 1989, Bell 1998).

Ngarrindjeri people also engage in burning and clearing practices and re-vegetation of dunes to protect and manage their country. Often families have particular rights and responsibilities for certain areas. There are also gender restrictions associated with places, practices and knowledge. Prior to the 1980s, the Ngarrindjeri managed their country without significant Government recognition of their rights to engage in this process.

Since the 1980s, the Ngarrindjeri have accepted the challenge of working with Government organisations to educate the non-Indigenous public about their culture and traditions. The establishment of Camp Coorong has provided a major impetus in the teaching of Ngarrindjeri culture and history. One of the key themes that Camp Coorong staff has focussed on in their teaching has been the degradation of the environment of the area and the cultural consequences of this for Ngarrindjeri and non-Indigenous people. The new Ngarrindjeri ecotourism venture at Warnung (Hack's Point), whilst operating as an ecotourism venture, continues to have as its main messages the Ngarrindjeri connection with the land and waters and the impact of the continuing degradation of the environment on Ngarrindjeri culture. As pointed out in the NRWG's submission (NRWG 1999):

> *Too much water has been diverted from the River system and not enough water now reaches the Lakes and Coorong. The quality of the water has also fallen. The water is cloudy, polluted and not fit for drinking. The Murray, the Lakes and the Coorong are no longer environmentally healthy and this is partly why the Ngarrindjeri people are not healthy. The Ngarrindjeri know that the Coorong, Lakes and River are dying.*

It should also be remembered that the Ngarrindjeri people's native title claim, which includes the Murray Mouth area, has been registered in the Federal Court. This provides certain legal obligations to consult with the Ngarrindjeri through their Ngarrindjeri Native Title Management Committee. Damage to Ngarrindjeri native title rights and interests is potentially a subject for compensation.

The South Australian *Aboriginal Heritage Act 1988* is also relevant to the implications of Murray Mouth closure. An important Ngarrindjeri site is being damaged through a complex series of actions that continue to lead to increasing environmental degradation. The authors of this paper recognise that the only real solution to this problem is through long-term planning. This planning must be done in partnership with the Ngarrindjeri.

Ngarrindjeri Culture

Ngarrindjeri Perspectives On Ramsar Issues

A significant part of the Ngarrindjeri lands and waters is designated as a wetland of international significance under the Ramsar Agreement.

The Indigenous owners of these wetlands, which include the Murray Mouth area, have a fundamental role to play in their sustainable management. In their submission to the Ramsar management plan, the NRWG supported the principles of 'wise' and 'sustainable' use of the wetlands (NRWG 1999). This is what Ngarrindjeri have been doing since the creation of their land and waters.

One of the six objectives identified in the Ramsar management plan highlights the need for 'increased opportunities for participation by the Ngarrindjeri people in the planning and management of the Coorong and Lower Lakes Ramsar Wetlands subject to South Australian Government policy relating to the resolution of native title claims' (Department for Environment, Heritage and Aboriginal Affairs 2000a). The Ngarrindjeri people have, in numerous forums, expressed their desire for a central role in the management of their land and waters - not the least through the lodgement of their native title claim which includes the Murray Mouth area. The Ngarrindjeri authors of this report would like to see a hand-back of the Coorong National Park, with a lease-back agreement and joint management with the agency responsible for national parks. They believe that the Ngarrindjeri native title claim should not be an impediment to the development of formal agreements regarding joint management.

The consultative process developed for Ngarrindjeri input into the Ramsar management plan has been identified by Ngarrindjeri people, and more broadly, as an example of appropriate consultation (see Thomsen 2001). The Ngarrindjeri authors of this report believe that the NRWG's submission should be treated as a starting point for discussions with the Ngarrindjeri concerning the implications of Murray Mouth closure (NRWG 1999).

The following are some of the relevant statements and recommendations contained in the submission:

- Ngarrindjeri people strongly support the Ramsar principles and objectives.
- The production and implementation of a Ramsar Plan provides an opportunity for reconciliation.
- Ngarrindjeri seek a more valuable role in the future management of the natural and cultural resources contained within the Ramsar planning area. Ngarrindjeri believe such a role would be beneficial to all members of the community, not just the Ngarrindjeri.
- Ngarrindjeri support moves aimed at increasing water flows and water quality for environmental purposes.
- More water should be made available to reach the Lower Lakes and Coorong. This water will help to support all life and nourish Ngarrindjeri country, Ngarrindjeri culture and Ngarrindjeri people.
- The quality of the water should be improved.
- The Upper Southeast Drainage Scheme's waters should be added to the Coorong at Salt Creek. Many Ngarrindjeri Elders can remember freshwater flows into the Coorong during the late 1950s and believe these flows brought new life to the southern lagoon.

> The Ngarrindjeri lands- in particular the River, the Lakes and the Coorong are crucial for the survival of the Ngarrindjeri people. They have a spiritual and religious connection with the land and the living things associated with it. The fish, birds and other living things are the Ngartjis (totems) of the Ngarrindjeri people. Many Ngarrindjeri people have a strong spiritual connection to their Ngartjis and a responsibility to protect them. Without their Njartjis they believe they cannot survive.
>
> (Ngarrindjeri Ramsar Working Group 1999).

- o The manipulation of the barrages and the manipulation of Lake levels to improve natural environmental processes is supported by Ngarrindjeri, particularly if this is in association with increased water flows and an improvement in water quality.

It was very disappointing to the Ngarrindjeri that the NRWG submission was not included in the final report or even its appendices - as initially expected.

Discussion

The Murray Mouth is an important cultural and spiritual place for the Ngarrindjeri people (see for example: Bell 1998). It is part of an area that is fundamentally important to the health of Ngarrindjeri people. There are Dreaming stories such as Thukabi, Ngurunderi and the Seven Sisters associated with the Murray Mouth area that informs the Ngarrindjeri people's understanding of its significance. The relationship of the Dreaming ancestor Ngurunderi to the area has for example been the subject of publications, museum exhibitions and films (see Hemming *et al.* 1989, Bell 1998). The Murray Mouth area is also a part of the 'meeting of the waters', a place where the mixing of the waters is spiritually very important to the Ngarrindjeri (Bell 1998: 563).

The NRWG (1999) makes the following point about the area's cultural and spiritual significance:

> *The waters flowing down the Murray-Darling system bring life to the River, the Lakes and Coorong. The waters bring life to the Ngarrindjeri too. This is both a practical and a spiritual statement. There are extensive culturally significant teachings explaining how the Ngarrindjeri world was created. Ngurunderi and the Seven Sisters are two of many teachings which describe how the land and water, animals and people came to be what and who they are.*

The threat to Ngarrindjeri Ngartjis connected with the closure of the Murray Mouth is of particular concern to the Ngarrindjeri. As stated by the NRWG (1999):

> *Many Ngarrindjeri people still retain a special relationship with specific wildlife species occurring within the planning area. This totemic relationship is deeply embedded in Ngarrindjeri culture and spirituality. Many Ngarrindjeri people have their own Ngartji or special friend. This association with wildlife provides a special perspective on Ramsar values and the maintenance of habitats.*

Importantly for this report, it is often not understood that the Ngarrindjeri have few resources and little infrastructure to respond to the growing pressures on them from a wide range of Government departments and agencies. To properly engage in the process of 'natural resource' management the Ngarrindjeri need substantial resources and infrastructure. A considerable portion of what the Ngarrindjeri do as part of their 'responsibilities', as a result of heritage and native title legislation, is still largely voluntary. This creates enormous pressures on individuals, families and communities and significantly adds to community stress and general poor health. The decision to take part in the development of this report has posed

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serious difficulties and created considerable stress for its Ngarrindjeri authors. The short time-frame and lack of resources has not enabled broad community consultation, placing the authors in the difficult position of having to explain and justify their decisions and involvement in the report process to the broader Ngarrindjeri community.

This highlights the urgent need for Governments to recognise the funding needs of the Ngarrindjeri to further develop relevant expertise and appropriate infrastructure to assist their effective contribution to the long-term management of their lands and waters.

The growing environmental degradation of the Murray-Darling Basin and the threatened, continuing closure of the Murray Mouth, has already, and will continue to place enormous pressure on the Ngarrindjeri community. Along with the impact of the loss of lands, waters, Ngartjis and other 'environmental' features comes an imposed, inappropriate approach to involving Ngarrindjeri people in the management of their lands and waters. All of these factors cause considerable cultural trauma for the Ngarrindjeri.

Conclusion

The Murray-Darling Basin Sustainability Plan states that 'natural resources management in the Basin requires', along with several other key points, the 'recognition of the rights and aspirations of Indigenous Australians' (Murray-Darling Basin Commission 1999). Along with the broader issues raised by this report, this also requires careful consideration of the implications of the Ngarrindjeri native title claim and Ngarrindjeri heritage interests over the Lower Murray, Lower Lakes and Coorong for the management of the area. A number of recently developed plans have recognised the importance of the Ngarrindjeri people's role in the management and planning process (see for examples: Department for Environment, Heritage and Aboriginal Affairs 2000a and 2000b, and Alexandrina Council 2001). For example, the Hindmarsh Island Management Plan raises the need for 'protocols to involve the Aboriginal Community in management decisions' (Alexandrina Council 2001).

The urgent need for government bodies such as the MDBC to negotiate an appropriate process enabling Ngarrindjeri to have a central role in managing their land and waters is highlighted in the following passage by the NRWG (1999):

> *The sense of feeling, sense of belonging, sense of responsibility for the River, Lakes and Coorong experienced by Ngarrindjeri people has survived occupation, dispersal and attempted assimilation. It continues to exist irrespective of where Ngarrindjeri people currently live. The link with the land lies at the heart and soul of Ngarrindjeri culture. A proper relationship and role in management of the land is a fundamental platform in building and maintaining Ngarrindjeri culture and Ngarrindjeri self respect. Ngarrindjeri believe that their future involvement in the management of the land would be positive and beneficial to all members of the community, not just Ngarrindjeri. It would represent a significant step in the process of reconciliation and co-existence. The strengthening of Ngarrindjeri people and their culture requires a serious involvement in the managing of their traditional lands.*

To begin to address the implications of the closure of the Murray Mouth for the Ngarrindjeri the following recommendations need to be seriously considered by the MDB Ministerial Council.

Key points

- The Ngarrindjeri are culturally and spiritually part of the Murray Mouth area and the Lower Murray, Lakes and Coorong region. The value and uniqueness of Ngarrindjeri knowledge, beliefs and culture must be valued, recognised and respected by the MDBC and the wider community for the well-being and health of the Ngarrindjeri people and their land and waters to be assured.
- The value of Ngarrindjeri cultural and spiritual knowledge to the MDB planning and management process must be recognised and where culturally appropriate, respectfully utilized.
- Funds are required to enable Ngarrrindjeri communities to meet, discuss and develop a long-term strategy for maintaining the health of their lands and waters - including the Murray Mouth area.
- A formal agreement and long-term process should be developed between the Ngarrindjeri and the MDBC to secure a healthy future for Ngarrindjeri people, their lands and waters.
- Dredging of the Murray Mouth and surrounding areas is considered culturally inappropriate. The Ngarrindjeri authors of this report believe any short-term fix will have dire consequences for the Murray Mouth area. Proper and appropriate planning must take place. This sentiment has been expressed widely by Ngarrindjeri people. Recommendations were made during Ramsar consultations that broad Ngarrindjeri community negotiations and discussions should be undertaken to determine the issues associated with any dredging in the area. The problem lies not at the Mouth - it exists at many other places throughout the River system.
- We recommend the NRWG's submission to the Coorong, Lake Albert and Lake Alexandrina Ramsar Management Plan (NRWG 1999) as a valuable extended discussion of issues relevant to the impact of the closure of the Murray Mouth on the Ngarrindjeri. This submission was endorsed by the Ngarrindjeri community.

We believe that it is in the best interests of all Australians to work closely with the Ngarrindjeri and other Indigenous groups to plan and secure a healthy future for the Murray-Darling Basin.

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"Many fish species depend on movement from the ocean into the estuary and freshwater Lower Lakes for reproduction and recruitment."

Garry Hera-Singh, Southern Fisherman's Association

Fishing Industry

GARRY HERA-SINGH Southern Fisherman's Association

If the passage for fish between the sea, Lower Lakes and estuary is prevented by closure of the Murray Mouth, several economically important fish species will decline.

This chapter outlines the Southern Fisherman's Associations' opinion on the expected implications of Mouth closure on major commercial and recreational fish species in the Coorong region and marine fisheries.

Introduction

Closure of the Murray Mouth would have a significant impact on the fishing industry in the Coorong. With the construction of the barrages, altered tidal regime of the Murray estuary and modified River flow, the threat of Murray Mouth closure has increased. Many fish species depend on movement from the ocean into the estuary and freshwater Lower Lakes for reproduction and recruitment.

Key species are Mulloway, Goolwa Cockles, Black Bream, Greenback Flounder and Yellow-Eye Mullet.

Mulloway (*Argyrosomus japonicus*)

This species breeds at sea. Mulloway one-year and older are attracted to the Coorong by freshwater flows leaving the Murray Mouth. They utilize the Coorong as an area to gain condition in preparation for spawning elsewhere. However, access to the region is not essential for their survival.

Regardless of Murray Mouth closure, Mulloway breeding and development will continue offshore. Hence the Mulloway fishery is not in danger from a likely Mouth closure.

Part of the harvest of Mulloway is undertaken off the ocean beaches in the vicinity of the Murray Mouth. Lack of flows through the Mouth will not attract these fish inshore sufficiently close for them to be accessible to recreational and commercial fishers. A reduced catch-per-unit-effort in these sectors does not necessarily mean that the stock has declined as previous perceptions have implied, but local commercial fishers will suffer significant economic loss and recreational fishers will suffer greatly reduced opportunities.

Photograph: Department of Water, Land and Biodiversity Conservation

Fishing Industry

Goolwa Cockles (*Donax deltoides*)
Cockle stocks are dependent on River Murray outflows during spring for strong recruitment and subsequent growth.

The cockles inhabit the beaches along the Coorong and are harvested in their second year of growth. If not harvested, they live for an average of four years.

Adult cockles are not directly impacted by Murray Mouth closure. However, recruitment is immediately impacted by reduced availability of nutrients, which in turn would lead to an increased rate of juvenile mortality. Worldwide, cockle populations have regularly declined following over harvest during certain periods and the species often fail to rapidly rebound when more favourable conditions eventuate.

The Goolwa cockle population in the Coorong region is the largest in the world and is protected from over harvest by restricting fishers to manual harvesting methods.

Black Bream (*Acanthopagrus butcheri*) and Greenback Flounder (*Rhombosolea taparina*)
These estuarine species live and reproduce in the Coorong. Breeding success is dependent on a smooth and consistent flow of freshwater into the Coorong.

Currently, stocks of Black Bream and Greenback Flounder are well below optimal levels. This is being mitigated, however, through revised barrage operations (by allowing for the slower release of freshwater into the estuary).

Although closure of the Murray Mouth would not have a significant impact on these species, changes in the Coorong habitat and a prolonged no flow regime will directly affect fish recruitment and growth with flow on effects to commercial and recreational fishers.

Yellow-Eye Mullet (*Aldrichetta forsteri*)
This species is extremely abundant in the Coorong. Current Yellow-Eye Mullet stocks would survive through a prolonged Murray Mouth closure.

If the summers are hot and evaporative losses are higher than average, there is potential for very large fish kills to occur due to low oxygen.

This would destroy Yellow-Eye Mullet stocks in the Coorong. (Yellow-Eye Mullet currently make up about 50% by weight of the current commercial Coorong catch.)

Other Species
Coorong crabs (Mottled Shore Crab *Carcinus maenas*), a key bio-indicator of the Coorong, would be reduced should the duration of a Murray Mouth closure extend beyond one summer.

Fish species, such as the Small-Mouthed Hardy Head (*Atherinosmoa microstoma*), would benefit through a reduction in predators entering the Coorong via the Murray Mouth (for example, Mulloway). The increase in these species, however, would have no beneficial impact on the fishing industry.

Other marine species which occur in the Coorong as vagrants (for example, Tommy Ruffs *Arripis georgianus*, Australian Salmon *Arripis trutta*, most species of Shark and Gurnards) will be denied access, but these are neither commercially nor recreationally important.

Discussion

The likely period for closure of the Murray Mouth would be following summer. If closure occurred during the cooler months and only extended over the following four to six months, impacts on fish stock survival would be minimal. The abundance of all species would be significantly reduced due to lack of natural migration between the ocean and the Coorong.

If, however, the closure was prolonged and included the following summer, or even extended for several years, the fishing industry would experience fish loss, threatening the economic viability of the commercial fishery[2] and creating an environment in which a recreational fishery cannot be carried.

Habitat impacts related to the fishery are also important to consider. Closure will likely occur during autumn. There is potential, however, for low oxygen kills related to algal blooms associated with warm, still, high nutrient water if Murray Mouth closure continued until the following summer. Closure during warmer months, would trigger fish kills over sand flats and shallow bays in the early hours of the morning after several hot, still days. If oxygen levels in nearby channels remain suitable for fish (that is, above 1-2ppm), this will not be of major concern.

Long periods of hot weather (greater than two weeks) would increase the probability of oxygen levels declining below survival levels of 1-2ppm. This would be a major concern to fish stocks.

The majority of the Northern Lagoon of the Coorong is likely to become hypersaline with an extended Mouth closure. The estuary region adjacent to the barrages would be less affected due to leakage of freshwater through the barrage network and adjoining islands (causeways).

[2] The commercial fishery involves 37 fishers employing approximately 110 people with a landed wholesale value of approximately $5.5 million per annum

Conclusion

As can be seen from the above discussion, closure of the Murray Mouth brings with it the possibility of the existing commercial fishery becoming uneconomic and recreational fishing also having to decline.

It is very unclear, if there is a long-term closure (several seasons) and major fish kills, how many years it would take for the fishing industry to recover.

"The Murray Mouth and the Coorong are unique, almost iconic sites…"

Freya Higgins-Desbiolles, School of International Business, University of South Australia
Glen Jones, Boating Industry Association of South Australia

Recreation & Tourism

Freya Higgins-Desbiolles School of International Business, University of South Australia
Glen Jones Boating Industry Association of South Australia

This chapter assesses the likely impacts that the closure of the Murray Mouth would have on the tourism and recreation industries of the Coorong and Lower Lakes area of South Australia as well as addressing the significance of the area from a variety of perspectives.

The importance of the Murray Mouth to the tourism and recreation industries should not be underestimated and requires appropriate management strategies.

Introduction

Much of the Coorong and Lower Lakes areas are designated as a wetland of international significance under the Ramsar Agreement. Tourism and recreational users are allowed access under the principle of 'wise use' which refers to "… their sustainable utilisation for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem" (Department of Environment and Heritage 2000).

This area is one of the most important tourism and recreation resources to the people of the Adelaide metropolitan area because of its unique natural beauty and proximity to the city (Berggy and Gilliland 1998).

To assess the perceived impacts of Murray Mouth closure on recreational and tourism stakeholders in the area, two meetings were convened in which a cross section of interested parties were invited to comment on perceptions of the relevant issues under consideration. Where particular stakeholders could not attend such meetings, they were consulted separately as required. Other information was gathered from published materials and is included in the reference list at the end of this chapter.

In considering implications of the closure of the Murray Mouth, the two important issues are the duration of the closure and the frequency of closures.

In 1981, for the first recorded time since European settlement, the Mouth closed completely for 17 weeks. However, it appears that when discussion is focused on the 'closure of the Mouth', it is often not well understood that the 'plug' that blocks the Mouth is not necessarily located right in the Mouth itself. For instance, the 'plug' that existed at the end of 2000, was a large area of drift sand on the inside of the Mouth which barred access from the Goolwa Lock, past the Mouth and on into the Coorong and vice versa.

When the Mouth is silted in this way, recreational and commercial boating access from the Goolwa area to the Coorong (and vice versa) must be via the hand operated Tauwitchere Lock.

Photograph: Department of Water, Land and Biodiversity Conservation

Recreation & Tourism

In 2001/2002, the Mouth silted up early in the spring/summer season. This is raising grave concerns because this situation may not change until significant rainfall occurs upstream at the top of the catchment. This silting will seriously impede recreational and commercial boating activities in the Goolwa, Murray Mouth and Coorong areas to the detriment of the regional economy. (See 'What is Possible: Hydrology and Morphology' chapter for further discussion on land form changes.)

With significant national tourism events[3] increasingly staged in the area, the implications of closure are being more widely recognised than at any time in the past.

Importance of the ecological character

While the various stakeholders consulted as part of this study have particular concerns, the majority of recreational and tourism users also have something in common – they are attracted to the area by its ecological attributes.

When the Mouth closes for a significant period, resulting in a severe decline in water quality, the attendant problems of smelly mudflats and degradation in the visual panorama will deter visits by ecotourists who are searching for pristine environments.

Birdwatchers will follow the waders to better wetlands, and recreational boaters and fishers who cannot find convenient passage between the Goolwa and Coorong channels are likely to leave for destinations 'upriver'.

Closure of the Mouth has been identified as one of the significant threats of concern during the community consultation process in the formulation of the Coorong National Park Tourism and Recreation Plan (National Parks and Wildlife SA 1999:25).

Recreational users

Recreational Fishing

Recreational fishing is important to the economy of the region. However, the value is difficult to quantify (pers comm. Hera-Singh).

It is estimated that recreational fishing on the River Murray contributes $400 million per year to the South Australian economy (Murray-Darling Association 2001). The region around the Mouth is important for recreational fishing due to the variety of fish that feed and breed in the area and the unique scenery to be found there.

Recreational fishers can use four-wheel drive vehicles or watercraft to reach the less accessible parts of the area, such as the Younghusband Peninsula, or use beaches and boat ramps at accessible points like Sugars Beach. However, the most popular area for recreational fishers tends to be that between the Mouth and Pelican Point and the most popular catches are Yellow-Eye Mullet and Mulloway (Kluske 1996).

Mouth closure has the potential to adversely affect recreational fishing in the area. When the Mouth silts up for a significant period, the water quality is degraded due to restricted flow of water through the Mouth causing the gradual heating up of shallow trapped water that can result in fish deaths and negative impacts on breeding patterns.

For more detail on the likely impacts for recreational fishers, see the 'Fishing Industry' chapter.

Recreational Boaters

The Coorong and Lower Lakes area is significant for recreational boating, offering over 800km^2 of 'boating opportunities'. The

[3] Such as the celebration in February 2001 when Tammy van Wisse reached the Mouth following her epic swim of the entire length of the River Murray, the "Source to Sea" Bicentennial Boating Event October 2001, and the launch of the International Year of Ecotourism 2002.

types of craft used in the area include powerboats, sailboats, jet skis and canoes. Some of the activities associated with recreational boating conducted in the area include water skiing and fishing.

The peak industry body for recreational and light commercial boating in South Australia, the Boating Industry Association of South Australia Inc. (BIASA), estimates that the number of trailerable watercraft in regular use in the area to be not less than 6000 (January 2001 Transport SA Survey). Total boat use is estimated at 120 000 user days per annum. Extrapolating from an estimate by BIASA of $40 per day average spending on consumables such as food, drink and fuel, this could equate to nearly $5 million being injected into the local economy annually from the boating industry alone.

Recreational boats operating in the area that are not trailerable (often by virtue of their size), number approximately 800 (March 2001 BIASA Survey). Average sized boats provide accommodation for four persons. Extrapolating from BIASA's estimate of $40 per day average spending on consumables referred to above, this could equate to a further (nearly) $3 million annually from the boating industry.

Significant boating events are also important tourism and recreational attractions to the area, including the Goolwa-Meningie Yacht Race (SA), Milang Goolwa Freshwater Classic and South Australia's Wooden Boat Festival at Goolwa.

Boating Statistics

- Taking into account 'all boats' (trailerable and non trailerable) in terms of visitation/recreation days spent in the Murray/Lower Lakes and Coorong system in South Australia, the Australian Bureau of Statistics estimates that 12.6% of South Australians are regularly involved in boating activities (in excess of 130 000 people).

- Nearly 700 000 leisure days or 'holiday days' are enjoyed, annually, on board boats which are moored in inland waters (River Murray, Lakes and Coorong) annually. This visitation involves fuelling, servicing of craft, catering, purchase of other supplies, gas, ice, fishing tackle, food and drinks and delivers an enormous economic benefit to the regional communities located en-route to, and on, the waterway. Of these 'holiday days', 170 000 are via the house boat industry and another 175 000 'holiday days' are contributed by more traditional types of craft, normally single hulled (including yachts and cruisers etc which are moored).

- Trailerable boats also provide live-aboard accommodation and deliver significant economic benefit to the communities en-route to, or on, the waterways.

Infrastructure development is occurring which will encourage further recreational boating use of the area, including the continued expansion of Hindmarsh Island Marina in 2002 and a $4 million Goolwa Wharf Precinct redevelopment project being undertaken by Alexandrina Council in 2002.

The silting up of the Murray Mouth has major implications for recreational boaters. The silting up of channels can block access between the Goolwa channel and the rest of the Coorong making boat passage extremely difficult.

Safety concerns are also significant. Boaters may be unaware that a channel previously open has become impassable overnight and can end up in grave difficulty. Furthermore, when the Mouth closes, the Marine Safety Officers, Fisheries Inspectors and other regulatory personnel cannot patrol their assigned areas and therefore are unable to carry out marine safety and associated regulatory checks on boaters using the area (pers comm. Neville Clifford).

Recreational boaters are drawn to the area to enjoy the opportunities and beauty of the Murray Mouth and the Coorong National Park. Recreational stakeholders consulted indicated that many of these people would permanently move 'upriver' should a Mouth closure prevent their free passage through the Coorong waterways. Therefore, other tourism regions such as the Murraylands might benefit at the expense of those 'down river'.

Birdwatchers

The wetlands of the Coorong and Lower Lakes attract some 85 species of waterbirds, ranking as one of the most significant five or six waterbird sites in the country (amongst the top handful in the world). Access to this area is therefore highly valued by birdwatchers (Murray-Darling Association 2001).

Mouth closure and reduced River flows would diminish the productivity of the estuarine

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waters, reducing their habitat value. Many waders would be forced to either leave for more amenable wetlands or die out (Department of Environment and Heritage 2000: 17).

The decline of migratory waders is of concern to committed environmentalists, birdwatchers and others (see 'Migratory Waders' chapter).

From a tourism perspective, research by the South Australian Tourism Commission (SATC) identified bird watching as one of the more lucrative tourism markets to pursue (South Australian Tourism Commission 2001). If birds are forced to leave the Coorong due to the impacts of Mouth closure, the tourism impacts would be significant.

Bush Walkers

Many visitors to the area enjoy the scenic beauty by using designated walking trails such as the Murray Mouth walk on the Sir Richard Peninsula.

Mouth closure might serve as an added attraction to bush walkers because it would invite viewing and areas previously inaccessible to walkers could become temporarily accessible. For example, walkers may be able to cross from Hindmarsh Island's Sugars Beach to the Mouth and between the Sir Richard and Younghusband peninsulas. Additional management may be needed to address potential impacts.

Four-Wheel Drive Users

Four-wheel drive enthusiasts are common visitors to the areas of the Sir Richard Peninsula and Younghusband Peninsula, which are located on either side of the Murray Mouth. Their vehicles are allowed access through designated tracks and under certain regulations. The representative body, the South Australian Association of Four Wheel Drive Clubs, does not see the issue of closure of the Mouth as a concern for their members because regulations enforced by the National Parks and Wildlife Officers in the region will come in force when the Mouth closes. Namely, four-wheel drive vehicles will be prohibited from using Mouth closure as an opportunity to cross between the Sir Richard and Younghusband peninsulas as an issue of safety (pers comm. Don Ransom).

Tourism

Tourism to this area is of growing importance as evidenced by the South Australian Tourism Commission's (SATC) 'Australian launch' of the International Year of Ecotourism 2002 in the Coorong National Park. In particular, because of the attractions of the Coorong National Park, this area is seen as ideal for nature-based and ecotourism promotion which is a lucrative niche market that is in high demand and provides high yield.

Tourism data specific to the location that would be impacted by changes in the Murray Mouth is not available making it difficult to ascertain quantitatively how valuable tourism is to the area. Data for the Coorong National Park provides some insight. In 2000/2001, 106 200 people visited the Park (SATC 2000/2001), the third highest number of visitors (after the Flinders Ranges and Innes-Yorke Peninsula national parks) of all of South Australia's non-metropolitan parks.

Coorong National Park

The South Australian Government has formulated a Parks Agenda in consultation with the community to provide a framework for the management of South Australia's natural resources.

Key elements of the Parks Agenda include:

- to create a representative and professionally managed parks and wildlife system
- to encourage an understanding, supportive and active community committed to its parks
- to deliver quality services which actively promote the conservation ethic, and
- to promote sustainable business opportunities (The Parks Agenda 1997:4).

The Parks Agenda also provides a "valuable framework for guiding the planning and development of visitor services within the Coorong National Park". Initiatives towards this include:

- a review of standards for parks visitor infrastructure and a strategic upgrade of facilities for key parks
- the systematic collection and evaluation of quantitative and qualitative visitor data to assess trends for visitor numbers and levels of satisfaction
- a review of standards for the delivery of information and interpretation services and monitoring performance against benchmarks
- the preparation of a marketing plan in consultation with the tourism industry
- the adoption of a client-oriented approach to service delivery
- the application of 'best practice' in the delivery of visitor services and the maintenance of quality standards by a regular review in consultation with other agencies
- the strengthening of our [National Parks and Wildlife SA] relationship with the tourism industry by joining and actively participating in industry groups and Regional Tourism Boards (The Parks Agenda 1997: 14-15).

Other Regions

Three tourism regions have an interest in the area:

- Fleurieu Peninsula Region, which encompasses the important tourist centre of Goolwa
- Limestone Coast Region (formerly known as the South East Region),which recently expanded to include the Coorong in its marketing campaigns, and
- Murraylands Region, which views the Coorong National Park as a key asset for attracting visitors.

Alexandrina Council in its recent Management Plan for Hindmarsh Island calls for the development of tourism in the immediate area of the Murray Mouth, including infrastructure to cater for large tour buses and their passengers and an interpretive centre near Sugars Beach on Hindmarsh Island (Day 2001).

Also important is the purchase of the Wyngate property by the South Australian and Commonwealth governments, which includes 1081 hectares of south-eastern Hindmarsh Island (opposite the Murray Mouth). Reasons underpinning the purchase are diverse, ranging from assisting the Save the Murray program, protecting wetlands and incorporating the Murray Mouth islands into the Coorong National Park. According to a Department for Environment and Heritage publication, enhancing South Australian ecotourism to the Mouth is also a significant motivation (Department for Environment and Heritage 2001).

Additionally, the Marina Hindmarsh Island development has the potential to boost tourism with plans to become the largest such development in the southern hemisphere, with over 1000 residential properties, 1100 berths, four-star resort, yacht club, tavern and retail facilities.

Finally, the South Australian Tourism Commission has focused considerable energy on promoting the nature-based attractions of South Australia[4]. The Murray Mouth and the Coorong are unique, iconic sites and serve to differentiate South Australia from its competition. As a result, the SATC's upcoming review of the State Tourism Plan 2001-2006 will have the Coorong as an important focus of promotion (pers comm. Leanne Muffet).

Ngarrindjeri Tourism

Many Ngarrindjeri are ambivalent about tourism's impacts because of the long history of being the subject of the tourists' 'gaze' and conflicts such as the Hindmarsh Island bridge controversy (see 'Ngarrindjeri Culture' chapter).

[4] See SATC brochure "South Australian Nature", 2002.

Recreation & Tourism

However, the potential for Ngarrindjeri contributions to enhance the tourism product of the area is well recognised and is evident in many documents and plans (see National Parks and Wildlife 1999 and Day 2001). Current involvement in tourism in the area includes two particularly significant ventures:

- Camp Coorong's Race Relations and Cultural Education Centre, located 10km south of Meningie, teaches about the environmental changes the Coorong has undergone from human impact. It has been featured in several important national tourism publications such as *A Talent for Tourism* (1996), and has received a number of tourism awards.
- Coorong Wilderness Lodge, located at Hack's Peninsula on the Coorong, receives visits from organised tourist groups and individual motorists on the Melbourne to Adelaide circuit.

Both of these ventures rely on the environment for the services they provide.

Environmental degradation will jeopardise the bush tucker and bush medicine walks offered, endanger the rushes required for the basket-weaving workshops and diminish the drawing power of their environmental education programs.

Also important to note, the Ngarrindjeri hold a registered Native Title claim to this area as of January 2000. This predicates specific legal obligations in any matters such as tourism development that subsequently effects this area.

Conclusion

While closure of the Murray Mouth might be an initial attraction, as tourists and visitors are drawn to see what is still a relatively unusual phenomenon, this impact would be short-lived and yield little immediate or ongoing economic value to the economy. There is little doubt among tourism stakeholders that in the longer term, the negative impacts would be significant, particularly for Goolwa, which is promoted as a gateway to the Coorong and the Mouth.

Tourism operators who conduct boat tours in the area will be directly affected by closure of the Mouth, but there are also many others that will feel the effects including: marinas, accommodation sector, and providers of services and amenities (such as food and liquor outlets, petrol stations, retail shops, etc).

There are currently 12 operators who consistently take tourists on cruises in the designated area. When the Murray Mouth silts up they must find alternative routes to the Goolwa channel. One alternative for the boat operators is to launch from the ramp at Mundoo Channel, as has been occurring since December 2001 because of the silting of the Mouth. However, this option is less than ideal due to the lack of facilities and infrastructure for adequate and safe parking, refuelling and handling the removal of 'blackwater' from the vessels. The other alternative is to divert the tour on a lengthy journey past Clayton and through the lock at Tauwitchere Barrage to reach the Mouth. However, in addition to the added fuel costs, this option may not be available in late summer when water levels drop and the lock can become impassable.

Although this article has focused on the effects in the immediate area of the Murray Mouth, there is concern that tourism in adjacent regions will be negatively affected in the event of Mouth closure (pers comm. Peter Campbell).

Some key points raised during consultations with tourism and recreational stakeholders include:

- Stakeholders see the reinstatement of River water flows as a significant issue. Because interest in this area is based on its ecological attributes and it is widely recognised as a Ramsar wetland, the perceived deterioration of water quality will significantly undermine the promotion of nature-based tourism and recreational use.

- All stakeholders advocated further research into the area and a commitment to adequate action to prevent further degradation.
- Some stakeholders advocate a commitment to keeping Scab Channel open as a more viable option than dredging the Mouth, as it is a less expensive option with more likelihood of success. This dredging arrangement may facilitate navigation but will do little to mitigate the damage to water quality that will accompany Mouth closure.
- Some stakeholders advocated research into the possibility of placing breakwaters at the Murray Mouth. This, it is argued, could make the passage more easily navigable for recreational boaters, assist Port Elliot's search and rescue boat in launching through the Mouth and encourage the development of marine industry in Goolwa and Hindmarsh Island. However, this proposal was a point for some argument regarding its efficacy.

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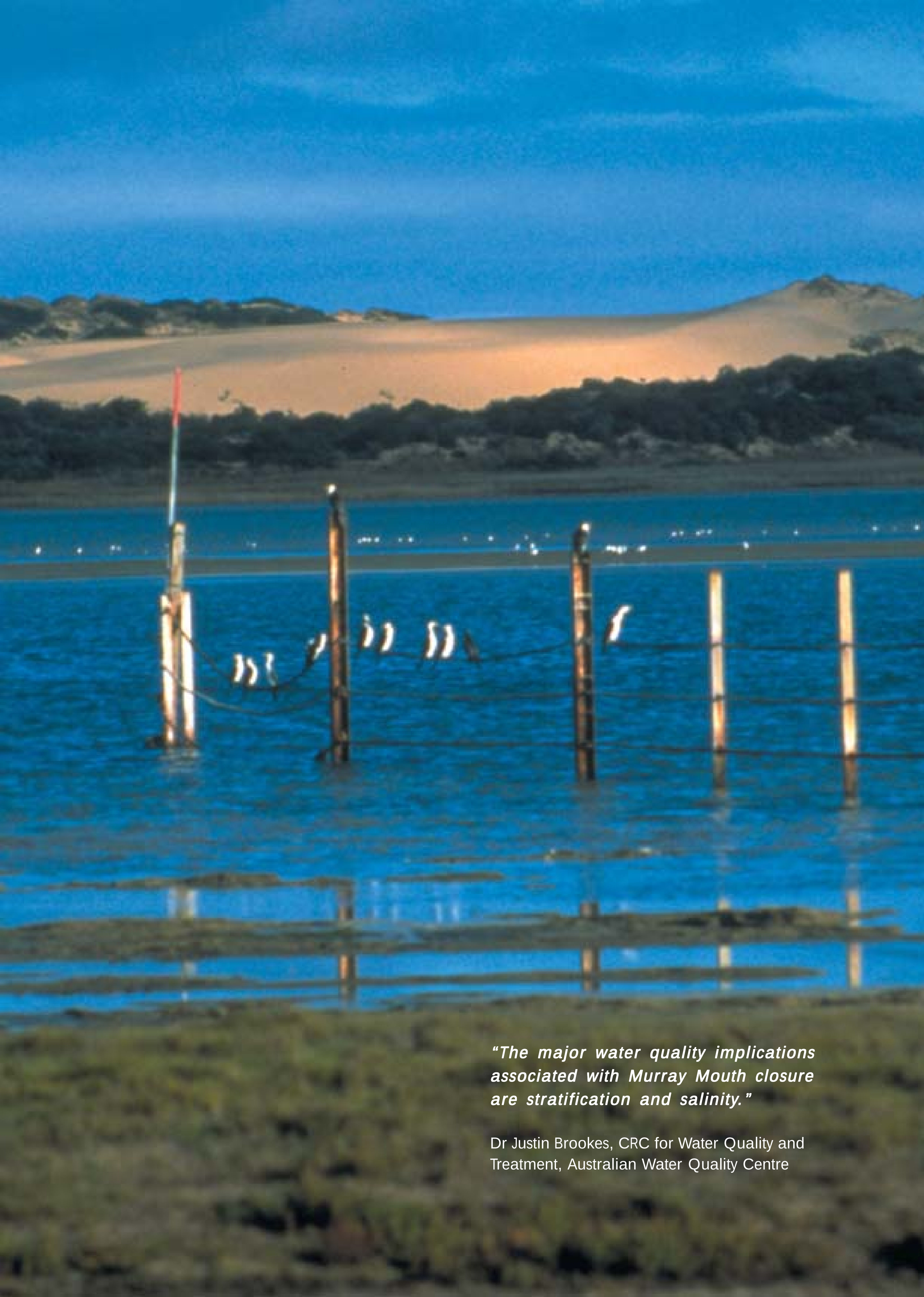

"The major water quality implications associated with Murray Mouth closure are stratification and salinity."

Dr Justin Brookes, CRC for Water Quality and Treatment, Australian Water Quality Centre

Water Quality

DR JUSTIN BROOKES CRC for Water Quality and Treatment, Australian Water Quality Centre

As some water quality concerns may eventuate before Murray Mouth closure (as a result of low flows in the lower River Murray) there are two questions to consider:

- *What minimum flow is required to maintain a satisfactory water quality within the Lower Lakes and Coorong?*
- *How does Murray Mouth closure affect water quality?*

Specific issues discussed here include quality of source water, stratification, phytoplankton, salinity and pathogens. In some instances, it was necessary to extrapolate from observations upstream or from similar

Introduction

The area of consideration from the Lower Lakes downstream can be divided crudely into four regions which differ in water quality, the quality and type of habitat they offer, and degree of interest of various stakeholders in the region. The four regions are:

1. the main channel of the lower River Murray
2. the Lower Lakes (Lake Alexandrina and Lake Albert)
3. the Northern Lagoon of the Coorong, and
4. the Southern Lagoon of the Coorong.

Although these regions differ in some respects, the underlying chemical, physical and biological principles determining water quality are similar and will be discussed concurrently. The water quality of the lower River Murray is important in determining the water quality of the Lower Lakes and so is included in this discussion.

The major water quality hazards, which may eventuate from Murray Mouth closure, represent a risk to stakeholders because they degrade habitat for aquatic organisms or present a potential health risk to recreational users.

Two major factors which will impact water quality at the Murray Mouth region are the quality of the water arriving from upstream (source water) and density stratification (defined below).

Density stratification will lead to a greater risk of several hazards, particularly toxic cyanobacterial blooms, anoxia in the hypolimnion and nutrient release from sediment. Pathogens and sainity are the other major water quality issues in the Coorong. Pathogen hazards are generally associated with contamination from external sources with the greatest risk occuring during periods of high rainfall, and salinity is affected by sea

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water entering the Murray Mouth, evaporation and freshwater inflows.

In this chapter there is a focus on the quality of the source water from the lower River Murray, stratification and hazards eventuating at the lower estuary site. Except in the case of salinity, it is difficult to isolate the impact of low flow from Murray Mouth closure as low flow leads to stratification which sets the physical environment for hazard generation.

Salinity and cyanobacteria represent the biggest water quality issues in the lower River Murray, and the Lower Lakes and estuary.

The cyanobacterial hazard not only presents a toxic threat to wildlife but is also poorly consumed by Australian zooplankton (Boon *et al*. 1994) and so during cyanobacterial blooms the sustainable biomass of grazers (zooplankton) may be reduced. This has implications for the sustainable biomass of higher order organisms.

Context

The Murray-Darling River system drains the Western slopes of the Great Dividing Range in south-east Australia. The River Murray originates in south-east New South Wales (NSW) and joins the Darling River (at Wentworth) which originates in north-east New South Wales. The Darling contributes about 10% of the total average annual discharge (Walker and Thoms 1992). This is an important feature for consideration as these different catchments deliver water of varying quality to the lower River Murray system.

Stratification

Density stratification is a natural feature of water bodies and is characterised by a vertical gradient in density caused by differential heating of the water surface and/or differences in salinity. A major water quality problem associated with stratification, and the restriction of vertical mixing, is the isolation of the hypolimnion from the atmosphere. Bacteria within the sediment and water column can rapidly deplete the oxygen in the hypolimnion and generate reducing conditions at the sediment-water interface and in the hypolimnion. Under low oxygen conditions nutrient and metal contaminants, which are resolubilised from sediment, remain in solution and can compromise water quality.

Although depth-dependent temperature is not recorded continuously in Lake Alexandrina, several assumptions can still be made regarding water movement of the Lake. The degree of stratification in the Lower Lakes is a function of stratifying thermal energy (temperature) and destratifying kinetic energy (wind and flow).

Baker (2000) suggested that the influence of wind in the shallow Lower Lakes (mean depth 2.9m) was significant in destabilising thermal stratification. Temperature data presented in Geddes (1988) suggests there is thermal stratification in Lake Alexandrina; however the time-scale of measurement does not allow interpretation of whether the water-body mixed to the bottom overnight or remained persistently stratified. The strong afternoon wind speeds, which are measured at Goolwa, would suggest that the Lake is regularly fully mixed.

With a restriction of flow through the Lower Lakes and Coorong, these sites would stratify, at least part of the time, and may be persistently stratified during warm stable periods with low wind.

Closure or restriction of the Murray Mouth would assist in the development of stratification which is a necessary physical condition for many hazards to eventuate including blooms of toxic cyanobacteria, anoxia in the hypolimnion and nutrient release from sediment.

Nutrients

The major nutrient sources are the catchment and the internal load derived from sediment and from the atmosphere.

The sources contributing to elevated nitrogen oxide species in the atmosphere (which can then end up in the River Murray via rainfall) include soil emission, fossil fuel combustion, lightning and biomass burning in forests and savannah (IPCC 1996). These sources, together with nutrients derived from the catchment, are difficult for water managers to control.

In a typical phosphorus cycle, phosphorus is remobilised from sediment or decaying organic matter and entrained into the water column, where it is taken up by algae. From there the phosphorus is either passed on to higher levels of the food web or lost to the bottom as the algae sediment. In deep lakes, the resolubilisation of phosphorus from the sediment is vertically separated from the algae and so each phosphorus molecule can only be accessed with entrainment from the hypolimnion to the epilimnion (surface water). In strongly stratified, deep lakes this may happen only once or twice a year during significant 'over-turn' events.

In contrast, shallow lakes, such as the Lower Lakes and the Coorong, have the zone of phosphorus resolubilisation much closer to the zone of greatest productivity and a single molecule may be recycled a number of times during the growing season (Reynolds 1997) and thereby sustain a high algal biomass for longer. This is why shallow lakes prove so much more difficult to restore than deep ones (Sas 1989, Reynolds 1992).

Geddes (1984) states that the nutrient levels in Lake Alexandrina reflect those in the lower River Murray. For the period 1975 to 1978, nutrient levels were 89mg to 385mg Total Phosphorus (TP) per m (mean 223mg m^{-3}) and Total Kjeldahl Nitrogen (TKN) 600mg per m to 2700mg per m (mean 1314mg m^{-3}). Although there is considerable variability in nutrient concentrations, the concentrations observed by Geddes (1984) are typical for the region. During the 1975 to 1978 period, the nutrient levels in Lake Alexandrina were in the eutrophic-hypereutrophic range of Vollenweider (1968) and in the eutrophic category of Walker and Hillman (1977) (Geddes 1984). This means that the Lake can support high algal populations and may be prone to cyanobacterial blooms.

There is a gradient in TP and TKN down the Coorong which correlates with an increase in salinity (Thomas 1999, Figures 1, 2 and 3). The source of the higher nutrients in the southern basin is unknown but it could be either higher algal biomass, or resuspended sediment. It is unlikely to be from catchment inputs as the tributaries, which used to provide freshwater inflows to the southern Coorong, have been diverted. Thomas (1999) classified the TP and TKN concentrations as moderate according to his water quality classification.

Slow flow and deposition of particulate organic material may increase the nutrient pool which is available for release when the water body stratifies. When River flow is sufficiently high, this particulate material should be scoured from the River or estuary bed and flushed from the system.

The major water quality hazard associated with nutrients is the toxic phytoplankton. The size of the sustainable biomass is often directly correlated with nutrient availability. Additionally, an increased nutrient pool may also increase bacterial activity which would increase the oxygen demand and increase the rate at which anoxia occurs. (See also pg 23 'Fishing Industry' chapter.)

Murray Mouth closure or restriction may lead to increased nutrients in the region of the estuary as nutrients are released from the sediments as a result of a reducing

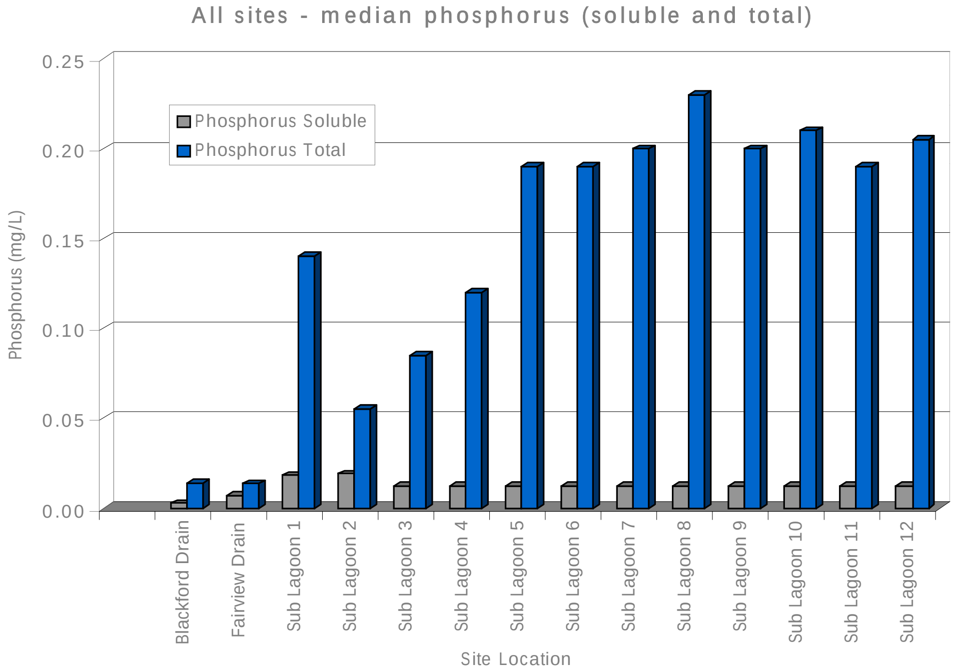


Figure 1: Median phosphorus at sites in the Coorong (reproduced from Thomas 1999)

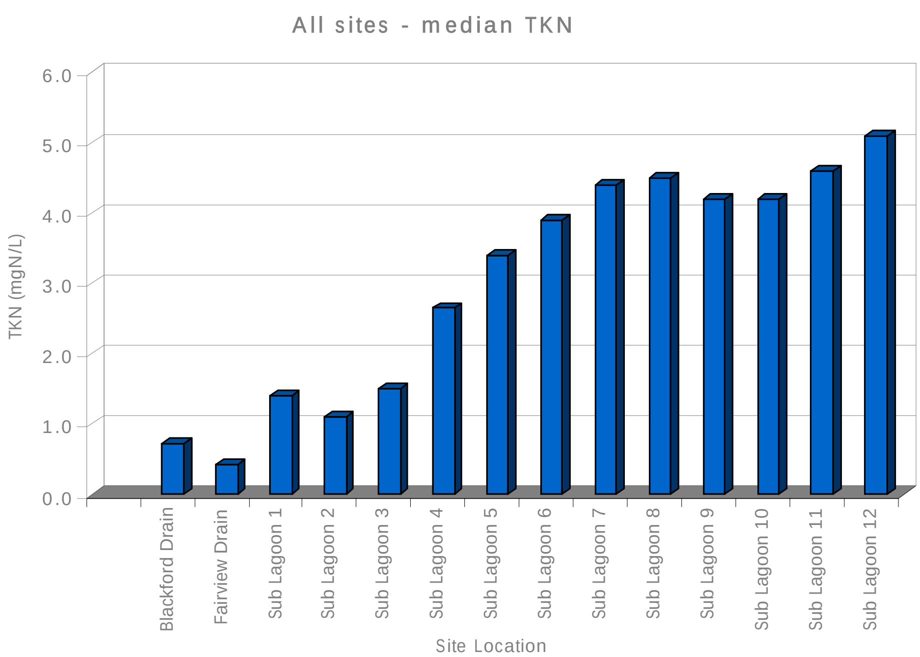


Figure 2: Median TKN at sites in the Coorong (reproduced from Thomas 1999)

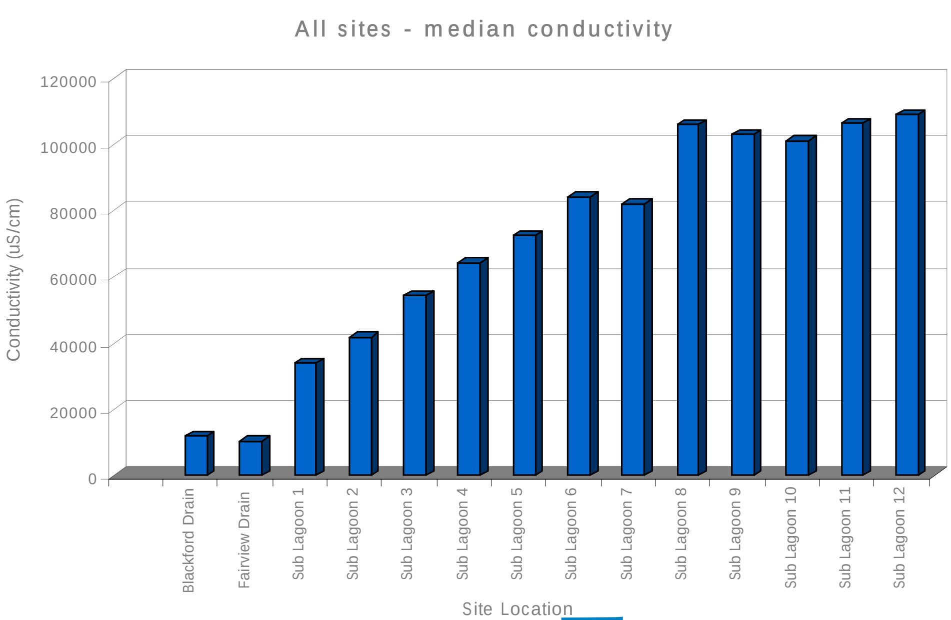


Figure 3: Median conductivity at sites in the Coorong (reproduced from Thomas 1999)

environment during stratification. Deposition of particulate material due to low turbulence may also have long-term impacts on the nutrient climate of the region. The nutrient concentrations in the region will also be highly influenced by the quality of the source water from the River Murray.

El Nino and source water: Inter-annual variability in flow and nutrients

Flow within the Australian context is highly variable and plays a significant role in nutrient transport from catchment to stream and the maintenance of particles in suspension. Consequently, regional weather patterns contribute to the inter-annual variability of water quality, quantity and the demand on the water resource by upstream consumers.

The nutrient concentrations in the region of the Murray Mouth display inter-annual variability which is a function of source (for example, upper Murray or Darling) and the duration of stratification resulting from low flow and low wind.

Implications of a salt wedge on stratification and nutrients

A natural feature of tidal estuaries is a saline intrusion which is often referred to as a 'salt wedge'. The intrusion of dense saline water from the sea below the fresher water in the river can travel a considerable distance upstream if there are no barriers in place. (See also 'Coastal Processes' chapter.)

Currently, the barrages at Goolwa stop the intrusion from travelling through the Lower Lakes and into the main channel of the lower River Murray. The saline intrusion increases density stratification and the lack of mixing between the fresh and saline water can lead to anoxic conditions in the intrusion. Consequently, the reducing condition in the intrusion can lead to nutrient release and the release of other contaminants such as hydrogen sulphide, which has an unpleasant odour.

Because of the extremely windy conditions at the Lower Lakes, and the expected cooling from the high evaporation, there may be considerable mixing which would negate the stratifying thermal energy. However, thermal stratification would occur at times and the degree of stratification would be strengthened by the salinity gradient.

Phytoplankton

Cyanobacteria in the lower River Murray - *Anabaena* and flow

Flow is a major factor determining the phytoplankton abundance and species composition in Australian lowland rivers (Burch *et al.* 1994, Hotzel and Croome 1994, Sherman *et al.* 1998). Of particular concern are the cyanobacteria as these organisms produce toxins, tastes and odours which compromise the quality of drinking and bathing waters.

In the River Murray at Morgan there is a transition between the dominant diatom species *Aulacoseira granulata* (non-toxic) and *Anabaena* spp. (possibly toxic) which is highly dependent on flow (Figure 4). The observations made at Morgan are similar to other lower Murray sites.

Observations from the lower River Murray

Baker *et al.* (2000) tracked parcels of water in a reach of the lower River Murray during the summer of 1994/1995 and calculated growth of the dominant cyanobacteria.

Water Quality

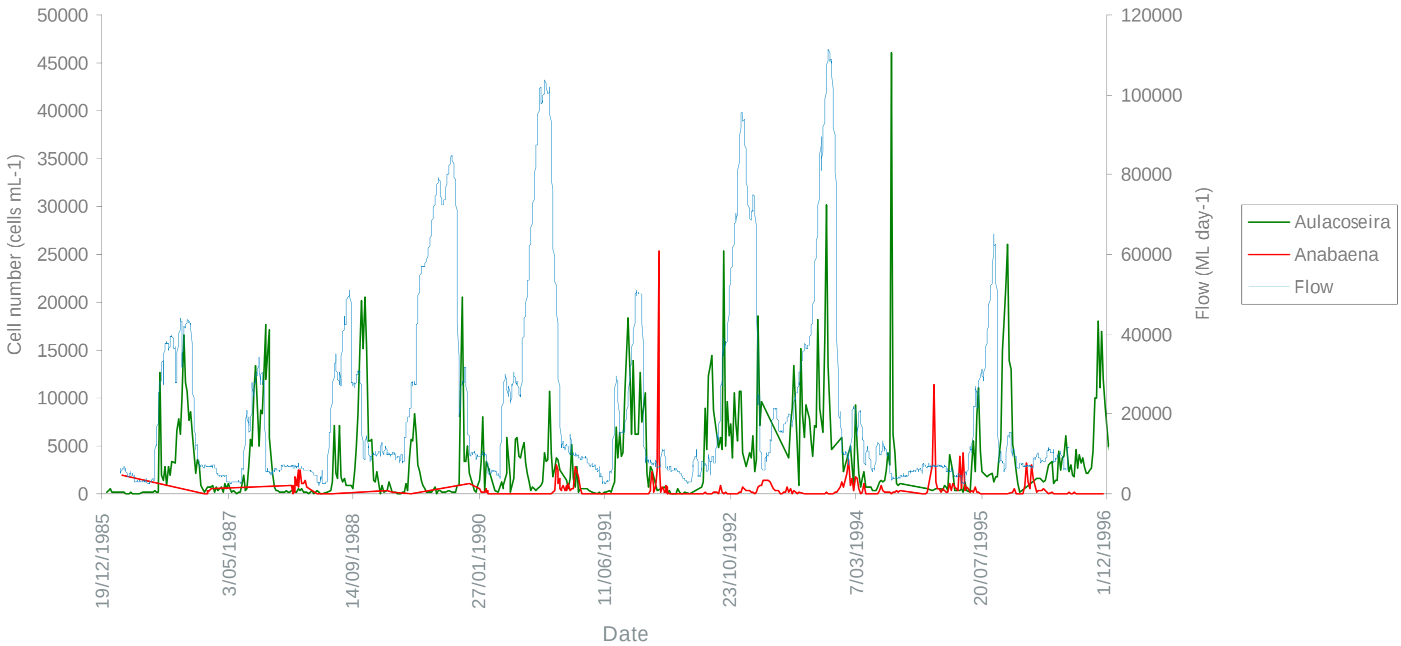
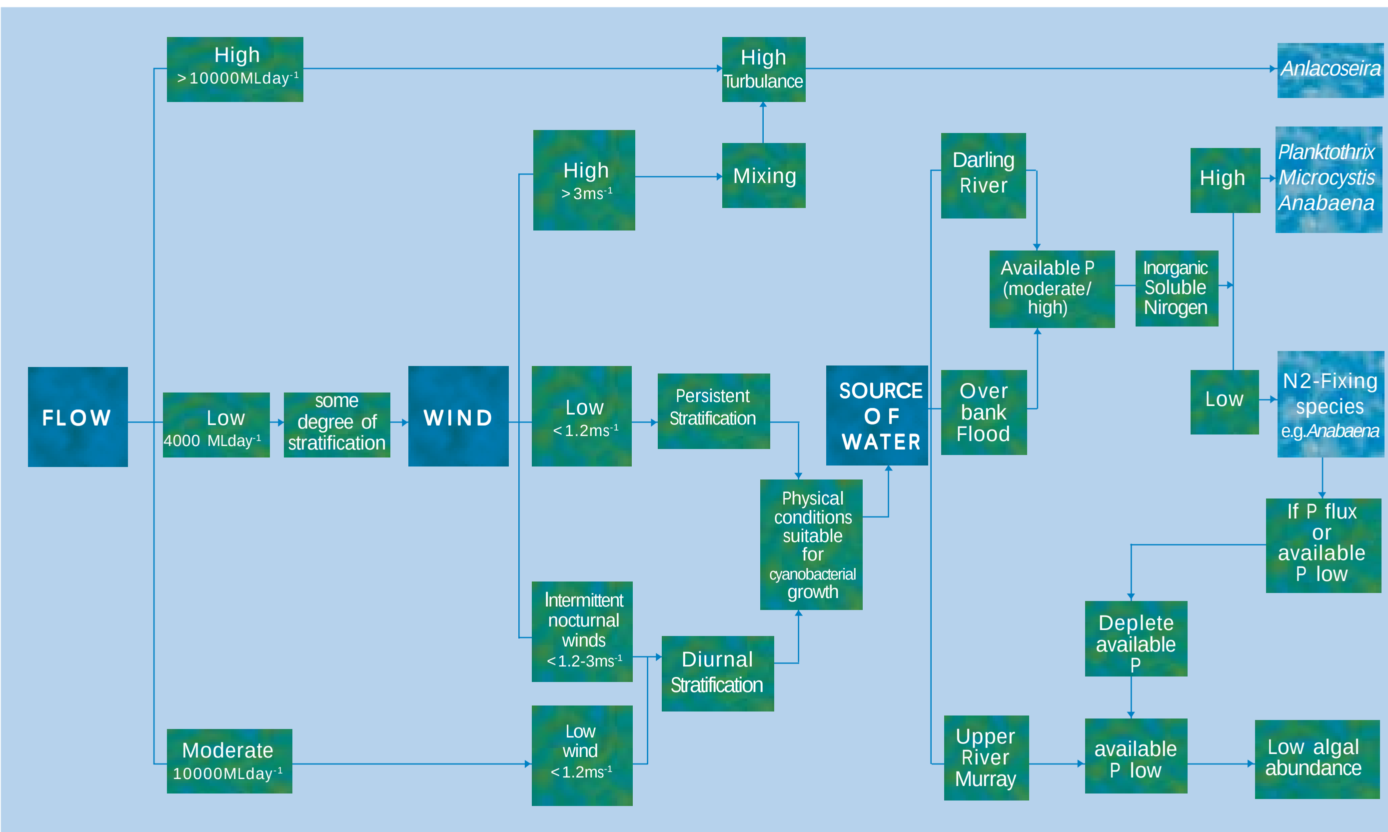


Figure 4: River flow and the dominance of *Aulacoseira* or *Anabaena* at Morgan on the lower River Murray

Figure 5: Conceptual model of the physical and environmental factors governing cyanobacteria abundance in the lower River Murray



Mean growth rates of *Anabaena circinalis* and *A. flos-aquae* were 0.176 and 0.132 per day respectively. However, maximum cell densities were only 2670 and 4560 cells per mL for each species, which is low abundance and suggests that nutrients or grazing were limiting phytoplankton growth.

During the summer of 1995/1996, nutrient growth bioassays and FDA-conversion bioassays (Brookes *et al.* 2000) revealed nitrogen limitation on several occasions in the lower River Murray was limiting phytoplankton growth. In contrast, phosphorus limitation was detected on only one occasion and between 8% and 70% of the total phosphorus was available to organisms for growth (Baker *et al*. 2000).

It is likely that although phosphorus may ultimately limit total phytoplankton biomass, low nitrogen concentrations in the River Murray favour nitrogen-fixing species, such as *Anabaena circinalis* and *Anabaena flos-aquae*, while limiting the growth capacity of non-nitrogen fixing species, such as *Microcystis aeruginosa*. The particular combination of physical and chemical conditions presumably favoured the growth of *Anabaena* in preference to non-nitrogen fixing cyanobacteria, albeit at sub-optimum conditions.

Conceptual model of cyanobacteria in the lower River Murray channel

A conceptual model has been developed to summarise the physical and chemical factors governing the abundance of cyanobacteria in the lower River Murray (Figure 5). Flow is ranked as the primary factor affecting the development of cyanobacterial populations.

High flow (>10 000ML per day) results in high turbulence and species such as the diatom, *Aulacoseira granulata* are favoured. When flow is moderate (ca. 10 000ML per day), stratification during the day occurs if wind strength is low (<1.2m per s). During periods of low flow, equivalent to summer entitlement flows (4000ML per day), turbulence is sufficiently low to allow some degree of thermal stratification, provided that wind strength is low to moderate (<3m per s). Persistent stratification may result when wind speed is <1.2m per s (and flow is low), while stratification during the day is more likely at wind speeds between 1.2m per s and 3m per s. Irrespective of flow, high wind speed (>3m per s) will disrupt thermal stratification and result in a mixed water column.

In the model, the source of water is the other environmental factor affecting algae behaviour.

If water is sourced from the Darling River, or if over-bank flooding has occurred during the high spring flows originating from the upper River Murray, phosphorus concentrations may increase. When phosphorus concentrations are high, nitrogen availability will then determine which species dominate.

High soluble inorganic nitrogen availability favours non-nitrogen fixing cyanobacterial genera, such as *Microcystis* and *Planktothrix*, and other phytoplankton. However, if nitrogen availability is low, nitrogen fixing genera, such as *Anabaena*, *Aphanizomenon*, *Anabaenopsis* and *Cylindrospermopsis* obtain a comparative advantage.

If River flow originates from the upper River Murray and flow remains within the main channel, available phosphorus will be low and consequently phytoplankton abundance will remain low.

Water Quality

River management for control of cyanobacteria in the main channel

The correlation between the occurrence of *Anabaena* with low flow suggests that the manipulation of flow may be used to control cyanobacteria. Bormans and Webster (1997) developed a mixing criterion for turbid rivers which is applicable to many lowland rivers. In summary, the degree of stratification in a water column is determined by the relative supply rates of stratifying thermal energy and destratifying turbulent kinetic energy. In regulated rivers, the magnitude and timing of discharge can be manipulated to disrupt stratification every few days thereby controlling cyanobacterial growth.

Maier *et al*. (2001) modelled various flow scenarios for the control of stratification. They found that under current entitlement flow there is little risk of sustained blooms in the lower River Murray at Morgan, which could be extrapolated to include lower reaches of the River. Consequently, the best mechanism for cyanobacterial control is not to increase base flow but to disperse existing blooms with flow derived from reducing weir pool levels upstream, providing the impacts on aquatic macrophytes and benthic algae are considered. (See 'Aquatic Plant Communities' chapter.)

Phytoplankton in the Lower Lakes

The dominant phytoplankton species in Lake Alexandrina is *Planctonema lauterbornei* and is generally present during conditions of high turbidity, low light availability and high nutrients (Geddes 1988, Baker 2000). However, the major phytoplankton species of concern are *Nodularia spumigena* and *Anabaena circinalis* as these species have been associated with toxic cyanobacterial blooms in the Lower Lakes (Baker 2000). It is well established that stratification can lead to the dominance of the phytoplankton community by cyanobacteria. However, in the Lower Lakes the small increase in base flow may not disrupt stratification, as it does in the lower River Murray channel and wind would play a greater role at dispersing cyanobacterial blooms. Baker (2000) reports that the occurrence of *Nodularia* in the summer/autumn of 1990/1991 and 1995 was associated with periods of low flow (<10 000ML per day), moderate turbidity (less than 50NTU), conductivity 400EC to 1100EC (freshwater) and variable nutrient concentrations. This is similar to observations in the main channel of the River Murray.

Phytoplankton in coastal lagoons

The species of concern in coastal lagoons are the cyanobacteria *Nodularia*, which has been observed in Orielton Lagoon in Tasmania (Jones *et al*. 1994) and Peel-Harvey estuary (Lukatelich and McComb 1986), and toxic dinoflagellates which produce paralytic shellfish toxins. The dinoflagellate genera *Alexandrium*, which are known toxin producers, and *Heterosigma*, which has been implicated in fish kills, have been observed in West Lakes and the Port River.

The bloom of *Nodularia* in Orielton Lagoon, Tasmania, occurred during a period of relatively low salinity (14g per L). However, later on the bloom salinities increased to 22g per L to 24g per L (Jones *et al*. 1994).

At the lower salinities, laboratory studies showed that akinete (reproductive resting spores) production was low relative to that at the higher salinities. This suggests that *Nodularia* prefers the lower salinities and prepares for dormancy as salinities increase.

Salinity was also implicated in akinete germination, with the extent of germination inversely related to salinity in the Peel-Harvey estuary (Huber 1985).
There are no phytoplankton records for the

Coorong on the Australian Water Quality Centre database and a current contents search for 'Coorong and Phytoplankton' yields no results. This represents a significant gap in our knowledge. The problematic dinoflagellates ('red tides') have, however, been observed in the Coorong estuary (Baker 2000).

Dinoflagellates and cyanobacteria are generally associated with stratification, which would occur during low flow and Murray Mouth closure. Boon (2000) states that in the Southern Lagoon there may be a limited number of phytoplankton including *Dunaliella*, *Amphora*, *Nitzschia* and several diatom species. There are no major water quality issues related to these phytoplankton.

Closure of the Murray Mouth may stimulate greater algal blooms than those currently observed during periods of low flow, particularly in the Northern Lagoon where the duration of stratification may increase.

However, cyanobacteria may become problematic in the main channel of the River Murray and in Lake Alexandrina at flows less than 10 000ML per day.

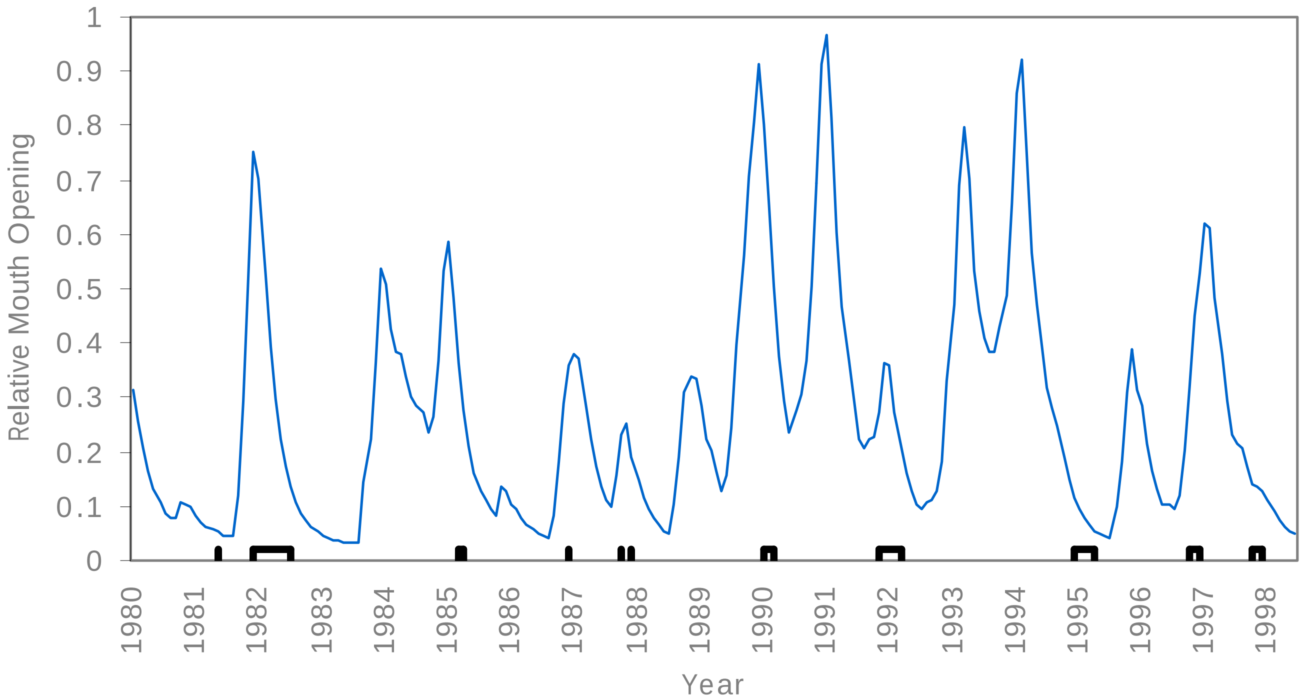
The cyanobacteria represent a poor food source for zooplankton which will have implications for higher order organisms including birds and fish.

Salinity

Perhaps the most astounding feature of the estuarine region is that it now only operates over 11% of its original area (Newman 2000). A consequence of this is that the gradual gradient from fresh to saline waters, which would have prevailed historically, is not evident in the present system. Consequently, there is large variability in salinity, which fluctuates at short time scales depending upon tidal action and River flow. (See 'Fish and Invertebrates' chapter.)

The Southern Lagoon is naturally hypersaline, but Geddes and Hall (1990) argue that the Coorong is more saline now than prior to River regulation. Monitoring of salinity during recent barrage closure allowed Geddes and Hall (1990) to document the impact of Murray Mouth restriction/closure on salinity. They report that between 1980 and 1983 River Murray flows were below average and there were long periods of barrage closure and

Figure 6: Predicted Mouth opening based on model of Walker (2000). A level where tidal influence is reduced to R<0.05 was selected to indicate Mouth closure. The bars indicate periods where conductivity at Long Point in the Northern Lagoon exceeds the conductivity of seawater (52 m^{-1}).



[5] Note: The salinity of seawater was subtracted from the salinity at Long Point and positive values were considered as periods of high salinity.

Water Quality

salinities were high throughout the Coorong.

The Southern Lagoon may have some moderately freshwater inputs in the near future from the Upper South-East Drainage System.

Salinity in the Lower Lakes is strongly influenced by the source water from the River Murray and so the region which may experience the greatest fluctuations in salinity and be most impacted by Murray Mouth closure is the Northern Lagoon.

Historical salinity at Long Point in the Northern Lagoon was used to determine how Murray Mouth closure has impacted the salinity in the Northern Lagoon (see Figure 6). The Northern Lagoon is tidal and so salinities equivalent to seawater would be tolerable ($52\ 000 \mu S\ cm^{-1}$).[5]
These values were plotted with the output from the model of Walker (1999) to determine whether high salinity in the Northern Lagoon was associated with Murray Mouth closure.

It is apparent that periods of high salinity do not always correspond to periods of predicted Mouth closure (Relative Mouth opening <0.05 using the Walker model (1999) – see 'What is Possible: Hydrology and Morphology' chapter). Therefore, it appears that salinity in the Northern Lagoon is also affected by the salinity in the Southern Lagoon. There could be considerable mixing of waters between the two basins with wind driven surface flows and deeper return flows. Differential heating and cooling within the two basins could also generate considerable flow and basin exchange.

The encroachment of hyper-saline water into the Northern Lagoon, from the Southern Lagoon, will restrict the available habitat for organisms which can only tolerate salinity as high as seawater.

Anoxia

The water quality problems resulting from anoxia are contaminant resolubilisation from sediment and a reduction of habitat for organisms which need oxygen to survive (for example, fish). The rate of onset of anoxia is a function of stratification, temperature, organic substrate and microbial activity.

As discussed earlier, the strong wind speeds recorded at Goolwa would suggest reasonably regular, rapid mixing in the shallow lagoons of the Coorong. However, during calm, warm weather anoxia may become an issue. Sediment may be resuspended when there is turbulence at the surface of the sediment due to either wind mixing in shallow regions or where there is wave-generated turbulence. Sediment disturbance increases the chemical oxygen demand and may induce low oxygen concentrations.

Turbidity

Light penetration will have a significant impact on plant growth in the Lower Lakes and Coorong. High turbidity currently restricts plant growth to near shore boundaries where it is susceptible to wind and wave action (Ganf 2000). (See also pg 71 'Aquatic Plant Communities' chapter.)

The factors influencing turbidity include the source water (Murray River, Darling River or oceanic), flow and wind induced turbulence, and phytoplankton abundance. Turbidity at Milang and Lake Alexandrina displayed annual inter-annual variability (Baker 2000) with high turbidity in each year corresponding with high flow. A peak in turbidity and nutrients at Milang in 1991 was attributed to a high proportion of River flow originating from the Darling River (Baker 2000). Wind action and wave-generated turbulence also contribute to high turbidity in the Lower Lakes.

It is anticipated that closure of the Murray Mouth would improve water clarity as particles would tend to drop out from suspension. The increased salinity resulting from evaporation would tend to flocculate colloidal material and further increase the rate of sedimentation.

Pesticides and herbicides

The risk of pesticide hazards eventuating in aquatic systems is a complex interaction between fate and transport of the organic compounds. Residue of the monitored pesticides and herbicides in the Coorong Lagoons are mostly below detectable levels (Thomas 1999). The risk associated with them is sufficiently low that Thomas (1999) recommended that they only be monitored once yearly. Closure or restriction of the Murray Mouth would not significantly increase the risk associated with pesticides and herbicides, which are currently considered low risk in this system.

Heavy metals

Thomas (1999) reports that the sub-lagoons of the Coorong have moderate to low levels of metals, with the exception of zinc (Zn) and silver (Ag) which have moderate to high concentrations (Zn: 0.042-0.174mg per L; Ag: 0.0003-0.0017mg per L).

Murray Mouth closure may lead to stratification and reducing conditions which may in turn lead to resolubilisation of some metals. However, the concentrations of metals in the sediment (Table 1) are below the guideline value (Thomas 1999).

There is low risk from metal contamination, with the exception of zinc, which is present in elevated concentrations in several sub-lagoons.
The risk associated with iron and manganese is usually that these compounds contribute dirty water problems as the ions oxidise upon exiting consumers' taps. Since the water of

Table 1: Sediment chemistry data from the Coorong Lagoons 8 April 1998 (Reproduced from Thomas 1999).

Metal (total)	Results from lagoons 1-12 (range)(mg/kg dry)	Guideline value (mg/kg dry)
Aluminium	282-4060	-
Antimony	All<0.2	2
Arsenic	0.8-7.4	20
Cadmium	All<0.2	1.5
Chromium	3.6-15.1	80
Copper	3.6-15	65
Iron	748-5070	-
Lead	1.23-4.04	50
Selenium	All<0.001	-
Silver	<0.2-0.5	1.0
Zinc	12-165	200

Water Quality

Lake Alexandrina is only used for limited potable supply, the risk associated with iron and manganese is considered low.

Pathogens

The major water-borne organisms which impact on human health in Australia are *Cryptosporidium*, *Giardia* and *Campylobacter*. These pathogens cause severe diarrhoea and dehydration and spread by the excretion of microscopic, spore-like cysts (*Giardia*) or oocysts (*Cryptosporidium*). While generally not life-threatening to healthy individuals, they can cause severe illness in young children, the elderly and individuals with an impaired immune system (Walker and Stedinger 1999).

The threat associated with pathogens in the Lower Lakes and Coorong is largely unknown. There is little draw off for potable supply and infection would generally be restricted to recreational exposure at sites where there is sewage contamination or agricultural runoff. Furthermore, pathogen contamination from the catchment occurs during significant rain events, which typically occur during winter and spring in Mediterranean climates such as ours, and so there would be considerable dilution.

Run-off from irrigated pasture may also present a pathogen source. The transfer of fresh faecal material into watercourses and the River is a major problem. A recent local example of pathogen contamination occurred at Aldgate Creek, South Australia, where concentrations of *E.coli*, *Enterococcus* spp, *Campylobacter* and *Cryptosporidium* increased by two orders of magnitude following 10mm to 15mm rain (pers. comm. Phil Adcock AWQC).

Enterohaemorragic *Escherichia coli*, which is associated with cattle and irrigation run-off, is also an emerging issue. This organism has a low infective dose, is potentially life threatening and has recently been implicated with outbreaks of disease related to poorly treated drinking water (Walkerton outbreak 2000). The implications of recreational contact have not been investigated at this stage.

It is anticipated that restriction of the Murray Mouth and low flow may alter the pathogen threat as sewage contamination and irrigation run-off is not diluted.

The risk of pathogens to recreational users of the Lower Lakes and Coorong is largely unknown and warrants investigation.

Public health and guidelines

While the pathogens are generally a risk following ingestion, the cyanobacteria present health problems from both ingestion and skin contact.

The hepatotoxins produced by *Nodularia spumigena* are known to produce chronic liver damage, whereas the neurotoxins produced by *Anabaena circinalis* present a low risk of acute poisoning and have no known sub-acute or chronic effects (Jones *et al*. 1993). *Nodularia spumigena* intoxication has been implicated in an individual suffering skin rashes and diarrhoea (Jones *et al*. 1994); hence contact with cyanobacterial scums should be avoided. Furthermore, there is some epidemiological evidence which implicate cyanobacteria in symptom occurrence from exposure during recreational activities at Goolwa (Pilotto *et al*. 1997).

The buoyant habit of cyanobacteria means they are easily wind blown and accumulate on leeward shores, where they present the greatest risk. The guideline for recreational exposure is currently 20 000 cells per mL of cyanobacteria (WHO 1999). Similar guidelines exist for pathogens
(see www.waterquality.crc.org.au/guide.htm
and www.waterquality.crc.org.au/guide.htm).

Whether Murray Mouth closure is likely to increase pathogen risk and exceed the guideline is unknown.

How much flow is enough?

Prior to the construction of the weirs, the River Murray would have displayed stronger seasonal variability in flow than presently observed as the magnitude of floods and low flow have been tempered. Low flow was a natural feature of the Murray system. Figure 6 in Close and McLeod (2000) shows a photo of Sir Ronald East straddling the River Murray near Swan Hill in March 1923. Close and McLeod predict that flow at this site without the upstream water extraction would have been 2000ML per day. This flow is below the entitlement flows which presently may lead to closure or restriction of the Murray Mouth.

It could be concluded that in its natural state the Murray Mouth may have closed over periodically. However, it is estimated that 79% of natural median flow is now extracted and consumed in the Basin. The consequence of this is that the River Murray now experiences severe drought-like flows in over 60% of years compared with 5% of years under natural flow condition (Close and McLeod 2000).

If the aim is solely to keep the Murray Mouth open, then River flow could be increased to flush the Mouth of sediment. However, it is prudent to note that there are other environmental impacts from elevated flow which demand consideration. Walker (2000) developed a model which predicted Mouth restriction based on flow through the barrages using relative tide amplitude differences between the barrages and Victor Harbour. Mouth closure was predicted for 58 months in the 35-year period from 1963 to 1998 (13.8% of the time). The model of Walker (2000) provides a prediction of how much additional flow is required to reduce the number of months the Murray Mouth is closed. To reduce the number of closures to 5% of the time, which is the approximate number of drought years under natural flows (Close and McLeod 2000), an additional flow of 840GL, delivered as a monthly supplement, would be required. (See also ‘What is Possible: Hydrology and Morphology’ chapter.)

An alternative strategy may be to expand the region of the tidal estuary and use oceanic water in combination with increased flows to destratify, oxygenate and maintain salinity. If the aim is to control salinity increases, then water could be released from the more Southern barrages to moderate the salinity gradient in the Northern Lagoon.

Conclusion

The water quality implications of low flow and Murray Mouth restriction/closure are numerous and compromise the Coorong habitat and recreational use of the region. Of equal importance, however, is the quality of the source water flowing into South Australia and the Lower Lakes/Coorong. This water has 1.5 million consumers and contributes significantly to agriculture and horticulture in South Australia.

The maintenance of quality source water is economically and environmentally important and plays a fundamental role, along with the quantity of source water, in determining the quality of water and habitat in the lower Murray, the Lower Lakes and the estuary.

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Government of South Australia

The Department of Water, Land and Biodiversity Conservation

Murray-Darling Basin Commission

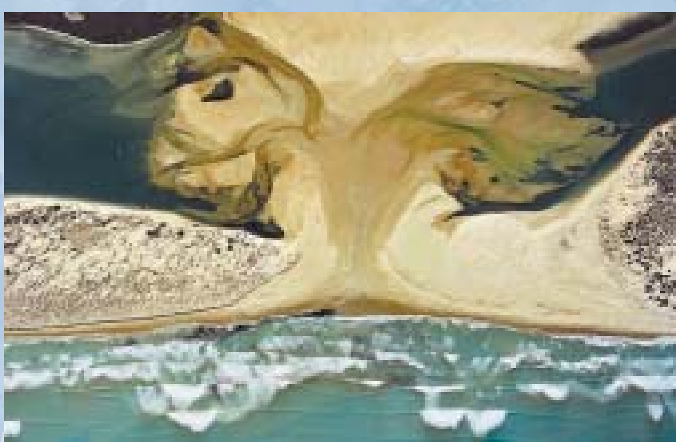
Images: Department of Water, Land and Biodiversity Conservation

Snapshots in time

1978

In 1981 the Murray Mouth closed for the first time in recorded history. It was closed for 3 months before being opened by dredging.

1989



1981

1995

1983

1997

1998

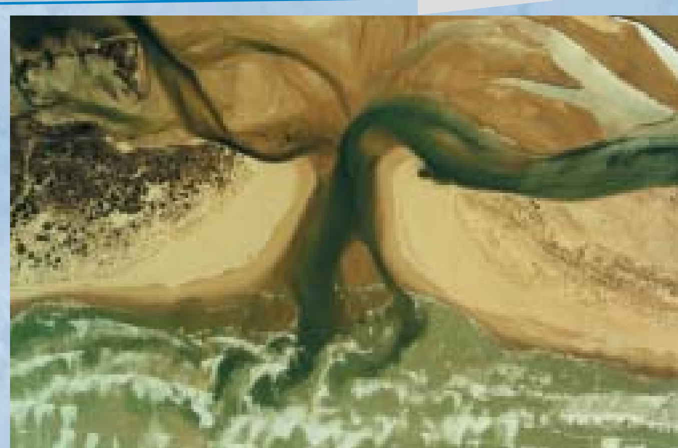
2001

currently the Murray Mouth is threatened with closure for the second time in recorded history

2000

1999

2002



Photography supplied by MAPLAND, Environmental and Geographic Information, Department for Environment and Heritage.

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Water Quality

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"The flow conditions in the River Murray and closure of the Murray Mouth... have a significant effect upon the hydrology of the Coorong and consequently, the biology of regional inhabitants."

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Fish & Invertebrates

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During periods of nil or low River Murray flow passing through the Mouth, suitable winds, tides and sea state can result in a closure of the Murray Mouth. The potential impacts of a long-term Mouth closure on the fish and macroinvertebrates of the Coorong are severe.

The following discussion covers invertebrates of the Coorong, fish of the Lower Lakes and Coorong (including life history), implications of Murray Mouth closure and the need for further research.

Introduction

During periods of moderate or high River Murray flow, the barrage gates are opened to varying degrees and freshwater flows from the Lower Lakes (Lakes Alexandrina and Albert) into the Murray Mouth region. The majority of freshwater flows out to sea via the Murray Mouth, but water is available for mixing into the Coorong, easily impacting on salinity patterns in the Northern Lagoon (Geddes and Hall 1990).

From the work of Geddes and his coworkers (Geddes 1984, Geddes 1987, Geddes and Hall 1990), the Coorong can be divided into three regions based on different salinity patterns:

1. Murray estuary (extending from Goolwa Barrage to the southern end of Tauwitchere Barrage at Pelican Point)
2. Northern Lagoon (extending from Pelican Point to the Narrows), and
3. Southern Lagoon (extending beyond Salt Creek).

There is almost always an increase in salinity southwards along the Northern Lagoon. During periods of flow across the barrages, the Northern Lagoon may range from fresh in the north and estuarine in the south, to seawater in the north and hypermarine (above seawater salinity) in the south during periods of ceased flow across the barrages (Geddes and Hall 1990).

Salinity patterns in the Southern Lagoon are more complex, more variable and more seasonal due to:

- Interactions of water exchange from the Northern Lagoon
- High net evaporation in summer, and
- Rainfall, groundwater and possibly surface water inflows in winter.

Historically, there have also been occasional inflows from Salt Creek into the Southern Lagoon.

Photograph: Department of Water, Land and Biodiversity Conservation

Fish & Invertebrates

During winter-spring, salinities are lowest and may be below seawater or up to two or three times that of seawater. In summer-autumn, evaporation causes a drop in water levels, an increase in salinity and the establishment of a longitudinal gradient with salinities as high as three to five times that of seawater at the southern extremity of the Southern Lagoon.

It can therefore be seen that the collective Coorong water mass is affected by a combination of tidal exchange with the sea via the Murray Mouth, freshwater inflow from the River Murray through the barrages, as well as rainfall and groundwater inputs. The flow conditions in the River Murray and closure of the Murray Mouth therefore would be expected to have a significant effect upon the hydrology of the Coorong and consequently, the biology of regional inhabitants.

Macroinvertebrates and fishes of the Murray Mouth & Coorong

Invertebrate fauna

As with much of the aquatic fauna of the Coorong, few studies directly investigate macroinvertebrates, besides the work of Geddes and his coworkers.

Geddes and Butler (1984) undertook a 16-month study between December 1981 and March 1983 into the aquatic fauna of the Coorong, finding a total of 21 macroinvertebrate species dominated by polychaete worms, gastropods and bivalves. A similarity was found between the Northern Lagoon fauna and that of other coastal lagoon systems such as Tuggerah Lakes (New South Wales), the Gippsland Lakes (Victoria), and the Peel Harvey system (Western Australia). A list of macroinvertebrates (see Table 1) has been assembled from available literature including Edyvane *et al*. (1996) and the work of Geddes *et al.* (1984 and 1990).

Fewer species are found in the Coorong compared to many large estuaries in south-eastern Australia, where on average more than 100 species can be collected (Geddes and Butler 1984). The low observed diversity is believed to reflect the extreme fluctuations in salinity. Those species present are believed to represent the most euryhaline section (species that are able to tolerate the greatest range of salinities) of the macroinvertebrate community normally present in estuaries (Geddes and Butler 1984). The same authors also state that a similar restricted diversity and species assemblage (the group of organisms sharing a common habitat by chance) was observed in the Peel Harvey system where salinities fluctuate widely.

Most of the invertebrate fauna listed can tolerate salinities from freshwater up to about 55‰[6]. At higher salinities the ‘estuarine-lagoonal’ fauna is replaced by ‘salt lake’ species such as insect larvae, especially the Chironomid (*Tanytarsus barbitsaris*), the Salt Fly (*Ephydrella* sp.) as well as a few crustaceans (Geddes and Hall 1990).

During the period 1981 to 1985, salinities in the Southern Lagoon were such that no members of the estuarine-lagoonal invertebrate fauna were collected; only ‘salt lake’ associated insect larvae and a few crustaceans persisting (Geddes & Hall, 1990). Mounds of tubes from previous populations of *Ficopomatus enigmaticus* and shells of *Notospisula trigonella* gave evidence of an earlier occurrence of ‘estuarine fauna’ in the Southern Lagoon (Geddes and Butler 1984). The high dispersal power of many of the estuarine-lagoonal macroinvertebrate fauna indicates that they would be expected to recolonise the Southern Lagoon once conditions were suitable (Geddes and Butler 1984). This hypothesis was specifically

[6] ‰ = parts per thousand.

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examined through the observation of fish and invertebrate presence before and after an extended high flow event. Observations by Geddes and Butler (1984) were made during a low flow or hypermarine phase between December 1981 and March 1983 that saw salinities in the Coorong rise as high as 100‰.

Following a period of significant freshwater flow through the barrages during 1983 to 1984, Geddes revisited the macroinvertebrate fauna patterns of the region (Geddes 1987). Following the flow event of 1983 to 1984, only two further species were collected in the Northern Lagoon, with no additional fauna recorded for the Southern Lagoon. It is thought that this was due to an insufficient duration of suitable conditions to allow re-colonisation of the Southern Lagoon by Northern Lagoon populations (Geddes 1987) and highlights the complexities of fauna and their vulnerability to changes in regime, such as Mouth closure.

Fish fauna

Several studies of the Lower Lakes and Coorong fish fauna have been undertaken over the past 30 years, concentrating mostly on commercial species. Although the relevant literature lists 78 species of fish recorded from the Murray Mouth, Lake Alexandrina and the Coorong lagoons, 34 of these are of marine origin and are only irregular visitors to the Coorong (see Table 2).

Species distribution appears to be affected by salinity in a similar pattern for the macroinvertebrate community, with biodiversity (species diversity) decreasing with increasing salinity (Geddes and Butler 1984, Geddes 1987, Geddes and Hall 1990, Molsher *et al*. 1994). When salinities are around 80‰ or greater in the Southern Lagoon, Small-mouthed Hardyhead (*Atherinosmoa microstoma*) may be the only species present, with other species only entering the Southern Lagoon when salinities

Table 1: Macroinvertebrates and fish of the Murray Mouth and Coorong

Class	Scientific name	
Crustaceans	*Australomysis sp.*	
	Melita	*zeylanica*
	Paracorophium spp.	
	Megamphopus sp.	
	Amarinus	*lacustris*
	Macrobrancium	*intermedium*
	Carcinus	*maenas*
	Paragrapsus	*gaimardii*
Polychaetes	*Ceratonereis*	*pseudoerythraensis*
	Nephyts	*australiensis*
	Australonereis	*ahlersi*
	Ficopomatus	*enigmaticus*
	Boccardia	*chilensis*
	Capitella	*capitata*
	Capitellides sp.	
	Fabriciinae	
	Prionospio	*cirrifera**
	*Questidae**	
Gastropods	*Hydrobia*	*buccinoides*
	Salinator	*fragilis*
	Tatea	*rufilabris**
Bivalves	*Notospisula*	*trigonella*
	Arthritica	*semen*
	Tellina	*mariae*
	Soletellina	*donacioides*
Insects	*Tanytarsus*	*barbitarsus*
	Ephydrella sp.	

Fish & Invertebrates

fall to within their tolerance range (Geddes and Hall 1990).

There is commercial interest in the larger fishes of the Lower Lakes and Coorong (see 'Fishing Industry' chapter); their capture in areas can vary around salinity. Between 1984 and 1988, Black Bream (*Acanthopagrus butcheri*) were captured in commercial quantities in the Southern Lagoon only in August -December of 1985-1986 when Southern Lagoon salinities were below 70‰. Yellow-Eye Mullet (*Aldrichetta forsteri*) were captured each year between July and December when salinities generally fell below 85‰ in the Southern Lagoon. Mulloway and Flounder were not caught during this period, possibly indicating their lack of tolerance to high salinities (Geddes and Hall 1990).

The major component of fish production in the Coorong is limited to a small number of species. All are estuarine dependent for at least part of their lifecycle (Geddes and Hall 1990). The commercially and recreationally important Mulloway (*Argrosyomus hololepidotus*), Yellow-Eye Mullet (*Aldrichetta forsteri*), Greenback Flounder (*Rhombosolea taparina*), and Black Bream (*Acanthopagrus butcheri*) are all presently believed to be estuarine-dependent species (although some debate surrounds the dependence of Mulloway on the Coorong). Other common estuarine species include River Garfish (*Hyporamphus regularis*), Congolli (*Pseudophritis urvilii*), Tamar Gobie (*Favonigobius tamarensis*), Blue Spot Gobie (*Pseudogobius* sp.) and Bridled Gobie (*Arenigobius bifrenatus*) as well as the Flat Headed Gudgeon (*Philypnodon grandiceps*).

Most of the freshwater fish of Lake Alexandrina have also been recorded in the Coorong. While certain species can inhabit both regions, it is believed that the majority of these fish are 'flushed' past the barrages from Lake Alexandrina during periods of freshwater outflow. Currently, most lakes fish are not able to return to freshwater due to physical limitations imposed by the lack of suitable fish passage across the barrages. This is being addressed in partnership with the South Australian Department of Water, Land and Biodiversity Conservation, SA Water, SARDI Aquatic Sciences and the Murray-Darling Basin Commission.

Although some species may be able to migrate back to freshwater (particularly diadromous species – those that migrate between freshwater and the sea as part of their life history), this is likely to be a comparatively small proportion of the fish 'flushed' over the barrages. Besides euryhaline species, those fish unable to return to the Lakes eventually die due to high salinity or predation by other fish and birds.

Life history patterns of the fishes of the Coorong

In studies of South African estuaries, fish species were categorised by their life history patterns to determine their estuary association (Whitfield 1999). Whitfield proposes eight categories of fish utilization in estuaries:

1. **Marine Migrant** - marine species that make extensive use of estuaries during juvenile and/or adult life stages
2. **Marine Straggler** - marine species where only a small proportion of the overall population make use of estuaries
3. **Estuarine Resident** - species of marine origin that reside in estuaries and can complete their entire lifecycle within these systems
4. **Estuarine Migrant** - species of marine origin that usually reside in estuaries as juveniles and adults but often have a marine larval phase
5. **Freshwater Migrant** - freshwater fish species that are often recorded in estuaries retreating into catchment rivers when conditions become unfavourable

6. **Freshwater Straggler** - freshwater fish species that sometimes enter estuaries when conditions are favourable
7. **Catadromous** - species that spawn at sea but use freshwater catchment areas during the juvenile and sub-adult life stages, and
8. **Anadromous** - species that spawn in freshwater environments but use estuaries and/or the sea for larval, juvenile and/or adult phases of their life cycle.

Using the above categorisation system, the fish species from the Murray Mouth, Lower Lakes and Coorong can be classified into these eight groups (see Table 2). This allows clear determination of the relative importance of free access to estuarine habitats with regard to species life history, reflecting those fishes most affected by closure of the Mouth.

Among the eight groups, Marine Migrants, Marine Stragglers, Estuarine Migrants, Catadromous and Anadromous species are those that will be directly affected by Mouth closure through impacts on population size or particular lifecycle stages.

As the Marine Stragglers do not rely upon the estuary to complete their lifecycle, they will persist locally with the Mouth closed and hence will not be affected in the long-term by Mouth closure. The prevention of migration into the estuary for these species will result in a short-term reduction of biodiversity in the Coorong, but it is expected that this would return to present levels following the opening of the Mouth to the sea, re-establishment of suitable water quality and the presence of suitable food/prey.

From Table 2, it can be seen that the following species will be directly affected by Mouth closure due to an interrupted lifecycle:

Climbing Galaxias (*Galaxias brevipinnis*)
Common Galaxias (*Galaxias maculatus*)
Pouched Lamprey (*Geotria australis*)
Short-Headed Lamprey (*Mordacia mordax*)
Shortfin Eel (*Anguilla autralis*)
Estuary Perch (*Macquaria colonorum*)
Congolli or Tupong (*Pseudophritis urvilli*)
Jumping Mullet (*Liza argentea*)
Yellow-Eye Mullet (*Aldrichetta forsteri*)
Southern Sea Garfish (*Hyporhamphus regularis*)
Mulloway or Dew Fish (*Argyrosomus hololepidotus*)
Sea Mullet (*Mugil cephalus*).

This list includes many of the species harvested by commercial and recreational fishers in the Coorong and a sizeable contribution to the diversity and abundance of Lower Lakes fauna.

The Goolwa Cockle (*Donax deltoides*), although not residing inside the Coorong, lives in populations on the surf beaches just outside the Mouth and its recruitment is believed to be strongly related to River Murray flow (Murray-Jones *et al.* 2002). With the closure of the Mouth, the recruitment of Goolwa Cockles onto the beach from adult populations may be depressed in the next season due to a reduction in food availability (see pg 22 'Fishing Industry' chapter). From recent studies during periods of near-continual River flow (2001 to 2002), it was found that there was always a proportion of the local Cockle population able to spawn. When flow is released, food availability increases, triggering the 'ripe' animals to spawn. Length frequency distribution data for Cockles on Goowa Beach shows several separate recruitment events (Murray-Jones *et al.* 2002).

Any interruption in successful recruitment or spawning for larger species will undoubtedly affect the economic viability of the commercial and recreational fishing industry, as well as the tourism industry of the area.

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As most Cockles are two or more years of age before reaching minimum legal length, the effects of lifecycle interruption will initially be masked. Over time, the effect will be reflected as a decrease in catch per unit of fishing effort in the commercial returns supplied to SARDI by commercial fishers.

The Catadromous and Anadromous freshwater species together with the Estuarine Resident species will probably not be affected by Mouth closure in the short term, except through secondary impacts such as:

- Salinity increases
- Reduced food availability
- Increased frequency of predator-prey interactions (due to the 'concentration' of residents)
- Increased risk of algal blooms (toxicity and/or eutrophication), and
- Reduced dissolved oxygen levels.

For the above mentioned species and to a lesser extent Catadromous and Anadromous species, fish passage across the barrages between the estuary and the Lower Lakes/ Lower Murray is of more relevance with regard to inhibition of lifecycle stages.

Species that will be indirectly affected by Mouth closure due to degraded water quality and salinity impacts include:

Black Bream (*Acanthopagrus butcheri*)
Bridled Goby (*Arenogobius bifrenatus*)
Small-Mouthed Hardyhead (*Atherinosoma microstoma*)
Tamar Goby (*Favonigobius tamarensis*)
Swan River Goby (*Pseudogobius olorum*)
Greenback Flounder (*Rhombosolea tapirina*)
Lagoon Goby (*Tasmanogobius lasti*)
Flathead Gudgeon (*Philypnodon grandiceps*).

Two of these species are commercial or sought after as a game fish. The Small-Mouthed Hardyhead (*Atherinosoma microstoma*), a non-commercial species, is very important ecologically as a major prey species for many birds and predatory fishes including Mulloway (Molsher *et al.* 1994, Hall 1986). If the Coorong population was depleted (for example, fish kills arising from low oxygen levels), the effect could be disastrous for the ecology of the region. (See 'Migratory Waders' chapter.) Because the macroinvertebrates that inhabit the Coorong complete their entire lifecycle within the estuary/lagoons, they will be affected similarly to the estuarine resident fish species.

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Table 2: Impacts of Mouth closure on recorded ichthyofauna of Coorong, Murray Mouth and Lower Lakes

(Some life history patterns of these species are inferred due to lack of data on those species within the Coorong itself.)

Primary Impacts
long term implications
short term implications

Secondary Impacts

Unaffected

* If landlocked, *G.maculatus* can reproduce entirely in freshwater

# denotes exotic taxa

^ denotes locally extinct taxa

Scientific Name		Common Name	Whitfield Classification
Galaxias	*brevipinnis*	climbing galaxias	Anadromous
Galaxias	*maculatus*	Common galaxias	Anadromous*
Geotria	*australis*	pouched lamprey	Anadromous
Mordacia	*mordax*	Short-headed lamprey	Anadromous
Anguilla	*australis*	Shortfin Eel	Catadromous
Macquaria	*colonorum*	Estuary Perch	Catadromous
Pseudaphritis	*urvillii*	Congolli	Catadromous / Estuarine Resident
Liza	*argentea*	jumping mullet	Estuarine Migrant
Aldrichetta	*forsteri*	Yellow-eye mullet	Estuarine Migrant / Resident
Hyporhamphus	*regularis*	River garfish	Estuarine Migrant / Resident
Acanthopagrus	*butcheri*	Black bream	Estuarine Resident
Arenigobius	*bifrenatus*	Bridled goby	Estuarine Resident
Atherinosoma	*microstoma*	Smallmouth hardyhead	Estuarine Resident
Favonigobius	*tamarensis*	Tamar goby	Estuarine Resident
Pseudogobius	*olorum*	Bluespot or Swan River Goby	Estuarine Resident
Rhombosolea	*tapirina*	Greenback flounder	Estuarine Resident
Tasmanogobius	*lasti*	Lagoon goby	Estuarine Resident
Philypnodon	*grandiceps*	Flathead gudgeon	Freshwater Migrant
Hypseleotris spp.		Carp gudgeon complex	Freshwater Straggler
Philypnodonsp.		Dwarf flathead gudgeon	Freshwater Straggler
Bidyanus	*Bidyanus*	Silver perch	Freshwater Straggler
Carassius	*auratus#*	Goldfish	Freshwater Straggler
Craterocephalus	*fluviatilus*	Murray hardyhead	Freshwater Straggler
Craterocephalus	*stercusmuscarum fulvus*	Fly specked hardyhead	Freshwater Straggler
Cryprinus	*carpio#*	Carp	Freshwater Straggler
Gadopsis	*mormoratus*	River blackfish	Freshwater Straggler
Galaxias	*olidus*	Mountain galaxias	Freshwater Straggler
Gambusia	*holbrooki #*	Eastern Gambusia	Freshwater Straggler
Leiopotherapon	*unicolor*	Spangled perch	Freshwater Straggler
Maccullochella	*peeli*	Murray Cod	Freshwater Straggler
Macquaria	*ambigua*	Golden Perch	Freshwater Straggler
Melanotaenia	*fluviatilis*	Crimson spotted rainbowfish	Freshwater Straggler
Morgunda	*adspersa ^*	Purple spotted gudgeon	Freshwater Straggler
Nannoperca	*australis*	Southern Pygmy perch	Freshwater Straggler
Nematolosa	*erebi*	Bony bream	Freshwater Straggler
Oncorhynchus	*mykiss#*	Rainbow trout	Freshwater Straggler
Perca	*fluviatilis#*	Redfin	Freshwater Straggler

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Tahle 2 cont.

Retropinna semoni	Australian smelt	Freshwater Straggler
Salmo trutta#	Brown trout	Freshwater Straggler
Tandanus Tandanus	Freshwater eel-tailed catfish	Freshwater Straggler
Tinca tinca#	Tench	Freshwater Straggler
Argyrosomus hololepidotus	Mulloway	Marine Migrant
mugil cephalus	Sea mullet	Marine Migrant
Achoerodus gouldii	Blue grouper	Marine Straggler
Aracana ornata	Ornate cowfish	Marine Straggler
Arripis georgianus	Australian herring	Marine Straggler
Arripis truttaceus	Australian salmon	Marine Straggler
Chelidonichthys kumu	Red Gurnard	Marine Straggler
Contusus brevicaudus	Prickly toadfish	Marine Straggler
Crapatalus arenarius	Sand fish	Marine Straggler
Cristiceps australis	Southern crested weedfish	Marine Straggler
Engraulis australis	Southern anchovy	Marine Straggler
Enoplosus armatus	Old wife	Marine Straggler
Eubalichthys gunnii	Gunn's leatherjacket	Marine Straggler
Gymnapistes marmoratus	South Australian Cobbler	Marine Straggler
Heliocolenus percoides	Red Gurnard Perch	Marine Straggler
Helotes sexilineatus	Striped perch	Marine Straggler
Heteroclinus tristis	Longnose weedfish	Marine Straggler
Hippocompus abdominalis	Big-bellied seahorse	Marine Straggler
Hyperlophus vittatus	Sandy sprat	Marine Straggler
Hyporhamphus melanochir	Southern Sea garfish	Marine Straggler
Melambaphes zebra	Zebra fish	Marine Straggler
Meuschenia freycineti	Six-spined leatherjacket	Marine Straggler
Mitsukurina owstoni	Goblin shark	Marine Straggler
Neosebastes nigropunctatus	Black Spotted gurnard perch	Marine Straggler
Neosebastes scorpaenoides	Common gurnard perch	Marine Straggler
Pagrus auratus	Snapper	Marine Straggler
Parika scaber	velvet leatherjacket	Marine Straggler
Phyllopteryx taeniolatus	Common Seadragon	Marine Straggler
Pristiophorus nudipinnis	Southern saw shark	Marine Straggler
Pseudocaranx dentex	Trevally	Marine Straggler
Scobinichthys granulatus	Rough leatherjacket	Marine Straggler
Sillaginodes punctatus	King George whiting	Marine Straggler
Spratelloides robustus	Blue sprat	Marine Straggler
Syngnathus curtirostris	Short-snouted pipefish	Marine Straggler
Tetractenos glaber	Smooth toadfish	Marine Straggler
Tetractenos hamiltoni	Richardson's toadfish	Marine Straggler

Implications of Mouth closure on macroinvertebrates & fishes of the Coorong

Diminished flow of freshwater into estuaries is a worldwide phenomenon resulting from heavy and competing demands for irrigation and domestic usage (Geddes and Hall 1990). One problem that results from reduced or low flows reaching the Coorong is a lessened volume of water available to maintain the geomorphologic character of the Murray Mouth channel (see 'What is Possible: Hydrology and Morphology' chapter).

During periods of reduced or low flow and low rainfall, the Murray Mouth is of central importance because sea water becomes the major source of water to 'freshen' the Coorong and to maintain water quality in the Murray estuary and Coorong (Geddes and Hall 1990).

If turbulence is low, processes like littoral drift cause complex sand bars to develop across the Mouth, greatly impeding water exchange and effectively isolating the estuary and the Coorong from the sea (Harvey 2001). This 'closure' has multiple effects on the plants and animals of the Coorong and Murray estuary. Not only would Mouth closure largely prevent fish and other organisms from migrating between the Coorong and the sea, thereby affecting lifecycle processes, but sand deposited inside the Mouth will also smother the productive mudflats in the local area of the Mouth, affecting food resources and water quality for birds and fish.

Further, secondary consequences of Mouth closure relate to elevated salinities and possible reduced dissolved oxygen concentration in the Coorong, as well as the effect of reduced food availability and increased predator-prey interactions due to the impact of increased salinity reducing suitable habitat for all species.

Short-term closures may have a comparatively small effect on fish populations if:

- Closure occurs outside times when salinity and water quality rapidly degrade, or
- Closure occurs outside periods of migration out of the Coorong by sub-adults or into the estuary by larvae and juveniles of Marine Migrant species or adults of Catadromous species.

Present knowledge of migration patterns for many of the relevant species is deficient for the Coorong, and so it is very difficult to determine what are the most detrimental times for Mouth closure are thereby representing an urgent area for investigation. Hall (1984) states that closures during the period of November to April are most likely to affect migration, whilst water quality and salinity are most likely to rapidly change during the summer period if the Mouth is closed.

Complete closures of the Murray Mouth have happened many times in the past, but have not been paralleled by a River Murray as restricted in flow or the pressure placed on aquatic ecosystems from a variety of sources as witnessed today. Previous recent and historic closures have fortunately been short in duration, with the Mouth being re-opened by flow or a combination of flow and human intervention (excavation) before significant degradation in water quality occurred. The risk now with reduced Murray median flows and diminished flooding frequency and duration, is that closure may persist for the long-term.

It is possible that during periods of prolonged low flow and Mouth closure that salinities may rise beyond the tolerance levels of some of the biota of the Coorong in the Southern Lagoon and even in the Northern Lagoon (Geddes and Hall 1990), thereby limiting distribution to the estuary and part of the Northern Lagoon. Although to date salinity in the southern end of the Northern Lagoon has not been observed by Geddes or others to rise above

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80‰, this salinity level is believed to be outside the range of many of the fishes listed as residing in the Murray estuary.

If closure persisted for an extended period with little or no input of water to 'freshen' the Coorong, low summer oxygen concentration potentially exacerbated by algal blooms may produce fish kills in these areas. If the area suitable for fish and invertebrates is substantially reduced because of rising salinity, the effects outlined above will be exacerbated by the relatively high density of fish in the area near the Murray estuary.

Conclusion

While closure of the Murray Mouth is just one reflection of the vastly altered hydrology of the River Murray, it has the potential to severely affect the local fish community.

The most severe effect would be witnessed if the Mouth remains closed for longer than a year. A 'short-term' closure is expected to result in a catch reduction of many of the recreational and commercial species harvested in and around the Coorong in the short term only.

Any closure of the Murray Mouth has the ability to impact on local biodiversity by restricting the migratory requirements of a number of non-commercial species and exceeding their physiochemical tolerances. Only if a closure was sufficiently short, and not during the hottest months, would salinity and water quality be expected to remain within tolerable limits over much of the Murray estuary and Northern Lagoon, allowing the persistence of the estuarine fish populations that presently reside within the Coorong.

By providing for fish passage across the barrages and into the Lower Lakes, the useable habitat in times of Mouth closure or low flow periods for estuarine species and some marine migrants will be significantly increased. This could possibly then improve not only the overall fishery during periods of flow, but also improve the 'elasticity' of the system to recover following Mouth closures through re-colonisation of the Coorong lagoons and the Murray estuary under more favourable conditions by populations retained in the lakes.

More information regarding migratory requirements of the resident fish species is required together with the impact of salinity on the productivity of the system, especially impacts of salinity on reproduction and growth in macroinvertebrates and resident fish species.

Information regarding the effect of salinity upon life-history for many of the fish and invertebrate species that utilize the Coorong is lacking. This knowledge would greatly assist managers and custodians in the sustainable management of the industries reliant upon the fish and macroinvertebrates of the Coorong. Research into fish passage and Lower Lakes habitat use is also recommended to better assess this as a method of mitigating Mouth closure effects on species utilizing the estuary.

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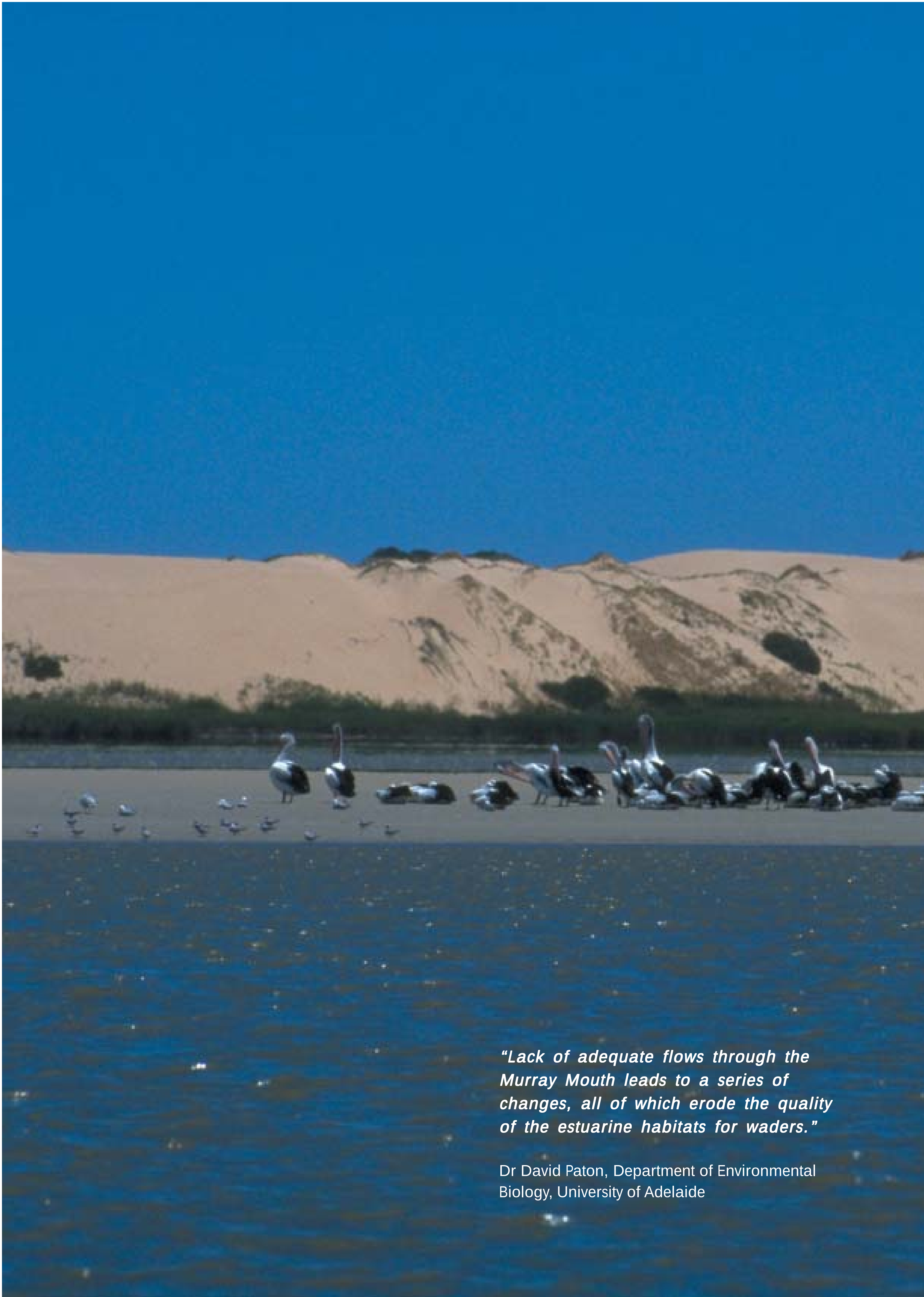

"Lack of adequate flows through the Murray Mouth leads to a series of changes, all of which erode the quality of the estuarine habitats for waders."

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Migratory Waders

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There have been significant reductions in the numbers of waders that use the estuarine regions associated with the Murray Mouth since the late 1960s. Lack of River flows has also led to reductions in the quality and quantity of the estuarine habitat available to shorebirds (waders).

This chapter assesses the likely effect that changes in flow over the barrages will have on estuarine habitats in the Murray Mouth region and in turn on small migratory waders.

Introduction

For the purposes of this chapter the estuarine area is defined as the waterways between the barrages and the Murray Mouth. This area stretches from Pelican Point on the Narrung Peninsula in the south to the Goolwa Barrage in the north.

These estuarine regions, along with samphire communities, were listed as the two environmental assets that were currently under extreme risk of ongoing degradation under the current management regime (ID & A 2001). In particular, the estuarine areas have experienced and are likely to experience further ongoing, significant ecological change as the Mouth becomes increasingly constricted. Furthermore, unless prompt action is taken, international obligations under the Ramsar Convention will not be met and key living and economic assets will become increasingly run down (ID & A 2001).

Walker (2001) has recently modelled how changes in flow over the barrages have influenced the extent of constriction to the Murray Mouth. He argues that if flows continue to be greatly reduced in volume and timing then the Mouth will remain significantly more restricted than under natural flows.

In conclusion, Walker (2001) explains that if the Murray Mouth closed then the immediate consequences are the risks of: flooding of towns, shack sites and agricultural land around Lakes Alexandrina and Albert; damage to the local tourism industry; public concern; and significant cost to re-open and clear the congested Mouth area. The extent of damage would depend on the duration of Murray Mouth closure and the intervals between closures.

In the longer term there would be issues of maintaining water quality in the Coorong, ecological damage to the Coorong, damage to the fishing industry in the Coorong and reductions in the conservation significance of the Mouth area and the Coorong.

Migratory Waders

Reductions in wader numbers using the estuarine region of the Murray Mouth

Over the last 30 or so years there has been a dramatic decline in the numbers of waders reported using the estuarine regions associated with the Murray Mouth.

In the 1960s in excess of 250 000 small migratory waders were recorded in one section of the estuarine region alone (Paton 1982). Subsequently, the numbers of small migratory waders counted in the region have dropped. In the 1980s there were 20 000 to 35 000 small migratory waders present in the estuarine region as a whole, while in the 1990s and 2000s there were only 3000 to 13 000 (see Table 1).

The declines have been particularly dramatic for Red-necked Stints (*Calidris ruficollis*) in recent years with counts for that species dropping from 14 000 to 24 000 in the 1980s to 6600 in 1994 to between 1541 and 5455 in the late 1990s and early 2000s (see Table 1).

Declines for the other species since the 1980s have not been as dramatic (see Table 1) (Wilson 2001).

The declines since the 1960s have been substantial and the cause(s) of the declines are not understood.

The magnitude of the declines, exceeding 50% for Red-necked Stints since the 1980s, is sufficient for that species to be listed within the region as Endangered under IUCN (2000) criterion A2. The causes of the declines may not be reversible, and are likely to be ongoing.

Activities and actions taking place anywhere within the range of the species (for example, along their migratory routes, at breeding grounds or in the non-breeding areas used in southern Australia), however, may be responsible for the declines.

Simply dismissing the declines as being due to factors outside Australia and/or outside the Coorong (for example, Wilson 2001), although providing a convenient scapegoat to relinquish responsibility, does not diminish Australia's responsibilities under international agreements (for example, the Ramsar Convention, the Japan-Australia Migratory Birds Agreement for the protection of Migratory Birds and Birds in Danger of Extinction and their Environment (JAMBA) and the Agreement between Australia and China for the Protection of Migratory Birds and their Environment (CAMBA)) to protect and enhance the habitats used by these migratory species.

In any case, the declines in Red-necked Stints cannot be easily attributed to environmental changes outside the Coorong. For example, if factors along the migratory routes used by the birds or at their breeding grounds were largely responsible, then the declines should be sustained across the whole of southern Australia. This, however, is not the case. Red-necked Stints, which tend to show high fidelity to their non-breeding 'wintering' sites (pers comm. J. R. Wilson), do not show such declines in at least one other area (note: few areas are regularly counted). Annual counts of Red-necked Stints in Westernport Bay, Victoria from 1980 to 2000 show no obvious decline in numbers over 20 years (Wilson 2001). Given this result, the dramatic changes in abundances of Red-necked Stints in the region of the Murray Mouth are more likely to be related to changes in local conditions.

Reductions in flows of freshwater into the estuarine area are likely to lead to reductions in the quantity and quality of estuarine habitats in the vicinity of the Murray Mouth and this ongoing loss of habitat and habitat quality could contribute to the decline of these birds.

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Table 1: Numbers of migratory and non-migratory waders counted in the estuarine regions between the Barrages and Murray Mouth during the 1980s, 1990s and 2000s

Species	1982 (Feb)[1]	1987 (Feb)[2]	1994 (Feb)[3]	1999 (Feb)[4]	1999 (Feb)[5]	2000 (Jan)[6]	2000 (Feb)[7]	2001 (Jan)[8]	2001 (Feb)[9]	2001 (Feb)[10]
Small Migratory Waders										
Red-necked Stint	14358	24363	6665	1541	2589	5202	4824	3368	5427	5455
Curlew Sandpiper	3036	6124	3000	1437	453	1459	4289	193	1410	2020
Sharp-tailed Sandpiper	4928	5119	2088	1276	148	5463	3398	1172	1864	1486
Sanderling	129	308	140				512		53	
Terek Sandpiper					5					3
Common Sandpiper		1	2	2	3	2				
Ruddy Turnstone			1							
unidentified small waders				340						
Total small migratory waders	22451	35915	11896	4595	3198	12126	13023	4733	8754	8964
Larger migratory waders										
Greenshank	360	237	160	347	376	333	253	132	188	249
Marsh Sandpiper		1	2	4						
Red Knot							80			
Great Knot							1			
Pacific Golden Plover	214	120	31	79	206	13	45	19	68	106
Grey Plover							9			
Black-tailed Godwit	185	105	26			140	210		115	1
Bar-tailed Godwit		2		1	2	1	8			
Whimbrel					3					1
Eastern Curlew	15	3	7	13	15	1	15			8
Japanese Snipe			1							
Double-banded Plover					7					
Total larger migratory waders	774	468	227	444	609	488	621	151	371	365
Endemic waders										
Red-capped Plover	242	79	188	356	251	180	76	24	285	266
Hooded Plover										1
Black-winged Stilt	319	59	33			250	170	125	144	156
Banded Stilt	94		500	5				47	16	138
Red-necked Avocet	444	21	150		17			44	49	24
Masked Lapwing	282	115	150	186	344	103	61	208	208	145
Pied Oystercatcher	170	25	65	34	25	31	39	56	7	92
Sooty Oystercatcher		1	100		21	28				1
Total endemic waders	1551	300	1186	581	658	592	346	504	709	823

Migratory Waders

Changes in the area of estuarine habitats in the region of the Murray Mouth

The area of estuarine habitat in the Lower Lakes and Murray Mouth region changed substantially following the construction of the barrages in the late 1930s. Estimates suggest that the estuarine areas are now around 12% of the area that they once were (Pierce 1995). Furthermore, they now lack the gradual transition between fresh and marine water. As a consequence the remnant estuary is likely to experience more abrupt changes in salinity. In addition, following extended periods with no freshwater flows over the barrages, estuarine salinities (that is, those salinities between fresh and marine) may be absent entirely from the region. Prior to barrage construction the estuarine conditions would have simply shifted further upstream when there were no flows and so would not have been temporarily eliminated.

Unfortunately, there are no estimates of the numbers of birds using the region before the construction of the barrages and so no way of assessing the likely impact on wader populations of losing substantial areas of estuarine habitat.

Since the estuarine regions have stayed more or less the same in area since the construction of the barrages, this suggests that area per se is not involved in recent declines. However, this fails to take into account changes in the accessibility of estuarine shorelines to the waders. As illustrated below, the actual area of estuarine habitat accessible to waders is reduced when the Murray Mouth is constricted.

Changes in the quality of estuarine habitats in the region of the Murray Mouth

Lack of adequate flows through the Murray Mouth leads to a series of changes, all of which erode the quality of the estuarine habitats for waders.

First, the lack of flows allows coarse marine sands to be pushed into the estuary. These coarse sands are likely to change the nature of the sediments. For example, coarse sediments or sediments with high sand content are known to reduce the growth rates, survival and abundance of invertebrates in other estuaries (for example, Quammen 1982, Wanink and Zwarts 1993). Furthermore, Quammen (1982) reported that heavy siltation of an intertidal lagoon due to flooding resulted in much finer sediments, a 2.4-fold increase in prey availability and a 20-fold increase in numbers of shorebirds using the lagoon compared with previous years.

Coarse sediments may also interfere with the birds' foraging, making prey capture more difficult because the birds can no longer easily distinguish between the size of the prey and the size of the larger sand grains (Quammen 1982).

In another study, sediment types also influenced feeding densities of waders (Nehls and Tiedemann 1993). Thus, reductions in the volumes and changes in the frequency, timing and duration of releases of water over the barrages clearly have the potential to erode habitat quality and feeding efficiency for migratory waders and other shorebirds. Consistent with this, Paton *et al*. (2000) reported lower abundances of benthic invertebrates in sediments with a high proportion of coarse sand compared to the numbers found in fine sediments where invertebrate densities were as much as four times higher.

Finally, the lack of flows leads to a reduction in the width of the Murray Mouth and to congestion of the channels inside the estuary due to incursions of marine sands (Walker 2001). This, in turn, leads to substantial reductions in the tidal flux and hence reductions in the intertidal zone around the shoreline.

A reduction in the intertidal zone reduces the availability of habitat to waders. Most small waders are limited in where they can forage by the length of their legs. For species like Red-necked Stints with short legs, foraging is limited to shores and mudflats covered by no more than about 3cm of water.

According to models produced by Walker (2001) when the Mouth and channels are not restricted, the amplitude of regular tidal changes in water level are typically of the order of 0.5m or more within the estuarine regions. However, under the current flow conditions the Mouth is restricted and the tidal flux greatly reduced to the point where it varies by 0.2m or less over tidal cycles (that is, is dampened by at least 60%).

For waders feeding around the shoreline, normal tidal changes in water levels shift the foraging of the birds over a relatively wide band of intertidal shoreline with the birds simply shifting their foraging up and down the intertidal zone with changes in water level. This spreads the foraging effort of the birds more broadly over the mudflats of the estuary. However, when there is limited tidal flux the birds are restricted to a narrower band of the mudflats. In other words, the availability of accessible habitat is reduced to about 40% of what could be available to the birds if the Mouth was not as constricted. Thus, the potential of the current estuarine area to support populations of waders that forage around the shoreline is reduced.

Furthermore, when the foraging of the birds is concentrated on a smaller area of habitat for longer each day there is far greater potential for the birds to reduce their food supply. Thus, not only is the area of habitat suitable for foraging reduced for the waders, but the waders are more likely to erode the quality of that habitat.

Ironically, total closure of the Mouth might lead to a slight elevation in water level fluctuations above those that currently exist due to wind-induced water level changes. These changes, however, would not operate on the same time scales as the regular twice-daily changes associated with tides. At most, the level of wind-induced water level changes will be 0.3m (based on measurements taken in the southern Coorong) when the Mouth is fully closed, and probably much lower depending on how much the constricted channels dampen water movements within the enclosed estuary. Furthermore, water levels might not change for extended periods of time (several days) if there is little wind or little change in the direction and strength of the wind.

When the Mouth is open, changes in water level generated by changes in the direction and intensity of winds will be masked substantially by the tidal changes.

Finally, when the Mouth and associated channels are constricted, releases of freshwater over the barrages are more likely to lead to water levels rising substantially within the estuary. When this happens, most of the shallow mudflats will be covered by too much water that will effectively prevent shorebirds from having access to the sediments, particularly those with short legs.

During late December and early January 2000-2001, an attempt was made to flush the Murray Mouth by releasing a substantial volume of water over the barrages. This resulted in all of the tidally exposed mudflats within the estuary being totally flooded, forcing almost all the waders to vacate the area (pers comm. R. Owen). The low numbers of waders counted in the estuarine regions on 13 January 2001 (see Table 1) may in part have been due to the earlier flooding of the birds' habitat, even though the barrages had been closed for ten days before these counts were made.

Conclusion

There is sufficient evidence to show that under the current management regime the estuarine habitats are declining in area and quality, particularly as habitat for migratory waders.

The lack of adequate flows of water to the Mouth of the River Murray will continue to erode the estuarine habitats of the region. Coincident with this, the abundances of migratory waders have declined substantially over the last 30 to 40 years. Based on changes in abundances of one species, the Red-necked Stint, the magnitude of the changes in the last 20 years alone is sufficient for the species to be classified as Endangered for the region under IUCN (2000) criteria.

Continuing to allow these estuarine habitats to deteriorate contravenes Australia's obligations under a series of international agreements, including the Ramsar Convention, JAMBA and CAMBA. Our knowledge of natural systems remains severely limited, and this impedes management decisions, but we do know that complete closure of the Murray Mouth will exacerbate the degradation.

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"A consequence [of River regulation] is a depauperate flora, weed invasion and a loss of biodiversity... To do nothing and allow the Murray Mouth to close would... further reduce plant biodiversity."

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Aquatic Plant Communities

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Jensen et al. (2000) reviewed the River Murray barrages and the environmental flow requirement of the Lower Lakes and Coorong. Since then, Walker (2001) has modelled the influence of freshwater flows on the opening of the Murray Mouth.

These two publications provide the background for this discussion on the implications to aquatic plant communities of Murray Mouth closure. This discussion is divided into sections dealing with: plant succession; fresh, brackish and salt water flora; plant biodiversity; hydrology; and the ecological consequences of additional annual flows

Introduction

Although there are no precise descriptions of the flora prior to the construction of the barrages, there is sufficient ecological knowledge to infer the likely status of the Murray estuary.

The historical environment of the Lower Lakes and the Murray estuary would have been dynamic allowing a succession of plant species to come and go. These species would have provided a diverse range of habitat, food source, nesting and hiding places, as well as contributing to the primary production of the ecosystem.

Plant succession: A response to natural flows?

Historically, the Murray estuary was subjected to a fluctuating environment (Newman 2000). Average spring flows of 1400GL to 1600GL per month from the Murray produced a freshwater environment from August to November (Walker 2001, 2002). These flows were ideal for the germination and growth of many freshwater aquatic plants (van der Valk 1981).

As flow decreased in December, these plants would have experienced increasing salinity stress which would have promoted flowering

Photograph: Mapland SA/Andrew Tatnell

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and seed set (Payne 1998), thereby ensuring a replenishment of the seed bank and/or the formation of asexual propagules (for example, modified underground stems such as rhizomes from which new shoots arise, or turions above ground that are starch filled reproductive structures found in Tassels *Ruppia* spp). Mud flats would also have been opened up to support a succession of mud flat dependent species (Rea and Ganf 1994, Payne 1998, Siebentritt *et al.* 2002). Low flows were of sufficient duration for species to grow and flower before the River flows began to increase again in April and May.

Historically, salinity tolerant plant communities (*Ruppia* spp – Clubrush *Isolepsis* spp, Beaded Samphire *Sarcocornia quinqueflora* – Emu Grass *Distichlis distichophylla*, Samphire *Halosarcia* spp – *Distichlis distichophylla*) would have dominated the saline mud flats during times of minimal flow from February to April.

The Murray Mouth provided habitat for marine angiosperms such as Eelgrass *Zostera muelleri* and Seagrass *Heterozostera tasmanica* and macroalgal communities (Paton 1982, Edyvane *et al.* 1996).

The transition zone between fresh and saline water provided an ideal habitat for floodplain and littoral species such as Sea Club Rush *Bolboschoenus caldwelli,* Marsh Club-rush *B. medianus*, Brass Buttons *Cotula coronopifolia*, Pale Rush *Juncus pallidus*, Sea Rush *Juncus kraussi*, Creeping Monkey Flower *Mimulus repens*, Water Finger-grass *Paspalum distichum*, Coastal clubrush *Schoenoplectus littoralis*, and on the higher ground by two species of Thatching Grass *Gahnia* (*G. filum* and *G. trifida*).

Submerged species in the zone of fluctuating salinity would have included species now present in the Coorong such as Tuberous tassel *Ruppia tuberosa*, Many-fruit tassel *R. polycarpa* and Large-fruit tassel *R. megacarpa* as well as Long-fruit Water-mat *Lepilaena cylindrocarpa* and the more salt tolerant species of Pond Weed *Potamogeton* (for example, *Potamogeton pectinatus*).

The Stoneworts *Chara* spp, *Nitella* spp and *Lamprothanium* spp would have flourished in brackish water.

The freshwater areas would have included emergent vegetation such as Cumbungi/ Bullrush *Typha domingensis*, Common reed *Phragmites australis* and possibly members of the genus *Baumea* (Rushes) and other members of the *Cyperaceae* (for example, Spiny Flat Sedge *Cyperus gymnocaulus*, Spikerush *Eleocharis* spp and Sharp Leaf Sedge *Schoenoplectus pungens*).

The submerged and semi-emergent vegetation would have included species such as Water Ribbons *Triglochin procerum*, Lax-marshflower *Villarsia reniformis*, Ribbon Weed *Vallisneria americana* and Milfoil *Myriophyllum* spp, as well as species belonging to the genus *Potamogeton.*

Fresh v brackish v saltwater flora

A comparison of the flora associated with the northern (freshwater) and southern (salt water) shores and inundated areas of Hindmarsh Island (Renfrey *et al.* 1989, Edyvane *et al.* 1996, Ganf 2000) demonstrates how increasing salinity influences the floristic composition. Thus, the more saline and permanent waters of the Coorong and Murray estuary are dominated by three species of *Ruppia*, *Lepilaena* and Foxtail Stonewort *Lamprothamnium papulosum*. In addition, the saline but less permanently inundated soils of the coastal region are dominated by *Sarcocornia quinqueflora*, *Halosarcia* spp, Saltmarsh *Wilsonia* spp, Austral seablite *Suadea australis* and Swamp Reed *Selliera radicans*, as well as the more terrestrial members of the *Chenopodiaceae* (for example, Ruby Saltbush *Enchylaena tomentosa*).

Typha spp, *Phragmites australis* and *Bolboschoenus medianus*, *B. caldwelli* dominate the emergent vegetation on the northern, freshwater side of the barrages. These often form dense monospecific (single species) stands that obscure the smaller species that add to the biodiversity of the area. For example, Bladderwort *Utricularia* spp., Duckweeds: *Wolfia* spp., *Lemna* spp., and *Spirodella* spp and many of the shade loving Stoneworts (*Nitella* spp and *Chara* spp), as well as herbland species such as Streaked Arrowgrass *Triglochin striatum* which occur beneath the canopy of these extensive stands.

Submerged plants frequent the freshwaters to the north of Hindmarsh Island and Rat Island (for example, *Vallisneria americana*, Hornwort *Ceratophyllum demersum* and *Potamogeton tricarinatus*).

The subtidal salt water habitat is characterised by opportunistic macroalgal species, such as *Enteromorpha* and *Rhizoclonium*, but the complete absence of sea grasses.

Plant biodiversity

Prior to River regulation, a rich diversity of plants were distributed across the floodplain, temporary wetlands and main channel. However, with the increase in turbidity the aquatic flora is now restricted to the littoral zone and the lack of inundation of the floodplain, coupled with grazing and clearing, has impacted upon plant biodiversity.

The submerged vegetation in the Lower Lakes is now restricted to inshore areas, whereas anecdotal evidence suggests that these species were once more widely distributed throughout the Lake basin.

The explorer Sturt commented on the extreme variability of the water clarity that ranged from transparent to so turbid that it was impossible to see objects (Blanch 1997). In 1962, following exceptionally stable water levels and low turbidities (< 25NTU), Harris (1963) described a rich aquatic flora 20km upstream of Blanchetown which extended out into the main channel 20 or 30 feet (8-10m). Whether this water clarity was apparent in the Lower Lakes and the Mouth is unknown.

Due to a lack of ecological foresight, the construction of the barrages and the over use of water has not only increased the probability of the closure of the River Murray Mouth but also dramatically reduced plant biodiversity.

The plant successional sequences that occurred as the River discharges ebbed and flowed have been replaced by a static system punctuated by sudden and often ill-timed water releases of insufficient duration to allow completion of the life cycle. Partial completion of the life cycle does not permit a species to replace itself via seed set or asexual reproductive strategies.

A consequence is a depauperate flora, weed invasion and a loss of biodiversity. The 1995 biological survey of the Murray Mouth concluded that although estuaries are traditionally areas of low biodiversity, the Murray Mouth had a particularly low diversity that was attributable to poor water quality and flow manipulation (Edyvane *et al.* 1996).

Hydrology

The River Murray, the Lower Lakes and wetlands as well as the Northern and Southern lagoons of the Coorong have been subjected to intense manipulation. The diversion of the Snowy River, the construction of the deflation basin lakes in New South Wales, dam construction (Hume, Dartmouth) and the drainage system in south-east South Australia are a few examples. These have dramatically altered the hydrology. (For a more detailed discussion on hydrology, see 'What is Possible: Hydrology and Morphology' chapter.)

Aquatic Plant Communities

Mitsch and Gosselink (1993) state that the hydrology is the most important variable in wetland design and it is not surprising that major ecological changes have occurred. Furthermore, the hydrology is currently subject to further manipulation via the input of brackish water into the Southern Lagoon of the Coorong from the drainage system in the upper south-east of South Australia.

The most recent assessment of the behaviour of the River Murray Mouth (Walker 2001) was done in isolation from the effects that the Upper South-East Drainage System will have upon the Southern Lagoon of the Coorong. Walker notes, however, that within living memory the Mouth and its environs have been subject to extended periods of freshwater to estuarine conditions with wide fluctuations in salinity.

However, the construction of the barrages has led to freshwater conditions in Lake Alexandrina and the periodic freshening of the Coorong in the vicinity of the Murray Mouth as freshwater is released from the barrages.

More recently, the Murray Mouth has closed or partially closed as a result of reduced flows in the River Murray and the location of the barrages. This has caused the entrapment of millions of cubic metres of sand inside the Mouth.

A comparison between the unregulated River and the current regulated condition demonstrates that the regulated River Mouth is more likely to close under the current regulation than under a natural flow regime.

Furthermore, Walker (2001) explores the status of the Murray Mouth with additional flows of 0GL to 1200GL per either an annual pulse in September, an evenly spaced monthly release or a flow pattern that mimics more closely the historical flows. He concludes that to do nothing would cause the Mouth to close frequently and sand to accumulate in the Mundoo Channel making boat passage difficult if not impossible (see pg 27 'Recreation and Tourism' chapter). The outcomes of the other options would decrease the probability of the closure of the Mouth.

Another option briefly considered by Walker (2001) was the removal of the barrages. He concludes (pers com) that even though this option would increase the tidal prism, it is doubtful whether this option would prevent the accumulation of sediment behind the Mouth without the benefit of additional environmental flows. The reduced water velocity in the Coorong would allow sedimentation of sand brought in on the incoming tide due to rough coastal conditions stirring up the sand.

Ecological onsequences of additional annual flows

To 'do nothing' is undesirable for a number of reasons (see Walker 2001 and 'Migratory Birds' chapter). It is also undesirable for plant communities.

The sudden spatial transition from fresh to saline water provides little habitat for intermediate species and the duration of the freshwater flows is inconsistent with plant growth and reproduction. The accumulation and continually shifting sand in the estuary during low or non-existent freshwater flows provides an unstable substrate that prevents the establishment of plant communities. Consequently, the biodiversity of the macrophyte (macroscopic submerged, floating or emergent plants), marine angiosperm (flowering plants) and macroalgae (seaweeds) communities, particularly south of the barrages, is low. The occurrence of the opportunistic macroalgal species, such as *Enteromorpha* and *Rhizoclonium,* and filamentous algae, such as *Cladophora* spp and *Oscillatoria* spp, indicate a eutrophic (nutrient rich) environment. A similar situation occurred in the Peel-Harvey estuary in West Australia (State of the Environment Advisory Council 1996) which required major expenditure to solve. Furthermore, there are many international examples (Scheffer *et al.* 2001) of how shallow lakes have undergone a catastrophic shift from one stable state to another. Higher water residence times as a function of the lack of flushing have been implicated in the switch from macrophyte dominated states to algal dominated states and the appearance of turbid as opposed to clear water. This shift may proceed exponentially and is often difficult to reverse (Harris 2001). Closure of the Murray Mouth and the associated lack of flushing, sediment and nutrient accumulation are likely to increase the probability of this type of catsatrophic shift towards a cyanobacterial dominated system (Australian State of the Environment 2001).

The two additional options considered by Walker (2001 and pg 94 'What is Possible: Hydrology and Morphology' chapter) appear to achieve the objective of reducing the number of months the Mouth would close. However, both options have ecological consequences.

An annual flush concentrated in a single month is not recommended since it would be inconsistent with plant growth requirements (for example, rising water levels, sudden shift in salinity, insufficient duration).

Evenly spaced monthly releases or a release pattern that mimics natural flow are more likely to promote the growth of aquatic plants and have the additional benefit of flushing problematic algal blooms out to the ocean. It would be interesting to explore what the effect would be on the Murray Mouth if the annual supplements suggested by Walker were distributed differentially across the barrages (Goolwa, Mundoo, Boundary Creek, Ewe Island, and Tauwitchere). This will be the subject of consideration in the near future.

Nevertheless, additional annual flows of 500GL to 600GL represent a significant fraction of the average (6000GL per year), median (4047GL per year) or entitlement (1850GL per year) flow to South Australia (Newman 2000). Irrigation (30%, 573GL), metropolitan Adelaide and other towns (10%, 180GL) require 40% of South Australia's annual entitlement (1850GL). The remaining 60% of the entitlement covers the evaporative losses from the Lower Lakes and the transmission (passage) along the River channel (Newman 2000). In addition, at least 35 000ML are required each day to flood upstream wetlands and floodplain. Whether the flows required to maintain an open River Mouth are justifiable when balanced against the upstream requirements has not been debated but needs to be if the ecological problems of the River Mouth are not to be transferred upstream. The additional brackish water entering the Southern Lagoon of the Coorong (Boon 2000) further complicates the ecological state of the region. It does seem inappropriate to consider the Murray Mouth, the Lower Lakes, the Coorong and the upstream environment in isolation from one another.

Aquatic Plant Communities

Conclusion

Prior to River regulation, a rich diversity of plants was distributed across the floodplain, temporary wetlands and main channel. However, with the increase in turbidity the aquatic flora is now restricted to the littoral zone and the lack of inundation of the floodplain, coupled with grazing and clearing, has impacted upon plant biodiversity. Furthermore, an increased water residence time with the closure of the Murray Mouth (>60 days) would greatly increase the probability of a single celled algae (for example, toxic cyanobacteria or dinoflagellates, (State of the Environment 1996)) dominated ecosystem replacing a macrophyte dominated system.

As mentioned above, the 1995 biological survey of the Murray Mouth concluded that although estuaries are traditionally areas of low biodiversity the Murray Mouth had a particularly low diversity that was attributable to poor water quality and flow manipulation (Edyvane *et al,* 1996).

To do nothing and allow the Murray Mouth to close would be undesirable for plant communities, allowing depauperate conditions to further reduce plant biodiversity.

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"Should the Mouth close…, [it] would cease to act as a sediment sink and the sand would bypass the closed entrance."

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Coastal Processes

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The Murray Mouth has been restricted for many years now and the effects of this are clearly evident. The effects of closure on coastal processes, however, are somewhat different from those of restriction.

The following discussion explores the likely effects that restriction or closure of the Murray Mouth will have on coastal processes along the ocean shorelines of the Younghusband and Sir Richard peninsulas.

6

Introduction

The current severe restriction of the Murray Mouth is acting as a mechanism for further restriction.

The Mouth absorbs large amounts of sand from the coastal zone which would otherwise continue along the coast.

Should the Mouth close, the mechanism by which the Mouth absorbs sand would no longer operate as there would be no tidal intrusion through the Mouth. The Mouth would cease to act as a sediment sink and the sand would bypass the closed entrance.

Flow conditions

The influence of the barrages is to restrict the volume of seawater flowing through the Mouth each tidal cycle. The barrages prevent tidal movements from raising and lowering the water levels in the Coorong and Lakes Alexandrina and Albert. If there were no input of fresh water from the River system, the flows through the Mouth would consist only of the oscillatory tidal currents. As it is, there is currently a severely limited amount of fresh water from the River and this allows only a small flow of water through the Mouth to sea.

Littoral conditions

The coast on the seaward sides of the Coorong and Younghusband and Sir Richard peninsulas is high-energy beach upon which breaks a persistent south-westerly swell (Short 2000). This swell and the locally-generated wind waves break on the beach, suspending sand which is moved along the coast from the

Coastal Processes

south-east to north-west by the ocean current (a process know as littoral transport). This is evident from the steady movement of the Murray Mouth in a north-westerly direction in recent years. This means that the stability of Sir Richard Peninsula is at least partly dependent on sediment moving along the coast from the Coorong, along the Younghusband Peninsula and across the Murray Mouth.

Regular surveys inside the Murray Mouth since 1999 have provided information that gives some indication of the rate of sand movement along the coast. Between December 1999 and June 2000 the sand deposit inside the Mouth increased in volume by 88 000m^3. Assuming that the Mouth did not trap all of the sediment within the littoral transport system, the rate at which sand is moved (the net littoral transport rate) must exceed 176 000m^3 a year.

Reissen and Chappell (1993) used the sediment transport models developed by the US Coastal Engineering Research Center (CERC 1984) to determine littoral drift rates adjacent to the Murray Mouth. They calculated that the average net littoral drift rate between 1940 and 1990 was 260 000m^3 a year.

The influence of the Murray Mouth

The flows in and out of the Murray Mouth have a significant role to play in transporting sediment through and across the Mouth.

The tidal flows alone do not result in a net flow in or out of the Mouth. Sand suspended by wave action on the coast is transported into the Mouth by flood tides. Once inside the Mouth, there is less energy available to maintain the sediment in suspension as the waves do not extend far into the Mouth. Without the water being stirred up by the waves, the sand drops out of suspension and is deposited inside the Mouth.

Ebb tide flows alone are not sufficient to then transport all of this sediment out of the Mouth and back into the littoral system, especially with the reduced tidal prism.

The deposits in the Mouth initially form a flood tide shoal, which can then build up into sand bars and islands. The restriction caused by the flood tide delta, sand bars and islands further reduces the tidal prism. The limited River flows are not a sufficient addition to the tidal flows to clear the accumulated sediment from the area inside the Mouth.

Historically, the Mouth was mobile, and wandering along the coast depending on the wave, current and River flow climate (pers comm. EJ Barnett 2002, see also 'Introduction'). It is likely that sand accumulated in the Mouth during periods of low River flow, but that periodic flooding would have ejected significant quantities of sediment from the Mouth into the coastal zone. These flood events are restricted by the control of the River flows. The peninsulas themselves have not been breached by flood flows to create a new Mouth since the sea level stabilised to its current level, approximately 6600 years ago (Barnett 1993).

The sand that is trapped within the Mouth is not available down drift of the Mouth on the Sir Richard Peninsula and beyond as a supply of sediment for littoral processes. The erosion of the Sir Richard Peninsula, and corresponding accretion of the Younghusband Peninsula, is clearly evident as the Mouth progresses north-west. The restriction and redirection of the flows in the Mouth because of the sand accumulation have further contributed to the erosion of the Sir Richard Peninsula in recent years.

Conclusions

The Murray Mouth is currently significantly restricted and is acting as a sink for sand which enters the Mouth from the coastal littoral system. The sand entering the Mouth acts to further constrict the flow which exacerbates the situation. The restriction in the supply of sand to the downdrift side of the Mouth, the Sir Richard Peninsula, is allowing the Peninsula to erode and the Mouth to move steadily north-west.

If the Mouth became blocked with sand and closed, it would cease to absorb sand from the beach system and the littoral drift would continue along the beach uninterrupted. The scour and erosion-induced movement of the Sir Richard Peninsula would stop, although aeolian (wind-blown) movement of sand would obviously continue, especially given that the erosion has exposed large areas of unvegetated dune to the elements.

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The final solution, however, is likely to depend to a large extent on determining a viable pattern of releases from the Lower Lakes taking into account the health of the total River system.

What is possible: Hydrology & Morphology

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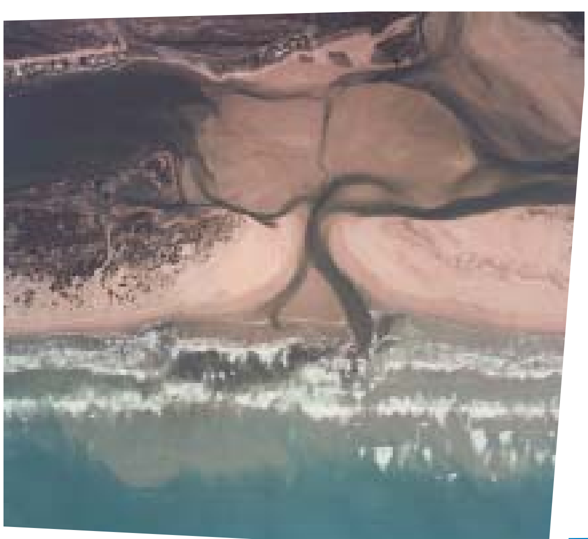
Recent concerns about the state of the River Murray Mouth have renewed interest in its behaviour, and in particular what measures might be taken to maintain an effective opening.

The following discussion outlines work undertaken to quantify the Mouth's opening and to determine if it is possible to manipulate flows so as to optimise the Mouth's opening

Introduction

For much of 1999, the Mouth was observed to move steadily towards total closure as large quantities of sediment were deposited on the flood tidal delta, restricting flows, water exchange and navigation. The situation at the Mouth in early 2000 is shown in Figure 1. The photograph shows a severely restricted Mouth with a series of well-defined channels crossing an extensive flood tidal delta.

Figure 1: River Murray Mouth, 29 February 2000



Current understanding of tidal inlets indicates that the state of tidal mouths depends on two factors: river flows and the coastal climate. The tendency for inlets of this type to close periodically has been observed in many seasonally open inlets both in Australia and around the world (Australian Parliament Senate Standing Committee 1981, Bally 1987, Ranasinghe and Pattiaratchi 1999). In this respect, the situation at the Murray Mouth is not unexpected, although closure would be a radical departure from historical behaviour.

Historical context

The size of the Mouth has varied from being several hundred metres wide during heavy flood flows to a situation where it closed completely at low tides in April 1981. The Mouth, at the time of the closure in 1981, is shown in Figure 2. It is evident that the blockage involved not just a plug of sand in the Mouth, but an extensive flood tidal delta that had built up over the preceeding months adjacent to Bird Island.

Main photograph: Murray-Darling Basin Commission

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Figure 2: River Murray Mouth in April 1981, showing full blockage at the Mouth and restriction of water exchange between the Goolwa (left) and Tauwitchere (right) channels.

Low flows and their effects, however, are not a recent phenomenon. What has changed is the frequency at which the low flow events occur.

According to Cullen (1999), over 80% of the median flow at the Mouth of the Murray is now removed for irrigation and other uses, and drought conditions occur one year in two rather than one year in twenty under natural conditions. Thomson (1994) found that at the Mouth low flows (less than 5000GL/year) occurred 7% of the time under natural conditions but 66% of the time under regulated conditions. Also at the Mouth, high flows (greater than 25 000GL/year) occurred 5% of the time under natural conditions and 2% of the time under regulated conditions. Thomson also points out that it is not just the flow that has been removed but the fact that the annual spring high-flow events are either much lower or fail to occur at all.

Following closure in 1981, the Mouth was opened artificially and then kept open by winter and spring River flows. Based on observations at the time, it was suggested that flows of 25 000ML/day to 30 000ML/day were required to expand and maintain the artificial opening. Currently, much effort is going into attempting to determine how to use River flows most efficiently to maintain an opening.

To illustrate the change in flows, Figure 3 shows the predicted flows at the Murray Mouth under natural and regulated conditions for a 10-year period. The flow predictions, supplied by the Murray-Darling Basin Commission, were based on a computer simulation that uses known River flows at an upstream lock and takes account of known water extractions, predicted losses due to seepage and evaporation, and the effects of barrage operation and Lower Lake levels. The predictions are necessary because the actual flow over the barrages is not measured. In Figure 3, the general reduction in flow is evident, as is the reduction in the peaks that would normally have occurred on an annual basis.

The change in the annual cycle of flows is best illustrated in Figure 4, re-drawn from Thomson (1994), which shows the median flow at the Murray Mouth under natural and regulated conditions. The spring peak in flows is seen to occur earlier with a significantly reduced flow rate.

Estimating Mouth Opening

The River Murray Mouth, its position and size, has been the subject of investigation and study since the days of European colonisation in the 1830s. However, proper study of its size has been hampered by a lack of quantitative data. While there have been a number of surveys of the Mouth region, the area does not lend itself to easy measurement although modern methods are making the task easier.

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Figure 3: Predicted monthly flows at the Murray Mouth for 1990 to 2000

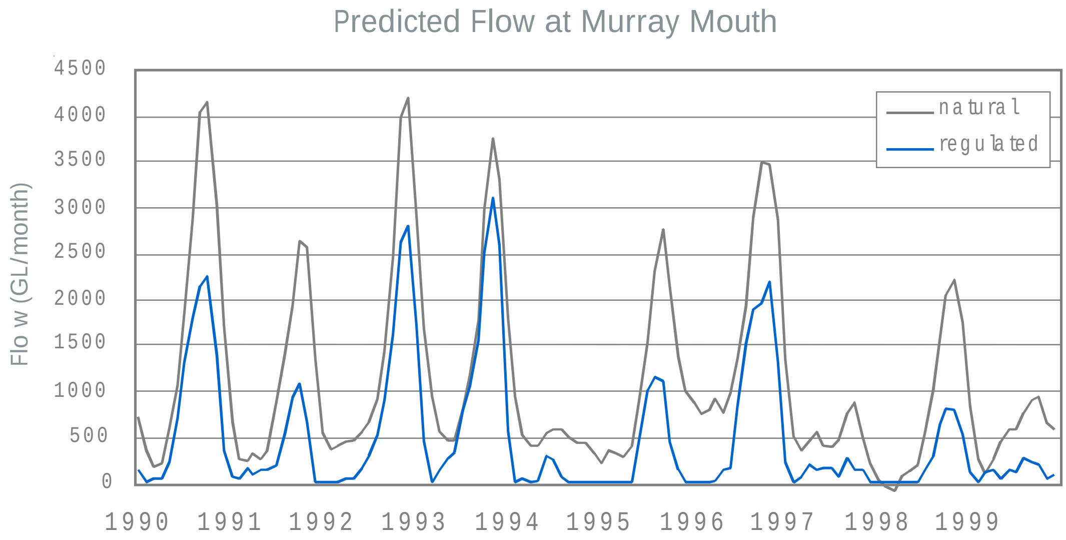


Figure 4: River Murray median monthly natural and current flows

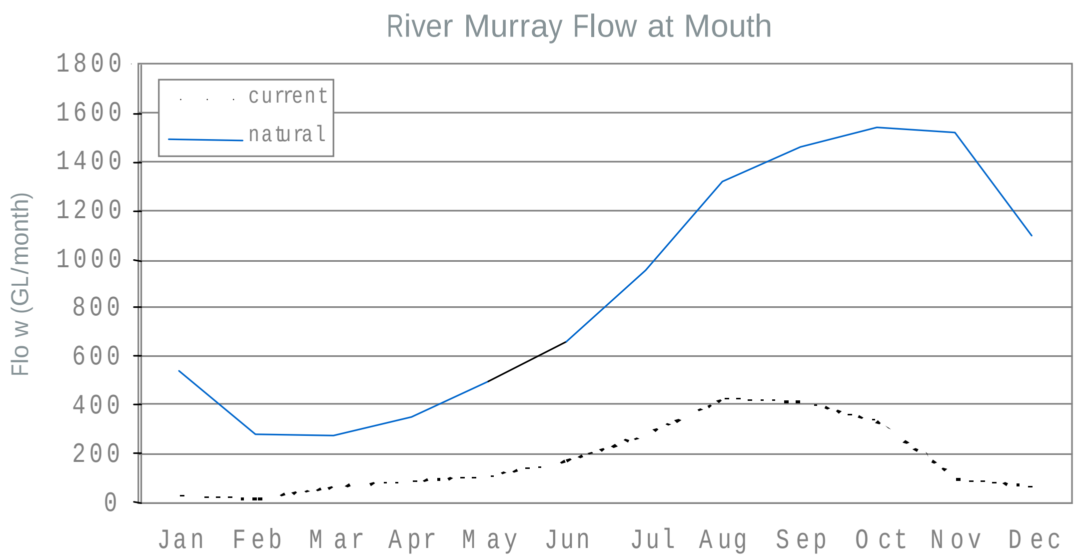
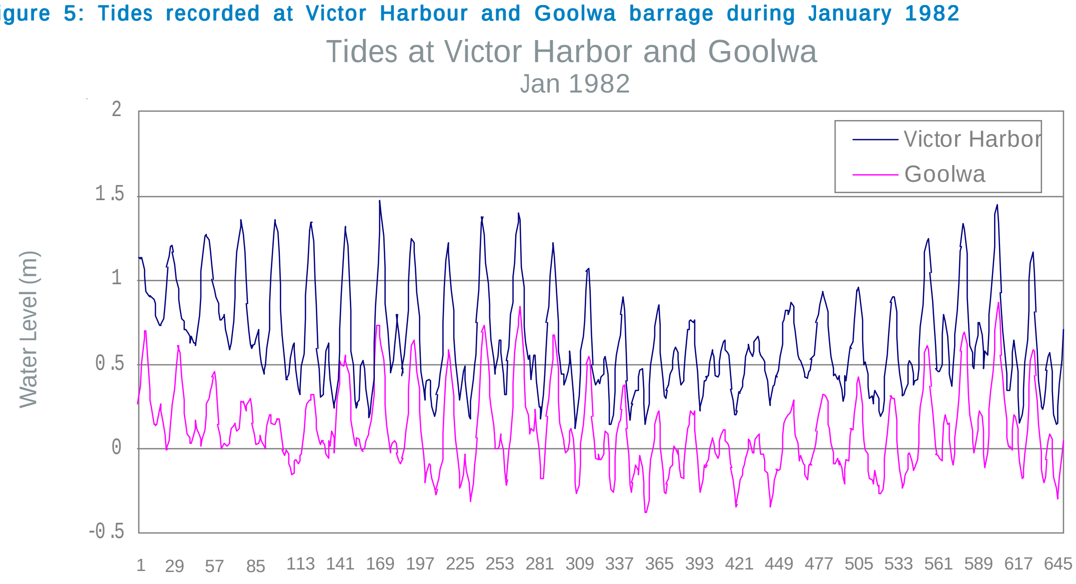


Figure 5: Tides recorded at Victor Harbour and Goolwa barrage during January 1982



(Note: The tidal signals have been displaced to assist in viewing the data.)

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Figure 6: Tides recorded at Victor Harbour and Goolwa barrage during January 1981

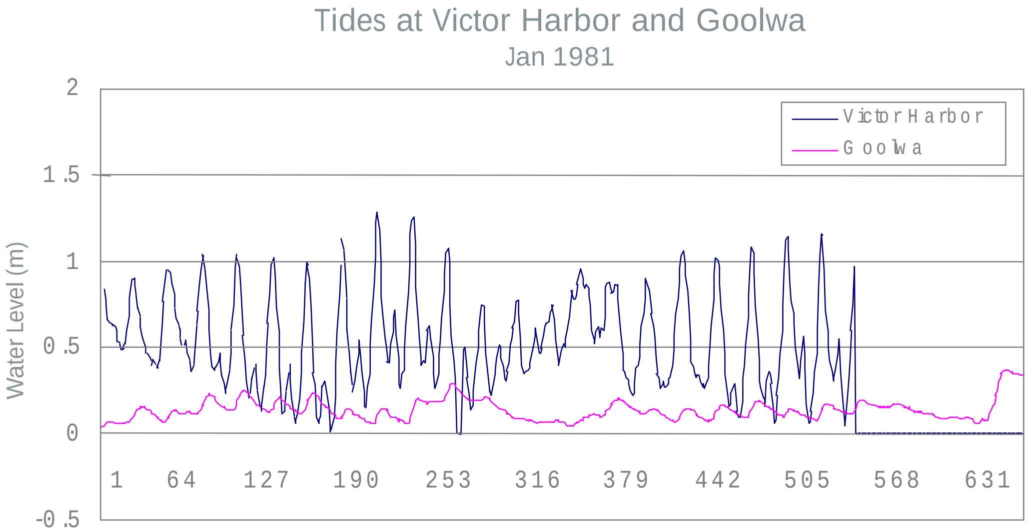


Figure 7: Tidal energy at Goolwa Barrage compared to the tidal energy at Victor Harbour

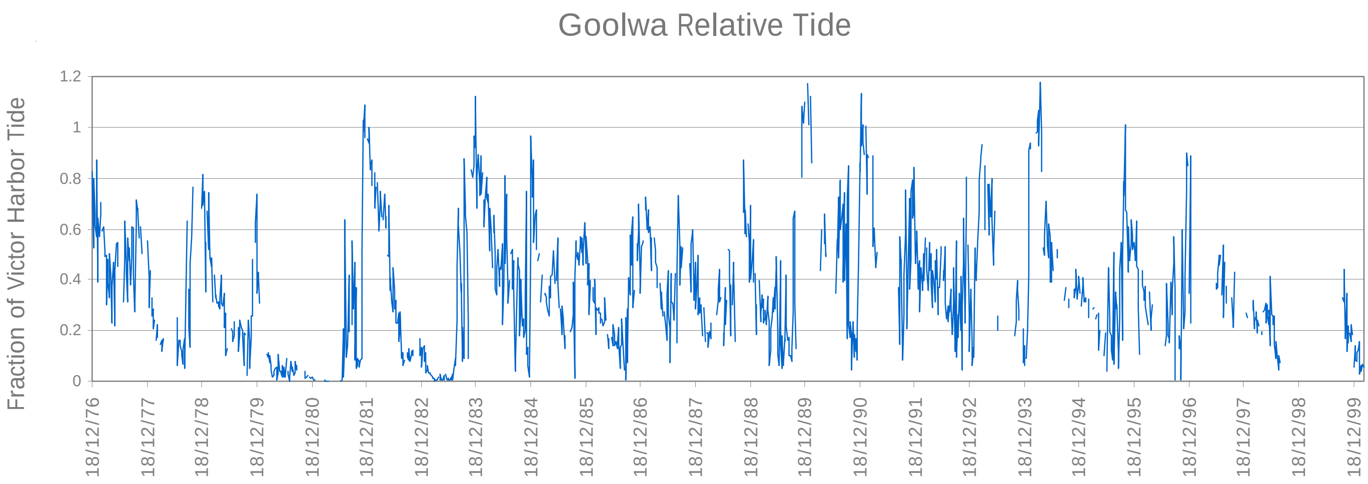
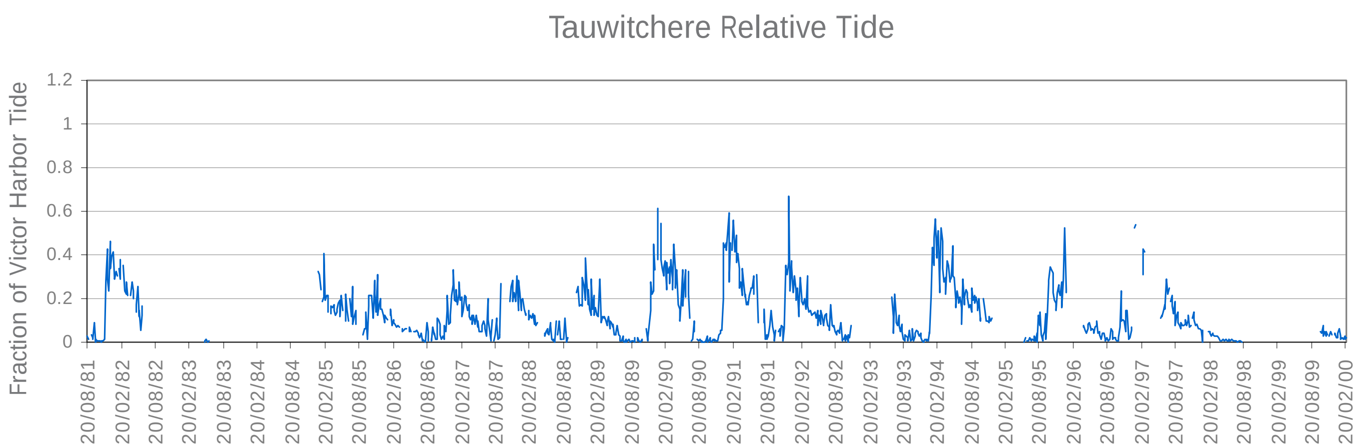


Figure 8: Tidal energy at Tauwitchere Barrage compared to the tidal energy at Victor Harbour



To overcome this lack of detail, Walker and Jessup (1992) used the tide data collected from Victor Harbour (outside the Mouth) and the Goolwa Barrage (inside the Mouth) to determine a measure of Mouth opening. The reasoning behind the method was that sediment building up in the Mouth would act to restrict the free flow of tidal waters from the ocean into the channels leading to the barrages. Any restriction would reduce tidal transmission and be reflected in reduced tidal amplitude at the barrages.
An example of an open Mouth, with good tidal transmission is shown in Figure 5. At this time in 1982 the Mouth had been cleared by high River flows and the tidal signal at Goolwa Barrage was almost identical to that at Victor Harbour.

An example of a restricted Mouth is shown in Figure 6 taken in 1981, just prior to closure. In this Figure the signal at Goolwa shows little resemblance to that at Victor Harbour indicating that the Mouth has effectively blocked tidal transmission.

The relative tidal energy (R) was defined:

$$R = \frac{E_{inside}}{E_{outside}}$$

where E = tidal energy in 12 hour components at locations inside and outside the Mouth. Based on this, R should vary between 0 (complete closure leading to no tides inside Mouth) to 1 (complete opening leading to full transmission of tides to barrages). Data from the tide gauges on the Goolwa and Tauwitchere barrages are shown in figures 7 and 8.

From these figures a number of features can be highlighted. In Figure 7 the variation in Mouth restriction is shown to have some long-term patterns and the closure of 1981 and near closure in 1983 are clearly visible. Recent restrictions in 1998, 1999 and 2000 are also evident although missing data leave some uncertainty in the fine detail.

In Figure 8 the size of the tide at Tauwitchere Barrage is much less than that at Goolwa. This can be explained by the long and narrow channel that leads to the Coorong and restricts the free flow of the tide. The tidal transmission at Tauwitchere shows some periodicity but, significantly, also appears to be reducing in the long-term.

Modelling Mouth Opening

Using a technique known as 'Time series analysis', Walker and Jessup (1992) were able to describe mathematically the variation in relative Mouth restriction at Goolwa Barrage in terms of River flow. The expression has recently been updated taking into account extra data and can be written:

$$R_t = 0.8\ R_{t-1} + 0.0002\ F_{t-2}$$

where R_t is the relative tidal energy in month t, and F_t is the estimated flow over the barrages (GL/month) in month *t*. (F_{t-2} is therefore the estimated flow two months previously).
The relationship indicates that at any particular time the relative Mouth opening depends on the opening in the previous month and the flow two months previously. Under zero flow conditions, the opening would reduce to 80% of the previous month's opening. If zero flows continued, the Mouth would continue to close to 64%, 51%, 41% and so on. The model predictions are shown in Figure 9.

Although the agreement between predicted and measured relative Mouth openings is not perfect, the model is shown to be able to reproduce, reasonably well, the various fluctuations that have occurred over the last 30 years. It should be noted that the only input data used to produce the predictions plotted in Figure 9 are the estimated River flows at the Mouth. The predicted flow over the barrages for the same period is shown in Figure 10.

(Note: the tidal signals have been displaced to assist in viewing the data.)

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Figure 9: Predicting Mouth closure using 'Times series analysis' model, 1972 - 2002

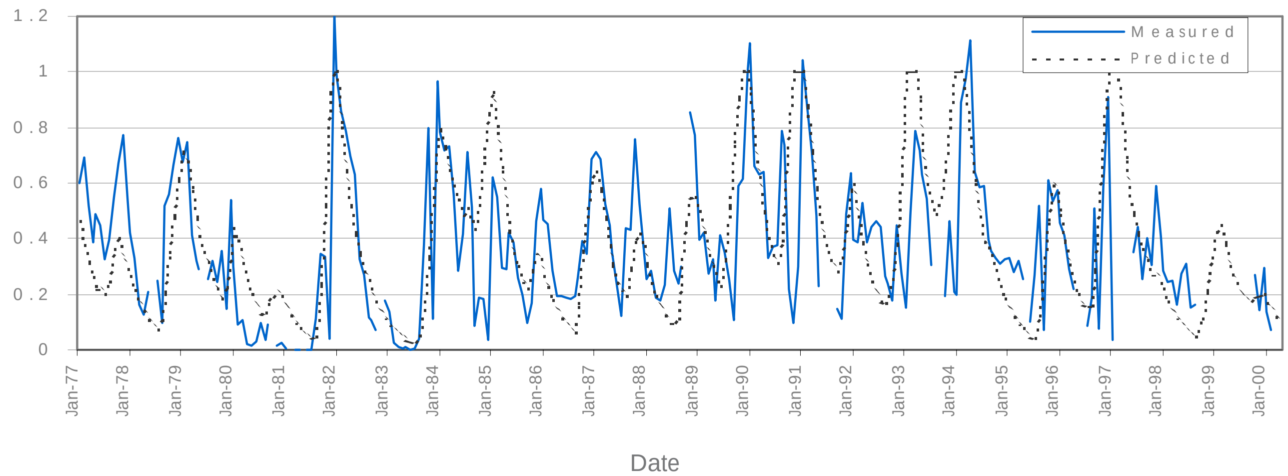


Figure 11: Predicted effect of additional flows either as an annual flush (Strategy option 1) or a monthly supplement (Strategy option 2).

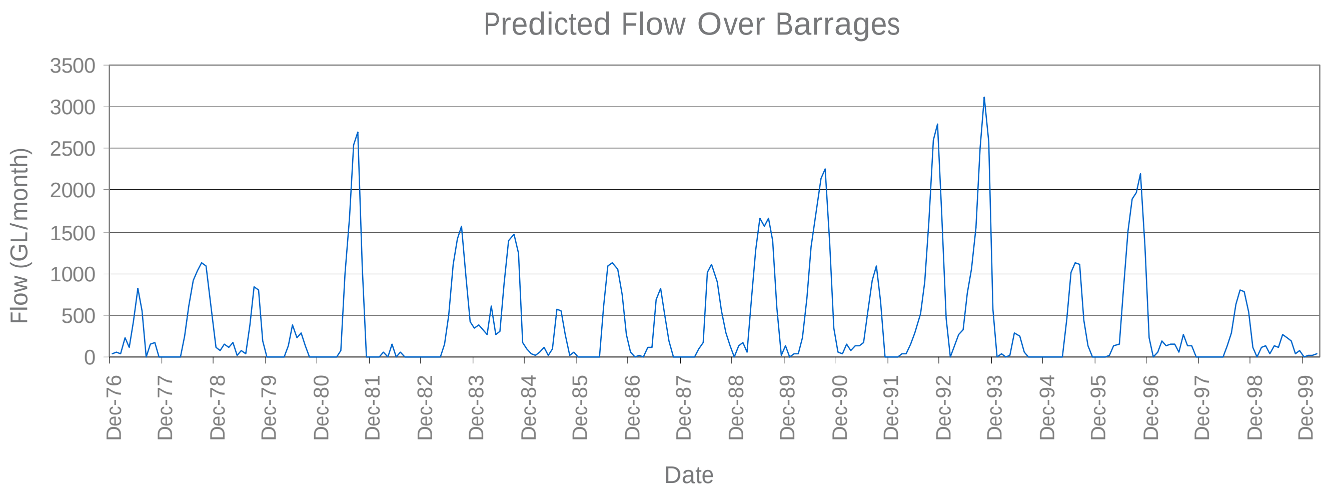
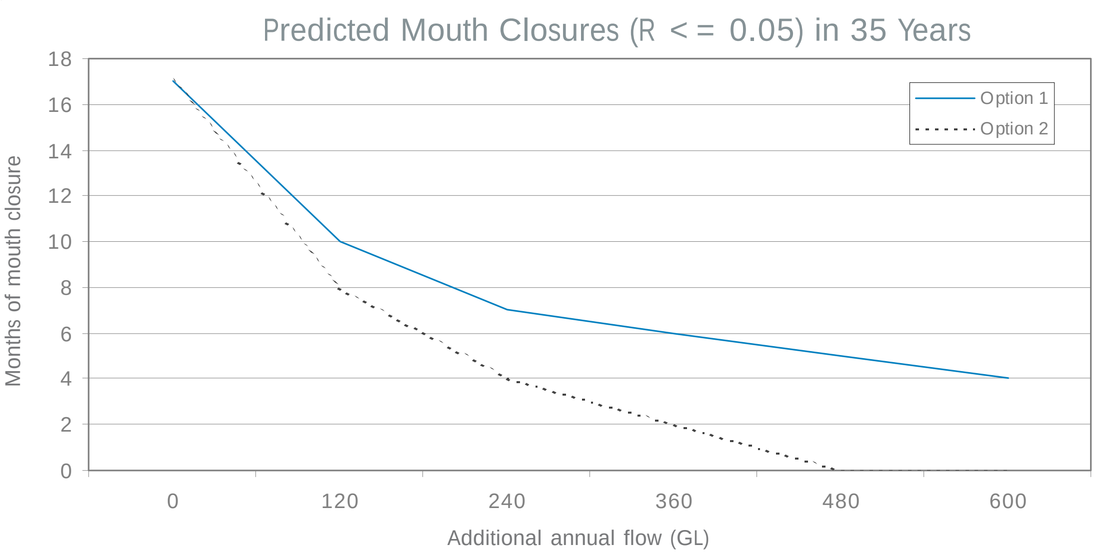


Figure 10: Predicted flow over the barrages, 1972 – 2002



The model also predicts the periods when the Mouth became severely restricted. Although, since it ignores the coastal processes, it is unlikely to be able to predict total closures accurately.

In addition to low flows, Culver (quoted in Australian Parliament Senate Standing Committee 1981) has observed that calm seas and reduced tides appear necessary for a complete closure. Work in Western Australia by Ranasinghe and Pattiaratchi (1999) has also highlighted the importance of coastal processes on the final closure of a restricted inlet.

Optimising Barrage Releases

The next phase in the study of the Murray Mouth is to determine if it is possible to manipulate the release of flows from the Lower Lakes over the barrages to optimise the Mouth opening.

Two basic strategies are being evaluated:

1. an annual concentrated discharge designed to flush out excess material that has built up on the flood tidal delta over the previous 12 months, and
2. additional flows to lift the month by month releases in an attempt to prevent the influx of sediment through the Mouth.

Early results indicate that both strategies should be effective, although an option that attempts to maintain some outflow throughout the whole year appears more effective based on the model developed to describe Mouth opening.

The options are compared in Figure 11 where a range of additional flows are assumed to be available to supplement what had been available historically over the last 35 years.

It is evident from the Figure that attempting to maintain even a low flow each month over the barrages and out the Mouth appears to provide a better result in terms of Mouth opening. This may be due to the fact that any flow from the River would tip the balance in the Mouth to a net outward flow that would assist in preventing sediment entering the inlet during a rising tide and assist in flushing during the ebb flows.

Conclusion

In conclusion, it can be seen that options exist for the maintenance of flows over the barrages to prevent Mouth closure.

The final solution, however, is likely to depend to a large extent on determining a viable pattern of releases from the Lower Lakes taking into account the health of the total River system.

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Glossary

aeolian	erosion and deposition of sediments by wind-blown movement
akinete	reproductive resting spores of plants
angiosperm	a flowering plant
anoxia	absence or deficiency of oxygen
benthic algae	a collection of plant species that thrive at the bottom of a water body, such as a lake. Many algae are primitive unicellular organisms.
bioassays	biological test
blackwater	polluted water (sewage or grey water) from boats
catchment	the area of land drained by a river and its tributaries
collodial	particles suspended within a liquid - not dissolved
cyanobacteria	aquatic bacteria that can photosynthesize
crustaceans	belonging to the Crustacea, a phylum of (chiefly aquatic) arthropod animals, including the lobsters, prawns, crabs, barnacles, slaters, etc., commonly having the body covered with a hard exoskeleton or carapace.
density stratification	formation of layers within water of different densities or weight.
destratifying	a natural feature of water bodies characterised by a vertical gradient in density caused by differential heating of the water surface and/or differences in salinity
dinoflagellates	microscopic, (usually) unicellular, flagellated, often photosynthetic protists, commonly regarded as “algae”
ebb tide	receding tide
entitlement flow	1850GL River flow per year guaranteed to South Australia each year under the Murray-Darling Agreement
epilimnion	a layer of water on the surface of some lakes
euryhaline	exhibiting or tolerating a wide range of salinity
eutrophic	having water high in nutrients
flocculate	collect into lumps or tufts
gigalitre	one thousand million litres
hypereutrophic	extremely high nutrients

hypermarine	ocean water with very high salinity
hypersaline	water with very high salinity
hypolimnion	the cold, lower layers of a body of water
ichthyofauna	the indigenous fish of a region
invertebrate	any organism that does not have a vertebral column and well developed brain or an animal lacking a backbone and internal skeleton
littoral zone	the area between the highest and lowest tide marks on the seashore
macroalgae	seaweed
macroinvertebrate	see 'invertebrate'
macrophytes	water plant that is not algae, and may be either floating or rooted
median flow	the flow that occurs in the most number of years
megalitre	one million litres
nutrients	any substance which has nutritious qualities – that is, which nourishes or promotes growth
pathogen	disease producing organism
propagules	any vegetative portions of a plant, such as a bud or other offshoot, that aid in dispersal of the species and from which a new individual may develop
saline intrusion	often referred to as a 'salt wedge', it is the intrusion of dense saline water from the sea below the fresher water in the river
shoal	a sandy elevation on the bottom of a body of water, a sandbank or sandbar.
stratifying	formation of layers
tidal prism	the volume of water that passes in and out of an inlet during a tidal cycle.
total Kjeldahl Nitrogen	inorganic nitrogen
total phosphorous	inorganic and organic phosphorus
turbidity	the murkiness of water caused by suspended sediment
turbulence	haphazard motion within water due to eddies

Abbreviations

ATSIC	Aboriginal and Torres Strait Islander Commission
AWQC	Australia Water Quality Centre
CAMBA	China and Australia Migratory Bird Agreement
CERC	Coastal Engineering Research Centre
cm	centimetres
EC	electroconductivity
g	grams
GL	gigalitres
IPCC	Intergovernmental Panel on Climate Change
IUCN	World Conservation Union
JAMBA	Japan and Australia Migratory Bird Agreement
L	litres
m	metres
MDBC	Murray-Darling Basin Commission
ML	megalitres
mL	millilitre
NTU	Nephelometric Turbidity Unit
ppm	parts per million
s	seconds
SARDI	South Australian Research and Development Institute
SATC	South Australian Tourism Commission
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
uS	microsiemens
WHO	World Health Organisation

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