River Murray Barrages

Environmental Flows

An evaluation of environmental flow needs in the Lower Lakes and Coorong

A report for the Murray – Darling Basin Commission — June 2000

MURRAY-DARLING BASIN COMMISSION

Department for Environment Heritage and Aboriginal Affairs
Government of South Australia

SIX GOVERNMENTS WORKING IN PARTNERSHIP WITH THE COMMUNITY

Edited by Anne Jensen, Michael Good, Prudence Tucker and Martine Long

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Project funded by
the Murray–Darling Basin Commission

Wetlands Management Program

Department for Water Resources

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CONTENTS

ILLUSTRATIONS

PLATES

FIGURES

TABLES

EXECUTIVE SUMMARY

BACKGROUND

The Murray-Darling Basin Commission (MDBC) is currently developing an environmental flow management program for the River Murray and Lower Darling River. This is being overseen by the Project Board for Environmental Flows and Water Quality objectives, which has sought input on key issues from a number of sources including expert scientific panels.

The development of an environmental flow management program is part of the Commission response to widespread concerns about the level of consumptive diversions from the river systems and the effects these are having on the condition of aquatic ecosystems within the basin.

A cap on further consumptive diversions was agreed by all the states in July 1997. This has provided further impetus to investigate options for optimising the benefits from the water available for the environment within the river systems. As part of this process the MDBC Project Board has sought an evaluation of environmental flow needs of the Lower Lakes and Coorong and an assessment of the opportunities for improved operation of the barrages to meet these needs. This report provides this assessment and evaluation.

PURPOSE OF THE STUDY

The objective of the River Murray Barrages Environmental Flows Project was:

> *to identify key environmental flow requirements in relation to management of flow through the barrages, and maintaining the ecosystem of the Lower Lakes, the Coorong Estuary and Coorong Lagoons.*

A Panel of appropriate scientific experts was drawn together to collaborate in the provision of this information. This Barrages Environmental Flows Project report by the Scientific Panel provides:

- an overview of the ecological needs of the region of the former River Murray estuary,
- an assessment of the environmental impacts of the barrages which separate marine and fresh waters near the Murray mouth,
- recommendations for changes in management to minimise these impacts.

This study has been conducted using a separate scientific panel to that used for the River Murray upstream of Wellington due to the different nature of the ecosystems involved.

The Barrages Scientific Panel comprises academic and state government agency experts in the fields of hydrology, geomorphology, riparian and aquatic vegetation, bird ecology, fish and invertebrate ecology and algal ecology. A steering Committee comprising state and MDBC agency staff has provided management advice.

BIOPHYSICAL ENVIRONMENT

The barrage structures divide the fresh waters of the Lower Lakes from the saltier waters of the Coorong and the sea just upstream of the Murray Mouth. Part of the original Murray estuary, the Coorong and Lower Lakes (Lake Albert and Lake Alexandrina) cover approximately 660 km2 adjoining the mouth of the River Murray. The Coorong is a narrow coastal lagoon running south-east from the river mouth for about 100 km, and is separated from the sea by a narrow dune system. The lakes are broad and shallow, with Lake Alexandrina containing a large number of sand and mud islands adjacent to the river mouth.

This diverse range of wetland habitats (marine, hypo-marine, hyper-marine, estuarine and freshwater) supports a high biological diversity. The entire area is of national and international conservation status, especially as habitat for birds. It is listed as a Ramsar Wetland, protected as a National Park and subject to two international bilateral migratory bird agreements (JAMBA and CAMBA). It also supports a significant commercial fishing industry, provides stock and domestic water supplies, and attracts major recreational fishing and boating use.

Since European settlement the area has been subject to many management pressures which threaten its conservation values. These include:

- an altered input flow regime due to upstream river regulation
- an altered lake and estuary flow regime due to the contruction of barrages separating the lakes from the mouth and the Coorong
- agricultural pressures (stock grazing, vegetation clearance and diffuse run off, nutrient pollution)
- recreational and tourism impacts (boating, fishing, 4WD vehicles)
- exotic plants and animals.

This report focuses primarily on the first and second issues due to their major impacts on flow regimes, influencing habitat changes, decline in native species and increases in exotic species.

KEY ISSUES

The Scientific panel identified four key issues driving the serious degradation of environmental values in the Lower Lakes and Coorong. These are:

- the reduced area of the estuary
- changed water regimes of the lakes and river
- freshening of brackish and saline habitats
- reduced habitat for aquatic plants

The first two issues are the most significant in terms of their impact and their influence in driving the other key issues.

In assessing the current status of the Lower Lakes and Coorong the panel found that:

- the River Murray does not end at the Barrages and flow management should take into account the flow regimes and ecological needs of the remnant estuary, the Coorong, the mouth channel and the offshore zone,
- the remnant estuary, including the northern and southern Coorong lagoons, is only 11% of the natural estuary area, with less fresh water inflows than the natural system allowing seawater to dominate conditions,
- total flow through the Murray system has been reduced to approximately one third of the median unregulated flow with the frequency of no flow at the river mouth increased from 1 year in 20 to approximately 1 year in 2,
- the current status and biodiversity of aquatic plant communities is reduced by the low through-flow of water, reasonably static water levels and high turbidity,
- the change to fresh water habitat and increasing nutrient inputs is favouring fresh water algal species in the Lower Lakes including bloom forming and potentially toxic cyanobacteria,
- the barrages have disrupted the transition between the fresh and salt water environments negatively affecting breeding and recruitment of estuarine plant and animal species,
- the abrupt changes in water level in the Coorong are limiting the available habitat for migratory birds which are protected under the China-Australia Migratory Bird Agreement (CAMBA) and the Japan-Australia Migratory Bird Agreement (JAMBA),
- the value of the commercial fishery in the remnant estuary is equal to that from the whole of the freshwater lakes which are nine times greater in area,
- the significant decline in fish catches is believed to be due to the rapid changes in flow and salinity caused by current barrage operation and the reduced estuarine area,
- the changed tidal and river flow conditions are increasing the likelihood of river mouth closures,
- the flow through Mundoo channel has been significantly reduced from natural conditions which is causing siltation of the mouth,
- the current limited evidence indicates that the primary major sources of sediment and nutrient inputs to the lakes are from their own catchments rather than from the River Murray,
- lake shore erosion caused by high constant lake levels, wind and highly erodible soils is a significant contributor of sediment and nutrients to the lakes.

In addition, the Panel identified two other long term issues of concern for the ecology of the Lower Lakes, Coorong and Murray Mouth area. These are concerns regarding the apparent increased frequency of major algal blooms and the salinisation of land surrounding the study area. These issues have not been addressed in this report as they will not be directly affected by management of the barrages in the short term.

Algal blooms and, in particular, toxic cyanobacterial (or blue-green algal) blooms, could have a significant effect on tourism and recreational uses of the area and may impact on the fishery.

Salinisation of the surrounding land by rising watertables could have significant long term effects on salt and water balances in the region.

In summary the Panel found that the current operating system for the Lower Lakes, Coorong and Murray Mouth is not sustainable with continued significant environmental degradation expected. In particular, it is anticipated that there will be increasing problems in both the lakes and the Coorong related to reduced through flows, increased sedimentation and accumulation of nutrients.

ECOLOGICAL NEEDS AND OUTCOMES

The Scientific Panel identified fifteen ecological changes needed to address these key issues. In addition the critical outcomes required to meet those needs were identified.

The ecological needs identified are:

1. protect aquatic plants in the Coorong and maximise mudflat habitat,
2. maximise estuarine area,
3. limit deposition at the Murray Mouth,
4. increase fish passage through the river mouth,
5. provide fish passage through the barrages,
6. protect and enhance salt marsh habitat around the Lower Lakes,
7. increase the diversity of riparian vegetation,
8. reduce sediment transport into the Coorong,
9. reduce nutrient inputs to the Lower Lakes,
10. maintain a diverse water quality regime in the estuary and the Coorong,
11. reduce exotic fish in the Lower Lakes,
12. increase aquatic vegetation throughout the Lower Lakes area,
13. reduce lake shore erosion,
14. reduce lake water turbidity.
15. reduce the area of dryland salinity affecting the Lower Lakes and Coorong,

KEY RECOMMENDATIONS

From these ecological needs, the Scientific Panel identified 15 opportunities for improved hydrological management (see Table i.1). These range from minor modifications to current operating procedures to investigations into major changes to the barrages. Implementation of the recommended package of actions would result in a significant improvement in the ecological condition of the area as well as social and economic benefits.

The broad categories of recommendations are:

- establish an environmental monitoring program as a basis for adaptive management,
- articulate detailed barrage operating guidelines to meet ecological needs,
- automate barrage gates for more flexible operation and sensitivity to ecological needs,
- investigate opportunities to manage lake levels over a greater range of levels,
- modify Mundoo Barrage to increase flow capacity and operate preferentially to limit sedimentation at the Murray mouth,
- evaluate options for relocation and revised management of the barrages to enlarge estuarine area to increase the range of habitats,
- undertake complementary measures (lake shore revegetation and stabilisation, carp control, regional revegetation),
- integrate flow management actions with other regional planing and management activities for maximum effectiveness.

The most significant short to medium term recommendation is for automation of the barrage gates and fine tuned operation to maximise fish passage, increase water bird habitat, increase the area of estuarine habitat and maximise the control of water quality.

Another key recommendation is to increase the scour capacity of the Mundoo Channel in order to restrict continuing sedimentation in the Murray Mouth Zone.

In the longer term, the feasibility of relocating the ageing barrage structures should be investigated, for the ecological benefits of increasing the area of the estuarine zone and the economic benefits of decreasing evaporative losses. Any feasibility study into this option should be linked to wider consultation and investigations regarding the social and economic implications of such a proposal.

The fundamental recommendation of the Scientific Panel is that these management changes should take place in a framework of active adaptive management, which requires the establishment of a monitoring baseline before any changes take place. Targeted monitoring designed to measure the effectiveness of various management strategies, with regular review (suggested at 5 yearly intervals) is required to evaluate and update these management strategies. Complemnetary actions such as control of lake shore erosion and revegetation of the lake catchment are also recommended.

IMPLEMENTATION

The entire package of recommendations should be implemented over the suggested timetable to provide the maximum ecological benefits. Many of these recommendations complement each other or are sequential or concurrent, with one action being dependent on or at least enhanced by others. For example fish passage would be promoted at low flows, while scouring of the river mouth zone would require medium to high flows to be effective. Importantly, long term actions need to be investigated in the medium term to allow sufficient time for planning.

A draft work program has been prepared by the steering committee for release with this report.

TABLE i.1 OPPORTUNITIES FOR IMPROVED HYDROLOGICAL MANAGEMENT

Implementation of short-term hydrological management opportunities (1-3 years)
(assuming work will commence by the end of 2000)

Code	Action	Timetable for actions	Work program (to be completed within time scales)
A1	Change the timing, sequence and frequency of opening and closing of barrage gates within current operating range of lake levels (0.60–0.85 m EL) to optimise the ecological, social and economic benefits.	2000	1 document the current operating guidelines and triggers (ie actions taken to achieve the operating rule of 0.75 m AHD lake levels) in order to identify constraints and opportunities for changes in operating guidelines
		2001	2 articulate detailed environmental operating principles and guidelines to meet identified ecological needs
		2001	3 implement short term optimal guidelines, for operation of the structures within the current agreed range of lake levels based on existing knowledge and an assessment of the environmental operating principles against social and economic constraints
		2000 (ongoing)	4 set up ecological monitoring program, based on active adaptive management principles and coordinate and include existing monitoring
A2	Develop specific arrangements for maximising the ecological benefit of the non-consumptive proportion of entitlement flows to South Australia	2000	5 identify short-term environmental flow needs (based on existing knowledge), eg for fish passage, in terms of volume, location, gate openings and timing
		2000 — 2001	6 develop specific rules and operating procedures for the use of environmental flows for maximum benefit at the barrages
A3	Assess proposal to build levees on island spillways to minimise impacts on the interface between fresh and salt water	2000 — 2001	7 assess spatial extent of salinity impacts from marine incursions (incorporate modelling and monitoring programs)
		2000	8 investigate alternative solutions to levees
		2001	9 cost-benefit analysis of proposed works
		2001	10 evaluate the proposal to construct levees as a basis for a decision as to whether to issue a permit for works under the Water Resources Act 1997

B1	Automate approximately 22% of gates across all five barrages and finetune timing sequence and frequency of opening and closing of automated barrage gates according to environmental guidelines within the current range of lake levels.	2000 — 2001	11 finalise feasibility studies of gate automation (engineering works, economics, funding arrangements etc)
		2000 — 2001	12 develop environmental guidelines for operation of automated gates within the currently agreed range of lake levels
		2001	13 install automated gates and operate within agreed guidelines.
		2000 (on-going)	14 monitor impacts of improved gate operation on fish movement, salinity control and ecological impacts.
		2001	15 design fish passage trials in land holder channels at Mundoo and at selected barrage gates
B2	Investigate operating automated gates at a greater range of lake levels (ie higher or lower than current 0.60-0.85 m EL).	2000 — 2001	16 assess the environmental needs for operation of the lakes over a wider range of levels and identify options for management of lake levels
		2000 — 2001	17 evaluate impacts of options and trade-off environmental, economic and social benefits against environmental, economic and social costs, using the Tong model of the estuary and Coorong lagoons to assess potential impacts and benefits of various management options
		2001	18 seek agreement on a trial of a new operating regime based on the preferred option
		2001 (on-going)	19 establish a monitoring program to assess impacts of a greater range of lake levels on irrigators, recreational users and the ecology of the lakes and the fringing saltmarsh land

Implementation of medium-term hydrological management opportunities (3-10 years)

B3	Investigate the benefits of different monthly and/or daily flows in the pattern of delivery of entitlement flows to provide seasonal flows at barrages and negotiate changes if appropriate.	2000–2001 2001–2002 2001	20 determine what different monthly and/or daily flows in the pattern of delivery of entitlement flows would be of environmental benefit through providing seasonal flow at the barrages 21 formulate guidelines incorporating upstream irrigation requirements, storage and weir management, and flow requirements for fish and water exchange 22 negotiate a different pattern of delivery of flows by submission from the SA commissioners to the MDBC
C1	First revision of operating rules for automated gates and flow allocations on basis of adaptive management monitoring results.	2005–2007	23 review effectiveness of changed operating guidelines and adapt management as required. (based on monitoring and other investigations)
D1	Investigate structural and operational modifications to Mundoo Barrage to increase scour capacity and operate preferentially to limit sedimentation at the Murray Mouth zone and implement if appropriate.	2001–2002 2000–2002	24 investigate options to change design and management of Mundoo Barrage to limit sedimentation in the mouth zone and formulate operational strategy satisfying multiple objectives ie optimum size of opening, flow size that can be generated, flooding risks and marine incursion risks 25 negotiate implementation of any structural or operational changes identified in this investigation
D2	Trial operation of the lakes at a wider range of levels (ie outside 0.6-0.85 m EL).	2000–2001 2001 2003	26 determine preferred operating guidelines and performance indicators 27 trial altered operating regime with wider range of lake levels (consult monitoring program and implement operational changes based on ecological data 28 renegotiate agreement on altered operating regime on the basis of the trial
D3	Automate more barrage gates as determined by adaptive management monitoring results and operate at a wider range of lake levels according to environmental guidelines.	2005–2007 2005–2007	29 evaluate environmental data from monitoring programs 30 Investigations – engineering design – economic analysis – cost-sharing arrangements

Implementation of medium-term hydrological management opportunities (3-10 years) continued

D4	Increase environmental flows to meet ecological needs in the Lower Lakes and Coorong through ongoing basin-wide water allocation reviews.	2000 (on-going)	31 investigate basin-wide opportunities for water savings for transfer to the Lower Lakes and Coorong environment to meet identified environmental needs (link to review of water cap arrangements)

Implementation of long-term hydrological management opportunities (>10 years)

E1	Second revision of operating rules for automated gates and revise flow allocations on basis of adaptive management monitoring results.	2010–2012	32 review effectiveness of changed operating guidelines and adapt management measures as required, update monitoring baseline
F1	Relocate the barrages upstream to Wellington or Point Sturt and invest evaporative savings into environmental flows for the Lakes and Coorong, to maintain a larger estuarine area.	2001	33 Investigate costs and benefits of relocating the barrages upstream to maintain a larger estuarine area as part of the scheduled maintenance review.
		2000 (ongoing)	34 Investigate alternative and innovative barrage design and operation for fish and boat passage
		2000	35 investigate options for relocation of barrages (eg to Wellington or Point Sturt) and for revised operation of the barrages, incorporating environmental needs, lake irrigators needs and public water supply requirements
			36 negotiate agreements for supply of fresh water to maintain estuarine environment
			37 formulate operational guidelines considering environmental needs, lake irrigators needs and public water supply requirements (time dependent on implementation of the action)
F2	Investigate the option of increasing the estuary area by converting Lake Albert into an estuarine zone, eg by constructing a barrage at Narrung Narrows and a channel from Marnoo swamp into the Coorong.	2001	38 evaluate option of operating Lake Albert as an estuary and investigate environmental impacts of this enlarged estuary and changed habitat
			39 negotiate agreements for supply of fresh water to maintain estuarine environment
			40 formulate operational guidelines considering environmental needs, lake irrigators needs and public water supply requirements (time dependent on implementation of the action)

PART 1:

INTRODUCTION AND METHODOLOGY

PLATE 1 RIVER MURRAY BARRAGES ENVIRONMENTAL FLOWS SCIENTIFIC PANEL ON TAUWITCHERE BARRAGE (PHOTOGRAPH: ANNE JENSEN)

INTRODUCTION

PROJECT BRIEF

This project aims to articulate the environmental needs of the Lower Lakes and Coorong in the region of the former River Murray estuary, and to identify opportunities to change management of flows at the barrage structures which separate marine and fresh waters near the Murray Mouth in South Australia.

The Murray–Darling Basin Commission has sought an environmental assessment of the operation of the flow regime for the length of the River Murray and Lower Darling, with a view to identifying management options for improving environmental conditions. The project is being conducted in response to:

- proposed changes to water resource allocation in the Murray–Darling Basin
- the recently agreed cap on any further diversion of water from the basin's rivers
- increasing concerns about the environmental health of the basin ecosystems.

A steering committee has been appointed. It has the task of identifying changes in river operations which should result in general improvements in the environmental condition of these river reaches, whilst recognising the current needs of existing water users.

The assessment has been undertaken using scientific panels. The purpose of this approach is to collate the best available knowledge and expertise to evaluate environmental issues with regard to altering the present flow regime of the river.

The overall objective of the River Murray Environmental Flows study is:

> *to identify changes in river operations for the River Murray and Lower Darling that should result in general improvement in the environmental condition of these river reaches whilst recognising the current needs of the existing water users.*

The recommendations from the assessment for changes in river operations for improved environ-mental outcomes will be directed to the proposed Interstate Working Group on River Murray Flows, for evaluation and preparation of recommendations for implementation.The Murray Scientific Panel on Environmental Flows undertook the assessment of the flow regime in the River Murray from Dartmouth Dam to Wellington in 1996–97 (Close et al in press).

Due to the complex interaction of fluvial and marine environments in the Lower Lakes and Coorong region and the need for different specialist knowledge to assess the environmental issues, a separate panel was established to consider the regions affected by the operation of the Murray Mouth barrages.

The objective of the River Murray Barrages Environmental Flows evaluation is:

> *to identify key environmental flow requirements in relation to management of flow through the barrages, as it relates to maintaining the ecosystem of the Lower Lakes, the Coorong estuary and Coorong lagoons.*

MEMBERSHIP OF THE PANEL AND STEERING COMMITTEE

In order to address the complex range of environmental issues facing the Lower Lakes and Coorong region, those appointed to the River Murray Barrages Environmental Flows Scientific Panel have expertise in the areas of geomorphology, hydrology, riparian vegetation and macrophytes, bird ecology, fish and aquatic macroinvertebrates and phytoplankton (Table 1.1).

The composition of the steering committee and the expertise of each panel member are shown in Table 1.2.

The project has been coordinated by Anne Jensen of the former South Australian Department of Environment and Natural Resources, now the Department for Environment and Heritage.

TABLE 1.1 COMPOSITION AND EXPERTISE OF RIVER MURRAY BARRAGES ENVIRONMENTAL FLOWS SCIENTIFIC PANEL

Area of expertise	Expert appointed	Organisation
hydrology	Bob Newman	Department of Environment and Natural Resources (DENR)
geomorphology, shore erosion and Murray Mouth	Bob Bourman	Faculty of Engineering and the Environment, University of South Australia,
riparian vegetation and macrophytes	George Ganf	Botany Department, University of Adelaide
bird ecology	David Paton	Zoology Department, University of Adelaide
fish and aquatic invertebrates	Mike Geddes	Zoology Department, University of Adelaide
phytoplankton (algae)	Peter Baker	Australian Water Quality Centre

TABLE 1.2 COMPOSITION AND MANAGEMENT AREAS REPRESENTED ON RIVER MURRAY BARRAGES ENVIRONMENTAL FLOWS STEERING COMMITTEE

Management area	Committee member appointed	Organisation
wetlands management	Anne Jensen	DENR
wetlands management	Jane Doolan	Department of Natural Resources and Environment (Victoria)
river operations	John Parsons	SA Water
natural resources policy	Bernice Cohen	DENR
fish biology	Bryan Pierce	SARDI
land management, visitor management	Phil Hollow	DENR
flow management and hydrology	Andy Close	Murray–Darling Basin Commission

FIGURE 1.1 LOWER MURRAY AND LAKES STUDY AREA (SOURCE: GEDDES AND HALL 1990)

METHODOLOGY

DEFINITION OF STUDY AREA

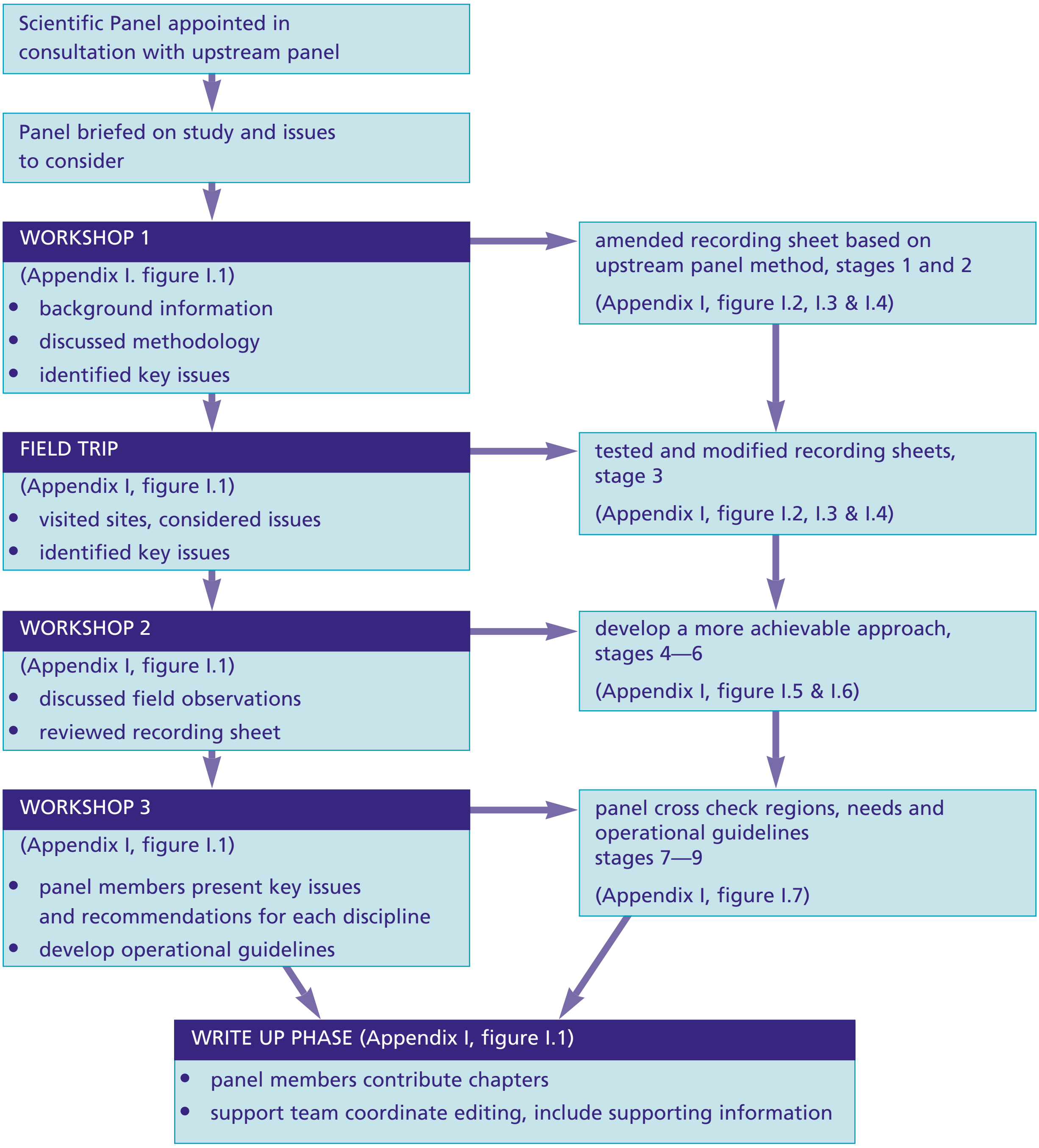
This study focuses on the effect of the barrages on the waterbodies and floodplains below Wellington which are part of the River Murray system. This area includes lakes Alexandrina and Albert, the Coorong estuary below the barrages, the Murray Mouth, the Coorong Northern Lagoon and the Coorong Southern Lagoon (Figure 1.1).

PROCESS OF EVALUATION

The process of evaluation adopted by the panel involved a combination of workshops and field trips, as well as other key sources of information (Figure 1.2).

As part of this process, the River Murray Barrages Environmental Flows Scientific Panel evaluated the system of recording sheets used by the Murray Scientific Panel on Environmental Flows. The methodologies of previous

FIGURE 1.2 METHODOLOGY FLOW CHART FOR THE RIVER MURRAY BARRAGES ENVIRONMENTAL FLOWS SCIENTIFIC PANEL



scientific panels were also considered. A modified approach was developed to suit the Lower Lakes and Coorong. The detailed process is outlined in Appendix I.

Initial discussion covered the following issues:

- former natural patterns of discharge to the Murray Mouth
- current volume, seasonality, frequency and duration of flow over barrages
- rate of rise and fall of flow rates over barrages
- rate of rise and fall in water levels in the Coorong lagoons and effect of rapid changes in level
- impacts of rises and falls in lake water levels on lakes shores and wetlands
- effects of no-flow periods and any critical factors related to length of closure
- effect of sequence of barrage use, including very infrequent opening of Mundoo and Boundary Creek barrages
- potential for controlled small releases to freshen the Coorong
- required flows to maintain the Murray Mouth
- critical periods for fish passage through the Murray Mouth
- impact of barrages as barriers to fish passage
- mass carp deaths when trapped in estuary.

From this list, the panel then identified several key issues to be addressed in the evaluation process, as summarised in order of priority below:

- changed water regimes
- reduced area of estuary habitat
- reduced suitable habitat for aquatic plants
- increased algal blooms
- freshening of brackish and saline habitats around lakes
- dryland salinity on floodplain and islands.

The key time scales, based on degree of planning, investigation, consultation and investment required, are:

- short-term (1–3 years),
- medium-term (3–10 years)
- long-term (>10 years).

The diverse environments of the region have been divided into five distinct biological/ecological areas, based on major habitat types (reflecting water regimes in particular):

- eroding lakeshores
- prograding lakeshores
- estuary
- Coorong Northern Lagoon (from Pelican Point to Hells Gate)
- Coorong Southern Lagoon (Figure 1.3).

There was discussion as to whether management opportunities could be grouped into two categories: upstream of barrage structures; and downstream of barrage structures.

Most recommended actions fall either upstream or downstream of the barrages, but it was found that in two areas the benefits cross the barrages — namely in reducing turbidity and providing fish passage. In addition, by retaining the five regional habitat divisions, greater detail on potential benefits could be included. The five categories have therefore been retained.

The full process of evaluation and development of the methodology is given in Appendix I.

FIGURE 1.3 FIVE ECOLOGICAL AREAS: ERODING LAKESHORES, PROGRADING LAKESHORES, COORONG NORTHERN LAGOON (FROM PELICAN POINT TO HELLS GATE), COORONG SOUTHERN LAGOON AND ESTUARY

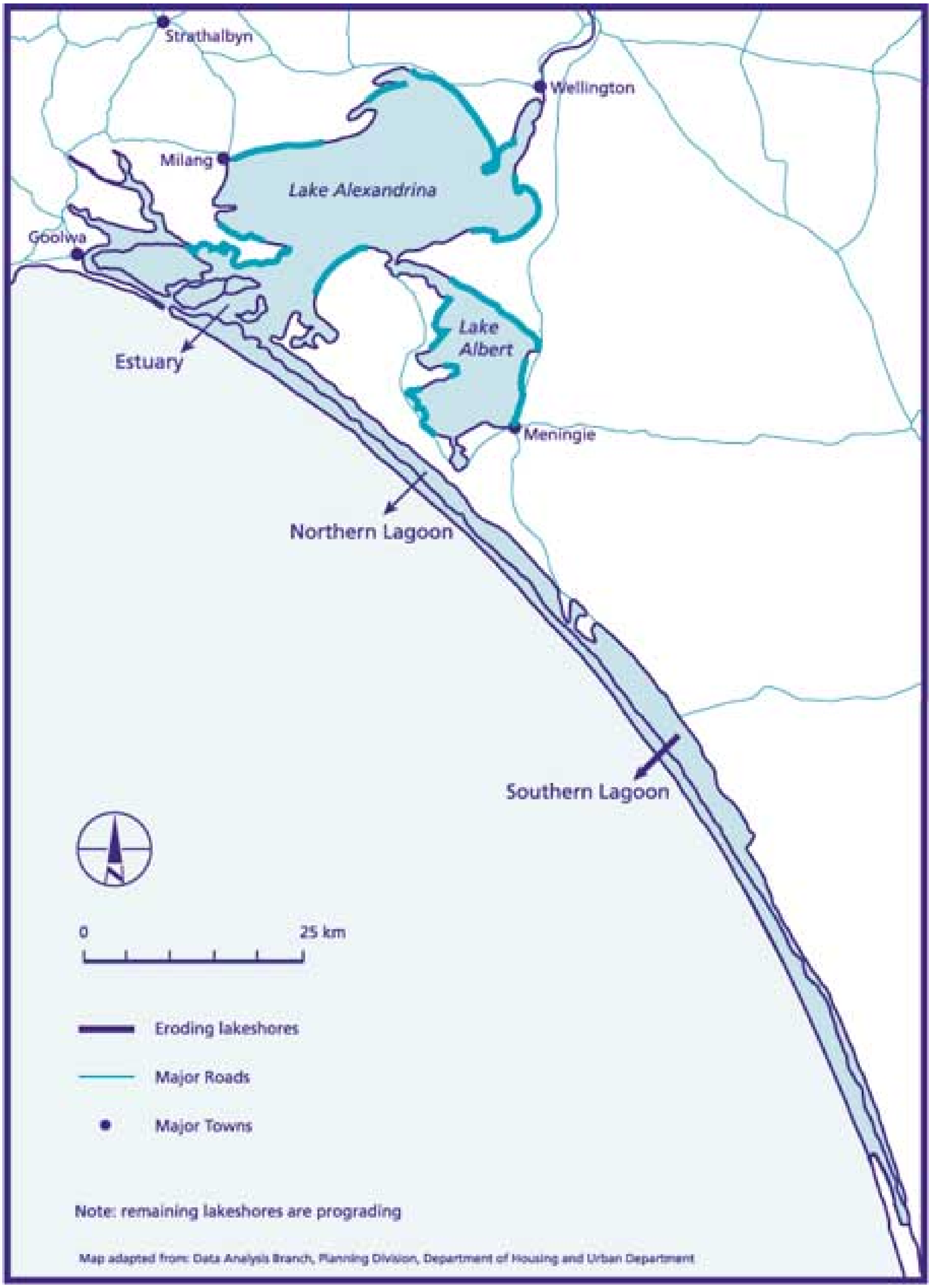


PLATE 2 MURRAY MOUTH – AERIAL VIEW

BACKGROUND AND CURRENT STATUS OF LOWER LAKES AND COORONG

The barrage structures separate marine and fresh waters across the chain of sand and mud barrier islands inside the Murray Mouth, 100 km south-east of Adelaide in South Australia (Figure 1.4). The barrages total 593 gates in five structures across the various channels in the mouth delta (Table 1.3). The barrages, linked by earthern causeways, create a barrier 7.6 km long. Originally built for navigation and agriculture, their primary purpose now is to retain fresh water storage for water supply diversions to regional communities.

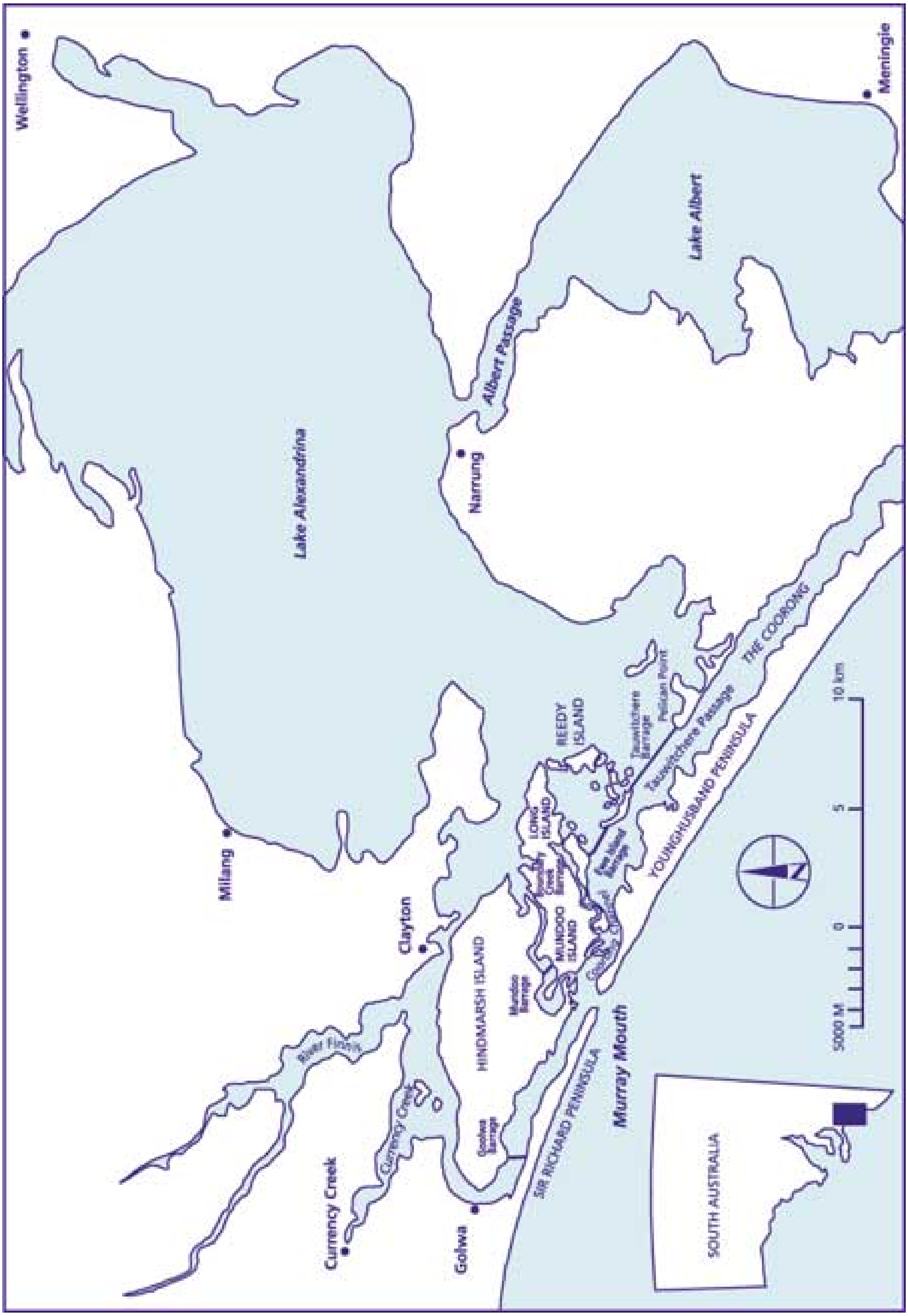
The Coorong lagoons and lakes Alexandrina and Albert are major wetlands situated at the mouth of the River Murray. The lagoons and the Lower Lakes span over 660 square kilometres, the remnant of what used to be an extensive Murray estuary (Barnett 1995; Geddes & Hall 1990)

FIGURE 1.3 BARRAGE STRUCTURES OF THE RIVER MURRAY ESTUARY

Barrage	No of gates	Type of gates	Comments	Total length
Goolwa	128	stop logs	largest capacity channel, boat access, frequently opened	632.5 m
Mundoo	26	stop logs	narrow opening in wide channel, infrequently opened	792.5 m
Boundary Creek	6	stop logs	narrow opening in wide channel, infrequently opened	243.8 m
Ewe Island	111	radial gates, concrete slabs	broad shallow lake connection, frequently opened	2270.7 m
Tauwitchere	322	radial gates	broad shallow lake connection, restricted boat access, gates frequently opened	3658 m

(Further details of barrage structures are given in Appendix IV)

FIGURE 1.4 THE LOCALITY OF THE FIVE BARRAGES INSIDE THE MURRAY MOUTH



Regulatory structures built on the major streams of the Murray–Darling Basin in the 1920s and 1930s have significantly altered the natural flow regime of the river. In the Murray Mouth region these changes to flow are compounded by the five barrages completed in 1940.

The unique assemblage of marine, hypo-marine, estuarine, hypermarine and freshwater habitats in the wetlands of the Lower Lakes and Coorong forms the foundation for the high level of biological diversity in the region. Its recognition as an area of outstanding national and inter-national conservation value is reflected in its National Park status, its listing as a Ramsar Wetland and its protection under the Japan-Australia and China-Australia Migratory Bird Agreements (Edyvane & Carvalho 1995).

The listing as a Ramsar Wetland acknowledges the range of habitats from freshwater through to hyper-saline lagoons and ephemeral salt lakes, as well as the summer feeding grounds for cape barren geese, more than 1% of breeding populations for swans and pelicans, nesting grounds for the threatened hooded plover, conditioning and moulting grounds for large numbers of migratory waders, and waterfowl numbers in excess of 20 000 (Upper South East Dryland Salinity and Flood Management Plan, 1993).

The Murray Mouth Biological Resource Assessment Workshop, a major workshop held in 1995, brought key experts together to consider the current state of knowledge for the Murray Mouth region and the priorities for future management (Edyvane & Carvalho 1995). Despite the outstanding conservation value of the region, workshop participants identified a number of threats and management issues undermining the conservation values of the region. These issues included the absence of data and management resources for the region, and the related issue of the lack of an integrated ecosystem approach to management.

The specific threats identified encompassed the following five areas (Edyvane & Carvalho 1995):

- altered flow regime
- impacts from land-based activities
- impacts from increased visitor pressure
- impacts from land and aquatic exotic and feral species
- impacts from the freshening of the hypersaline regime of the southern Coorong.

The Murray Mouth Biological Resource Assessment Workshop recommended ecosystem-based management of the Murray estuary and an integrated regional management plan for the Lower Murray, to conserve the natural and cultural values and resources of the region (Edyvane & Carvalho 1995).

The Murray Mouth Biological Resource Assessment Workshop recommended investigation of the following areas in order to determine appropriate flow regimes:

- diversity and quality of aquatic and riparian habitats
- adequate flows through the Murray Mouth
- passage for fish past the barrages
- improvement in water quality.

It was recognised that there is an urgent need to examine and revise flow management operating rules to provide greater environmental benefit from flows (Edyvane & Carvalho 1995). The development of an appropriate flow regime is considered the highest priority management issue in the Murray Mouth region.

It is in this context that the River Murray Barrages Environmental Flows Scientific Panel was appointed to identify the key ecological needs and to highlight options for improvement.

CONTEXT OF MANAGEMENT ISSUES AND CONSTRAINTS

The management context for this project was set through a series of presentations made by members of the steering committee and other representatives of interested groups.

The issues considered included:

- the need for consistency with the upstream scientific panel assessment methodology and draft recommendations (Appendix II and Part 3)
- interactions with the concurrent Ramsar Planning Process, which is conducting extensive community consultation on range of issues intimately linked with the condition of the lakes, estuary and Coorong (Appendix III)
- the current operating strategies and constraints, particularly existing user demands, which have led to present conditions (Appendix IV)
- current flow conditions and management constraints along the length of the River Murray, and the extent of change from natural conditions (Appendix V)
- the impacts of the barrages in increasing the rate of fine sediment transport into the Coorong and the associated high load of nutrients being transferred from the lakes to the Coorong (Appendix VI)

- the demonstrated benefits of automation of approximately 22% of barrage gates to allow significant passage of commercial species of fish (Appendix VII)
- interactions with land management issues in the Coorong National Park (Appendix VIII).

SUMMARY OF UPSTREAM PANEL FINDINGS AND RECOMMENDATIONS

The report of the Murray Scientific Panel on Environmental Flows is still in draft form and has not been finally approved by the authors. The following summary has been drawn from the current draft report (Close et al in press), as an indication of the likely findings of the panel.

Key considerations identified are:

- to maintain natural diversity of habitats and biota within the river channel, riparian zone and floodplain
- to maintain the natural linkages between the river and the floodplain
- to maintain the natural metabolic functioning of aquatic ecosystems.

The following two guiding principles have been developed:

- elements of natural seasonality should be retained as far as possible, in the interest of conserving a niche for native rather than invasive exotic species and in maintaining the natural functions of the river
- consistent and constant flow and water level regimes should be avoided as much as possible, because this is contrary to the naturally variable flow regime of the river.

For the Wentworth to Wellington Reach, the major environmental issues identified (Close et al in press) are:

- unseasonal wetting and drying of fringing riverine wetlands
- reduction in the frequency of flooding of most areas of the floodplain, affecting floodplain health and native fish breeding
- barriers to fish passage within the river and onto and across floodplains
- bank erosion downstream of weirs due to rapid rate of fall after re-installment of weirs
- increased risk of algal blooms
- increased turbidity in summer months affecting instream productivity with consequential impacts on food chain.

The draft recommendations of the River Murray Environmental Flows Scientific Panel (Close et al in press) include:

high priority

- reduce unseasonal wetting/drying of fringing wetlands and mainstream littoral zones
- increase flooding frequency on floodplain outside riverine fringing zone
  - conserve natural flood events
  - enhance floodplain watering
  - conserve the ecological functioning of the remaining floodplain
- improve fish passage
- combat bank erosion downstream of weirs
- maintain and improve abundance and distribution of snags.

medium priority

- reduce the risk of algal blooms
- decrease turbidity sourced from the Darling River in summer months affecting instream productivity with consequential impacts on the food chain.

MANAGEMENT FRAMEWORK FOR FUTURE OPERATION OF BARRAGES

Any recommendations for the future management of the barrages in the River Murray estuary need to take into account the framework of management objectives and imperatives associated with the vital water resource of the River Murray and Lower Lakes. In addition, the very high conservation values of the region place constraints on evaluation of management options.

The key constraints are listed below:

- the need to maintain ecosystem processes in the wetlands which are protected under the following multiple listings:
  - Wetland of International Importance under the Ramsar Convention
  - wetland habitats subject to JAMBA and CAMBA bi-lateral migratory bird agreements with Japan and China respectively

- National Estate register
- Coorong National Park, Mud Islands and Currency Creek Game Reserves and Salt Lagoon Conservation Park

- the role of the Lower Lakes as a balancing storage for water supplies to metropolitan Adelaide
- the water level required to maintain water supply to gravity-fed flood-irrigated dairy pastures upstream to Mannum
- the water level required to supply diverters around the Lower Lakes
- the water level required to minimise marine incursions into the Lower Lakes
- concerns about water quality issues in relation to water supplies to rural communities and townships around the Lower Lakes (salinity and algal blooms)
- the need for an integrated catchment management approach
- the need for community support and participation.

Recommendations relating to key environmental flow requirements to maintain the ecosystem of the Lower Lakes, Coorong estuary and Coorong lagoons will need to address the full range of ecological processes and diversity of habitats. A fully diverse ecosystem will incorporate a balance between representative and biomass, with an emphasis on conservation of a range of habitats and communities, rather than the highest numbers of individuals or protection of individual species.

The recommendations of this assessment should be compatible with the goal of the National Strategy for the Conservation of Australia's Biological Diversity, which is 'to protect biological diversity and maintain ecological processes and systems'. The strategy defines ecosystem diversity as the variety of habitats, biotic communities and ecological processes. The strategy describes biodiversity as not only the conservation of wildlife and habitats, but also the sustainable use of biological resources and safeguarding of life-support systems.

PART 2:

CURRENT STATUS, KEY ISSUES AND ECOLOGICAL NEEDS

PLATE 3 GOOLWA BARRAGE

HYDROLOGY OF THE LOWER LAKES AND COORONG

Bob Newman, Water Resource Manager Murray Mallee SA,
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CURRENT STATUS

Hydrology of the Murray–Darling Basin

The Murray–Darling is one of the world's great river systems. By length or area, the Murray–Darling ranks approximately twentieth in the world. However, the annual mean yield is very low, compared with the other major river basins of the world. For example, the yield of the Murray–Darling is 14 mm (or 14 ML/km2) compared with 68 mm for the Mississippi/Missouri or 900 mm for the Amazon (Table 2.1).

Twenty major tributary rivers discharge into the River Murray above Wentworth. The source of much of the flow is winter rainfall and snowfall on the Great Dividing Ranges. The Darling River delivers flow from summer sub-tropical storms further north. Most of the Murray–Darling Basin is in an extremely arid zone and evaporation is high. In fact many of the tributaries do not reach the main stem but rather terminate in inland marshes, where they evaporate or infiltrate into the groundwater system. For example, only in the most extreme events does the Lachlan River reach the Murrumbidgee River. Creeks such as the Billabong Creek and the Paroo River do not reach the Darling River.

The natural mean flow in the River Murray below Wentworth is 11 000 GL/a. However, the system is unusually variable, with peaks of around 40 000 GL/a and droughts of virtually nil flow (Eastburn and Mackay 1990). The flow variation appears to occur in cycles of seven to ten years. Periods of high flow are often followed by many years of drought. Recent advances in the understanding of global weather systems are beginning to offer an explanation. The El Nino and La Nina cycles affect the basin, particularly in the east and north regions.

The natural flows pattern below Wentworth and down to the Murray Mouth featured peak flows in spring to early summer and low flows from late summer into winter (Figure 2.1). Figure 2.1 illustrates the variability of the system and the change in flow volumes that has occurred due to present day development.

Construction of the barrages

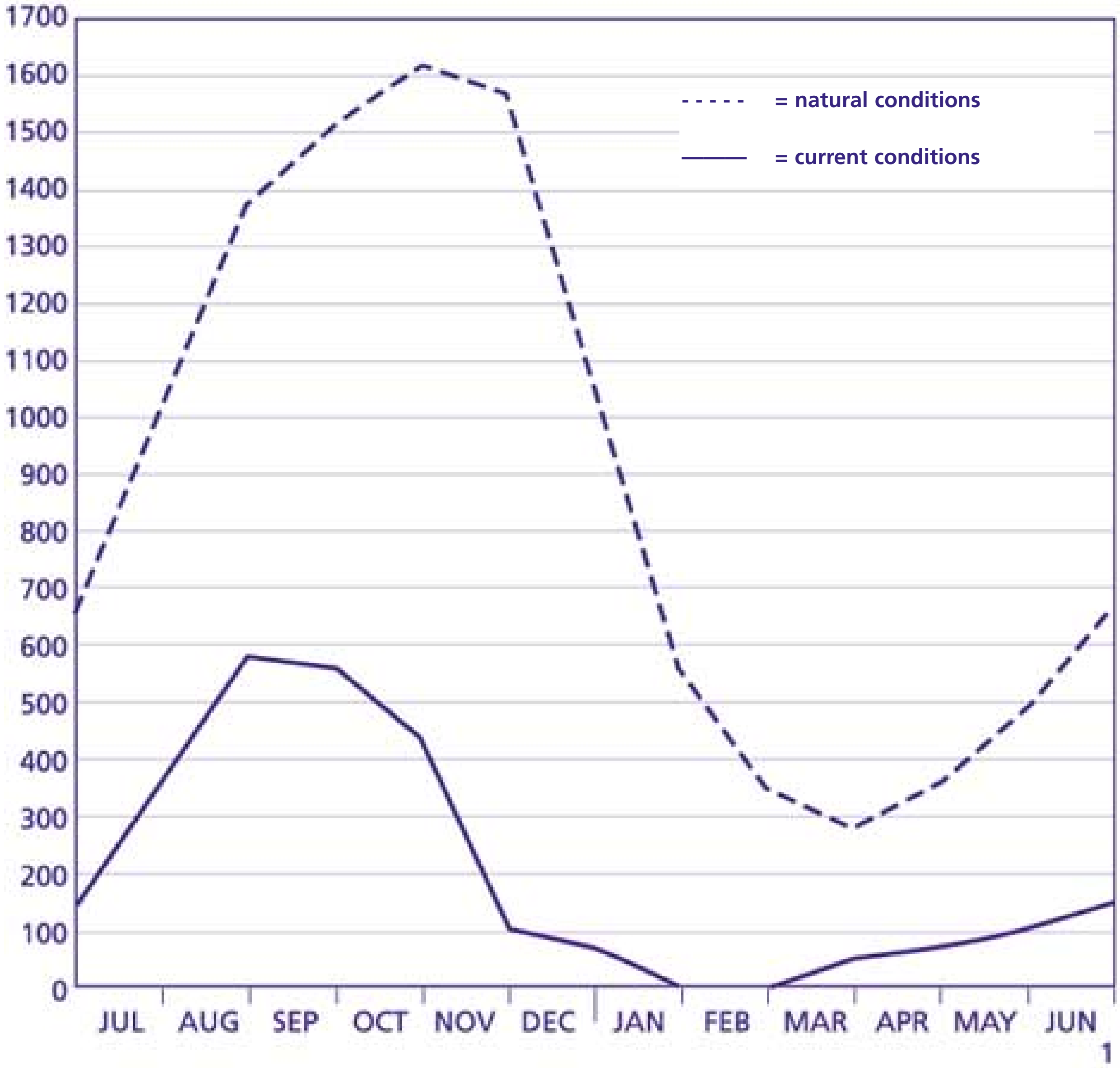
The barrages were the last of the major regulatory structures constructed by the River Murray Commission in the initial phase of development. The structure includes five low head weirs and earthern causeways linking the islands that once formed an old shoreline (Table 1.3). The barrages now block 7.6 km of previously (at times) passage channels and prevent tidal exchange into Lake Alexandrina, maintaining fresh water in the Lower Lakes and River Murray.

The barrage structures were constructed between 1935 and 1940 for the purpose of stabilising water levels and salinity regimes in order to provide a reliable water supply to the communities fringing the lakes. In particular the Lower Murray swamp irrigation systems as far upstream as Mannum rely on the higher levels in Lake

TABLE 2.1 DIMENSIONS OF THE MURRAY–DARLING SYSTEM COMPARED WITH MAJOR RIVER SYSTEMS OF THE WORLD (SOURCE: BRITANNIA 1996 AND MDBC)

River	Country	Length (km)	Catchment Area (sg km)	Annual Flow (GL)	Annual Yeild (ML/ha)	(mm)
Amazon	S America	6570	6150000	5518800	8.97	897.4
Yangtze	China	5980	1827000	1014700	5.55	555.4
Congo	Africa	4700	3460000	1293000	3.74	373.7
Yenisey/Selenga	Russia	5870	2619000	565700	2.16	216.0
Zambezi	Africa	3500	1330000	220752	1.66	166.0
Indus	India	2900	1166000	157680	1.35	135.2
Mississippi/Misouri	USA	6020	5980000	405100	0.68	67.7
Hwang Ho	China	4840	771000	51100	0.66	66.3
Nile	Africa	6690	2802000	88500	0.32	31.6
Murray–Darling	Australia	2560	1063000	14700	0.14	13.8

FIGURE 2.1 ANNUAL FLOW PATTERNS AT THE BARRAGES (SOURCE: MDBC 23.6.97)



Alexandrina and the lower river to provide gravity feed to the reclaimed swamps. Levee banks were constructed at the turn of the century along the river between Mannum and Wellington to 'reclaim' the fringing floodplains, for use as irrigated pasture for dairy cows.

The operation of the barrages is primarily targeted at holding the lake level at EL 0.75 m (0.75 m above mean sea level). Since the early 1980s the barrages have been operated to surcharge the lake by 100 mm to EL 0.85 m to ensure security of supply level at the end of the irrigation season (see Appendix IV). During periods of low flows, the barrages may remain closed for many months (Figure 2.2).

Lower Lakes and Coorong

The Murray–Darling River system discharges into a particularly large-scale terminal lakes system which would have previously offered a wide range of fresh, brackish, saline and hypersaline systems (Figure 1.1). The ecological systems would have evolved to take advantage of this diverse range of salinities.

It is useful to try to imagine these natural systems before European impact, so that the extent of change can be assessed.

The Murray Mouth was always relatively narrow so that

FIGURE 2.2 OPERATIONAL HISTORY OF BARRAGE OPENINGS AT GOOLWA, 1982–96

(SOURCE: DENR, BERRI)

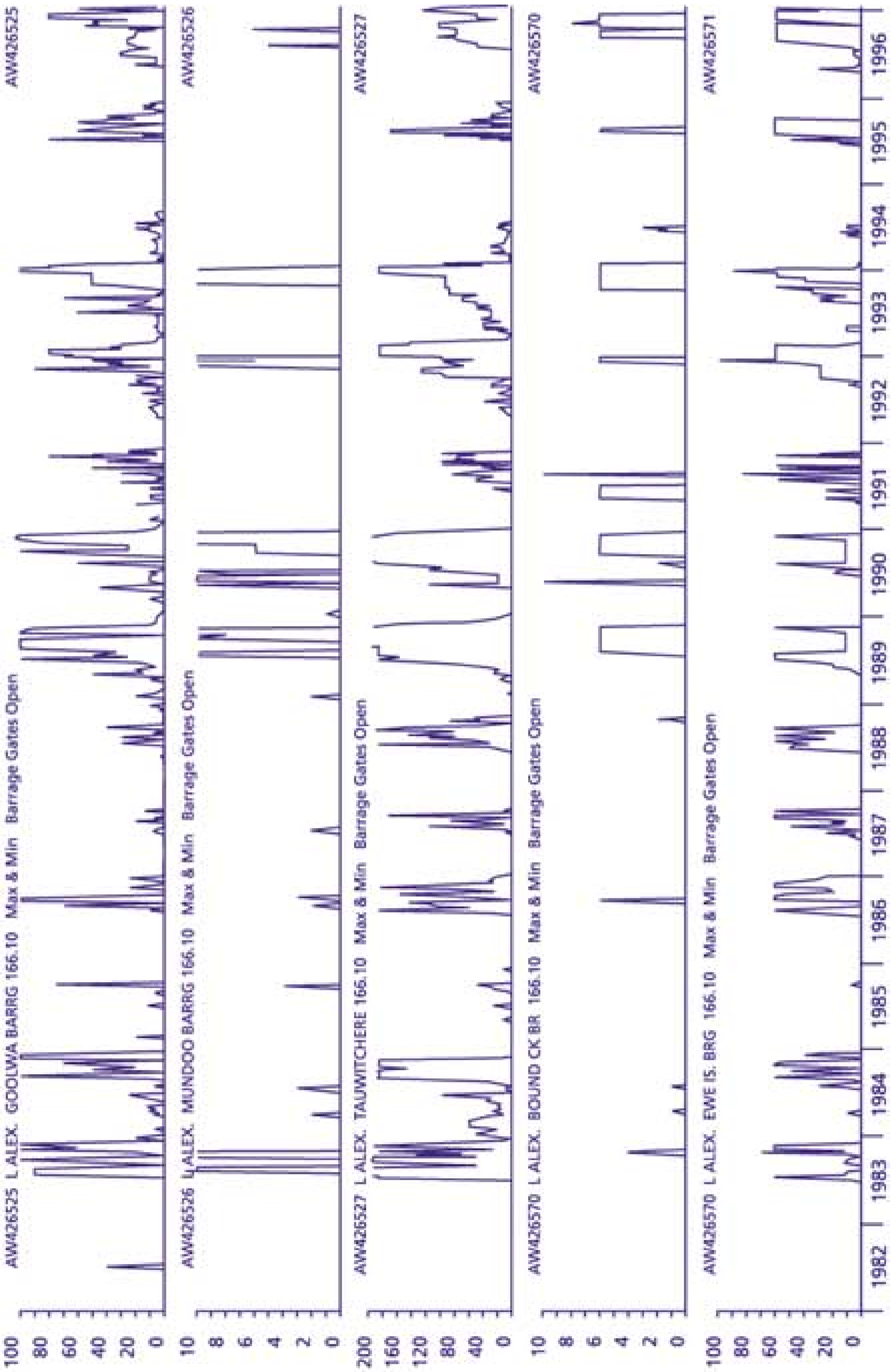
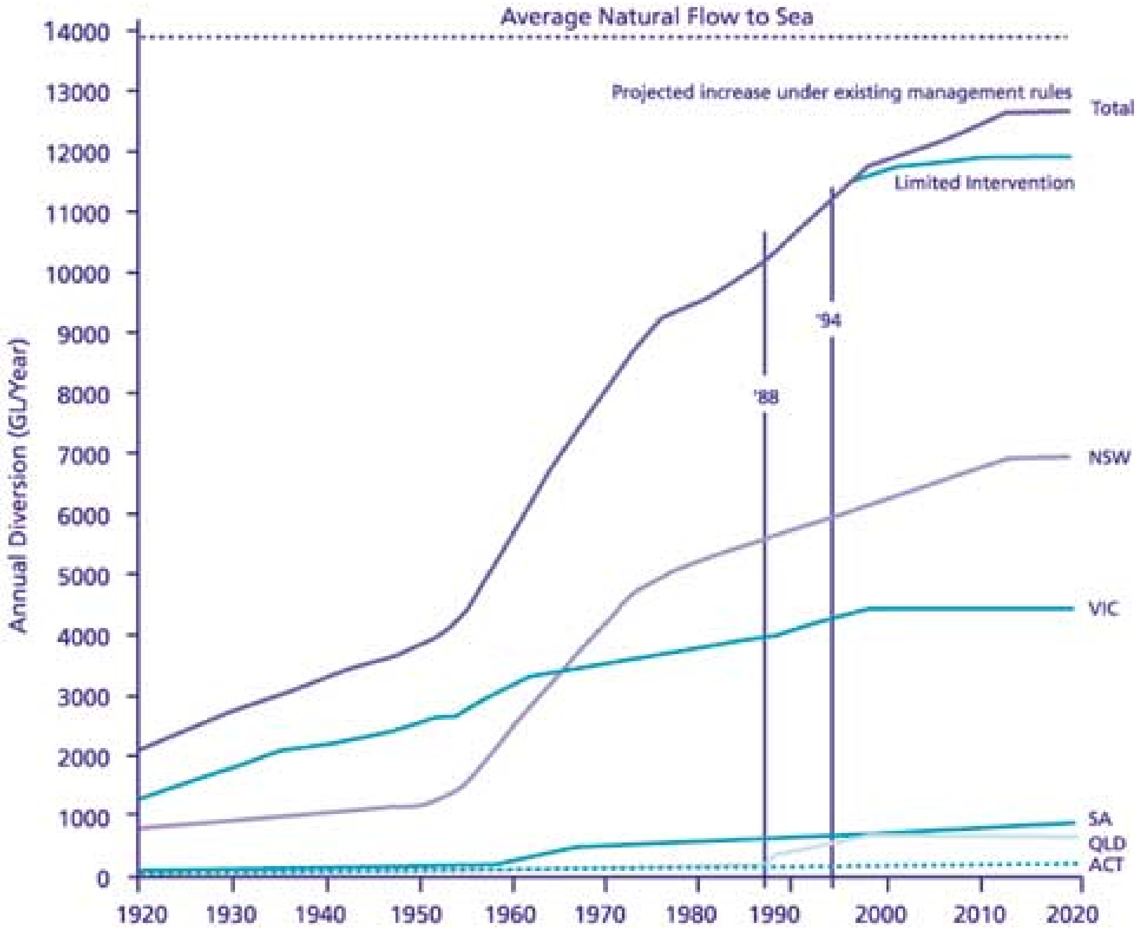


FIGURE 2.3 GROWTH OF DIVERSIONS IN THE MURRAY–DARLING BASIN (SOURCE: MDBMC)



the interface with the sea was localised. It has always been highly mobile (Bourman ibid). At the time of barrage construction in 1940, it was some 1.5 km further south and it has migrated northwards over the past fifty years.

The winter and spring river flows would have maintained an outflow at the mouth in most years; however, during the low flows of summer and autumn, and throughout the year in drought, the fluctuating tide levels would have allowed a substantial tidal exchange and semi-marine conditions would have established over most of the Lower Lakes. At the margins of the lakes brackish groundwater discharges and trapped sea water would have created salt marshes, with varying salinity over several seasons.

The Coorong would have received more frequent freshwater at the northern end, but would have been increasingly saline or sometimes hypersaline into the Southern Lagoon, much as it is today. There is considerable debate as to the freshening impact of surface inflows at the southern end of the system, prior to drainage in the South East. It is clear that the primary source of freshwater inflows from the river has been reduced to less than 30% of natural inflows. Flows from the South East were infrequent but significant when they occurred.

The land surrounding the Lower Lakes and the eastern shore of the Coorong would generally have been heavily vegetated with low scrub and saltmarsh. The lakes would have fluctuated in level and salinity on a seasonal basis, probably over a range of EL (AHD) 0 m to EL 0.5 m during most seasons, giving water depths of 1–2 m. Severe drought and flood would have increased this range.

The primary change for the lower River Murray, since the construction of the barrages and the dramatic reduction in flows, has been the loss of the vast estuarine system and the consequent loss of biodiversity and ecological resilience. The ecosystems are at risk of degrading into a uniform condition, having low diversity and interfering with the natural productive capacity of the region, particularly from a fishery perspective.

River regulation and development 1900 to 1980

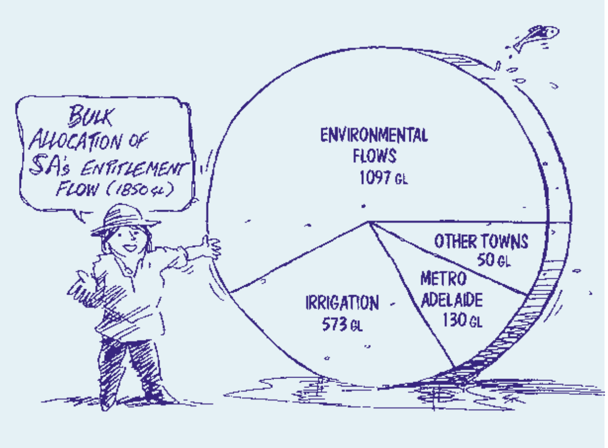
The 'development' of the resources of the Murray–Darling Basin has followed the traditional path of optimistic exploitation of the available water with little regard for the ecological consequences. As with all major river basins worldwide, the development or exploitation phase has gradually slowed as the stresses have become apparent and concern for the resource management issues begins to arise.

The River Murray and its tributary streams have been progressively regulated over the past century. With the formation of the River Murray Commission under the River Murray Waters Agreement of 1915, several major storages were constructed. The storage capacity is now 30 000 GL, which represents nearly three times the annual mean flow volume of 11 000 GL. Total diversions are approaching 9000 GL, or more than 80% of the mean annual flow volume (Figure 2.3).

Following regulation of river flows, many schemes have been developed to divert the water for productive use. There are many urban and industrial uses of the water including 1.4 million people in towns and districts along the main tributaries, and one million people in Adelaide and rural South Australia who rely on this water supply. However, it is irrigation ventures which draw the bulk of the water from the basin.

At the downstream end of the system, South Australia has negotiated an annual entitlement of 1850 GL to guarantee a reliable supply. The upstream states share the remainder (the bulk) of the resource as it becomes available and therefore have developed a more variable consumption regime. Further upstream the flow is more variable, especially upstream of major storages. In spite of the exploitative approach to development across the basin, the lower reaches of the river still retain some resemblance of variable flow due to the difficulty in harvesting the fluctuating flow occurrences.

FIGURE 2.4 SA DIVERSIONS AS A PROPORTION OF 'ENTITLEMENT FLOW' **(SOURCE: DENR)**



Flow to South Australia averages around 6000 GL/a, including large flow events. However, the median flow is only 4047 GL/a, marginally above the entitlement flow. The flow patterns in the lower reaches still maintain the seasonal spring flows, but these are greatly reduced in frequency and volume. A flow of at least 35 000 ML/day is required to inundate the river valley floodplains and trigger breeding and regeneration of waterbirds fish and plants in the wetlands. The guaranteed entitlement flow to South Australia is allocated to domestic, industrial and agricultural use (Figure 2.4), with a large proportion required to cover evaporation losses from the terminal lakes and transmission along the river channel. Initially, irrigation developments involved largescale infrastructure delivering water to government or community schemes. However, since the 1950s private development has dominated, using a variety of allocation policies in each state. These private schemes and the policies supporting them, particularly in the upstream states, have encouraged the diversion of the medium flow peaks in an opportunist manner. The loss or reduction of these peaks has placed further stress on the downstream ecosystem.

The Murray–Darling system generates considerable variability in flow. However, in the lower reaches, as the grade line is very flat, the river provides considerable warning of these medium flow events. This has enabled the development of pumping systems which can divert these 'opportunity flows' either directly onto seasonal crops or to short-term farm storages for use several months or up to one year later. It has been this increasing capacity to aggressively harvest these 'opportunity flows' that ultimately caused concern over the increasing exploitation of the river system for consumptive use. The question arose in 1995 as to when is enough enough? The Murray–Darling Basin Ministerial Council agreed that the current rate of diversions could no longer continue (MDBC 1995a) (Figure 2.3).

KEY ISSUES

Controlling diversions from the Murray–Darling system

The Murray–Darling Basin Commission Water Audit (MDBC 1995b) has very clearly established the extent of usage and the trends over the development phase of the basin. By 1994 around 75% of the mean flow was being abstracted for consumptive use and diversions were still increasing at around 1% per annum. The Murray–Darling Basin Ministerial Council has now taken the impressive decision to halt development at the 1994 level of diversions. It has taken more than two years to develop a strategy for defining the operational rules that can effect this outcome (MDBC 1995a). Since the 1960s the consequences of river regulation and diversions have been observed, especially along the downstream reaches of the River Murray. Some attempts have occurred both to limit growth in diversions and to redress some of the resource impacts, particularly those relating to reducing water quality for human use. Salinity issues were the first to become apparent and more recently the risks of blue-green algal blooms have dominated concerns.

Major changes in flow regimes

The changes brought about through the 'development phase' of the basin have resulted in artificial drought conditions coupled with constant unnaturally high pool levels and severe fluctuations in flow following a moderate to high flow event. Water levels have generally been maintained at unnaturally static levels, and the ebb and flow of water levels that occurred in the natural regime are now constrained. The operation of the regulating structures has been dominated by a management desire to hold water levels static. This is most pronounced during low to moderate flows (up to around 50 000 ML/d).

In addition, there is now a very abrupt interface between the marine system and the freshwater lakes which has been created by the barrages. In its natural state there would have been a very large and transient interface between the fresh river flows and the marine system, creating estuarine conditions.

An important effect of the extent of storage capacity and upstream diversion of water is the reduction in the frequency of medium flow events; for example, flows in the range 20 000 ML/d to 80 000 ML/d have reduced in frequency by threefold (Figure 2.3). In addition to the change in frequency of flow events, the duration of these events is now much shorter. In particular, as high flows pass weirs, the desire to retain pool levels at the weirs results in the increasing abruptness of the flood recession as the flood peak passes downstream. This change results in a loss of the natural smoothing of flow and level recessions. Apart from causing physical damage by the slumping of banks due to excess water pressure in the soil, there is also confusion in the natural ecological 'signals' and reduction in breeding and regeneration success in waterbirds, fish and plants.

Another change to the system — caused by regulation and consumption, land practices and the imbalance in aquatic biology — is the increase in silt and colloids load, resulting in increasing turbidity. This increase in solids, together with urban and agricultural drainage disposal, has also caused an increase in nutrient loads. Increased turbidity suppresses native plant and animal growth, while increased nutrients cause an imbalance in ecosystems which increases the risk of nuisance algal blooms.

Estuary–Murray Mouth zone

The estuary has serious hydrologic issues because the estuarine regime now operates over only 11% of its previous scale. However, the Southern Lagoon no longer operates as a typical estuary, reducing the total to about 7% of the overall area. This means that rapid changes in flow and level associated with barrage operations cause rapid major changes in both the water level and salinity (Paton ibid).

The mouth region is progressively silting, causing even further reduction of tidal exchange (Bourman ibid). The Murray Mouth closed over during low flows in May 1981, which is the first time since European settlement, although it would be an occasional possibility under the natural flow regime.

An important hydrologic consequence of mouth closures is the likelihood of flooding during the next high flow event. After the mouth closes, the high energy coastal processes cause the dunes to re-establish, creating a levee across the mouth some metres above lake level. If the mouth had not been mechanically opened in 1981 then all the townships and fringing lands would have been flooded as far as Wellington during the floods of October–November.

Access for recreational, tourist and commercial boats between the Goolwa Channel and the Coorong becomes limited if the mouth zone silts up. The closure of the mouth also causes changes in the ecologic regime. Apart from the increased likelihood of closure, the reduced medium flow regime has caused the mouth to migrate northwards. It has moved 1.4 km since 1940 (Bourman ibid, Figure 2.6). The high energy coastal process of dune migration also creates the possibility of the sea breaking through and threatening the Goolwa Barrage (Bourman ibid).

The Lower Lakes

The Lower Lakes have been hydrologically separated from the estuary by the barrages in order to provide a reliable water supply. However, as abstraction across the basin has increased, the ability of the lakes to provide this function has reduced. The lakes have become more frequently saline and the level now falls below an acceptable level for diverters during entitlement flow years. With the current development regime, entitlement flow years are now far more frequent than when the barrages were built. It is intended that the cap on diversions will prevent this trend from worsening (MDBC 1995a).

The Coorong

The estuarine-marine Northern Lagoon and the marine-hypersaline Southern Lagoon of the Coorong provide two major habitats within the Ramsar wetland site. Key habitats include the tidal mudflats of the Northern Lagoon and the extensive beds of Ruppia megacarpa in the Northern Lagoon and Southern Lagoon, which provide essential food sources for extensive numbers of waterbirds. These habitats are maintained by the hydrologic regime, in which key factors are:

- salinity ranges
- rates of rise and fall in water level
- wind-seiche effects
- tides
- mixing of river water and sea water.

The construction of the barrages has not only severely reduced the area of estuarine conditions, but has also disrupted the transition between fresh and salt conditions. The remnant estuary can change abruptly from salt to fresh conditions and back again in an unseasonal, unnatural pattern which disrupts breeding and regeneration of estuarine plant and animal species. The reduced tidal prism and flow velocities have allowed acceleration of siltation in the Coorong channels (Bourman ibid).

OPPORTUNITIES FOR IMPROVED BARRAGE OPERATION

As the decline of ecological indicators gradually becomes apparent, the community identifies with the changes taking place. Usually there is little historical data on the ecological changes. Anecdotal information abounds, and clearly confirms the extent of changes and the fact that the changes are occurring at an increasing rate. Even today the ecological databases are very limited. How can the ecological outcomes be optimised?

The main ecological need of the Lower Lakes and Coorong is for the re-establishment of higher flow regimes. In today's social situation with so many people dependant on the rivers, this is not likely to happen easily. The task is therefore to move towards a sustainable situation with as much replication of the natural systems as is feasible. It will be necessary to emulate or mimic the natural systems with only a fraction of the water that once passed through the system.

The barrage structures have ageing operational technology which means that they are not readily amenable to rapid response operation. Some parts of the structure are rarely operated because of operational difficulties. Upgrades of structures have concentrated on the Goolwa and Tauwitchere barrages. Modification of the barrages to allow rapid responses would have significant operational, water quality and environmental benefits.

No clearly defined environmental objectives have been determined for amended management of flows at the barrages. However, over recent years, discussions with the local commercial fishers have led to some changes in the operation of the gates to encourage better mixing of the fresh and saline water in the estuary below the barrages, to improve fish response.

From this assessment it is clear that there are significant opportunities to improve management of flows at the barrages in response to ecological needs. In particular, the minor successes with fish movements can be greatly expanded.

Clear environmental objectives need to be developed and translated into operating guidelines. Minor changes in flow patterns could bring positive benefits, for example by extending flows later into spring, or renegotiating the pattern of flow distribution for entitlement flows. These options should be further investigated.

Automation of the barrage gates would have multiple benefits, including:

- selective opening of barrages to optimise estuarine conditions
- fish exchange during high tide with little water loss
- improved operator safety
- rapid response to weather changes to prevent saline intrusions into the lakes
- selective opening of barrages to improve lake water quality
- selective opening of barrages to scour blocked channels.

The option of operating the lakes at a wider range of levels is worth investigation. More information is required on the constraints which determine the operating ranges, and alternative solutions which could allow more flexibility in barrage operations. Detailed information such as lake bathymetry and location and levels of pump offtakes will be needed. Community consultation will be a key ingredient in assessing this option.

In the medium to long term, there is a major opportunity to consider the options for renovation, redesign or relocation of the ageing, out-of-date barrage structures. There is an opportunity to consider all aspects of their operation, including:

- alternative locations, including Wellington and Point Sturt
- alternative designs to allow easy operation, fish passage, removal in floods and boat passage
- protection of saltmarsh habitat on the barrier islands
- operation of two sets of barrages, at the present location and further upstream
- operation of Lake Albert as an estuary.

There are many issues to consider, including the impacts on existing users, but the longer timeframe allows investigation, debate and room for innovation in considering how to replace the barrage structures when this becomes necessary.

The challenge

The challenge is to develop a range of short –, medium – and long – term management strategies which move from the current operational system to one which combines social and economic needs with ecological needs in order to maintain a healthier system. Priorities need to be set so that changes can be introduced sequentially with minimal disruption. The first priority is to adjust gate operation, with automation of gates in the short term to provide much greater operational control and flexibility.

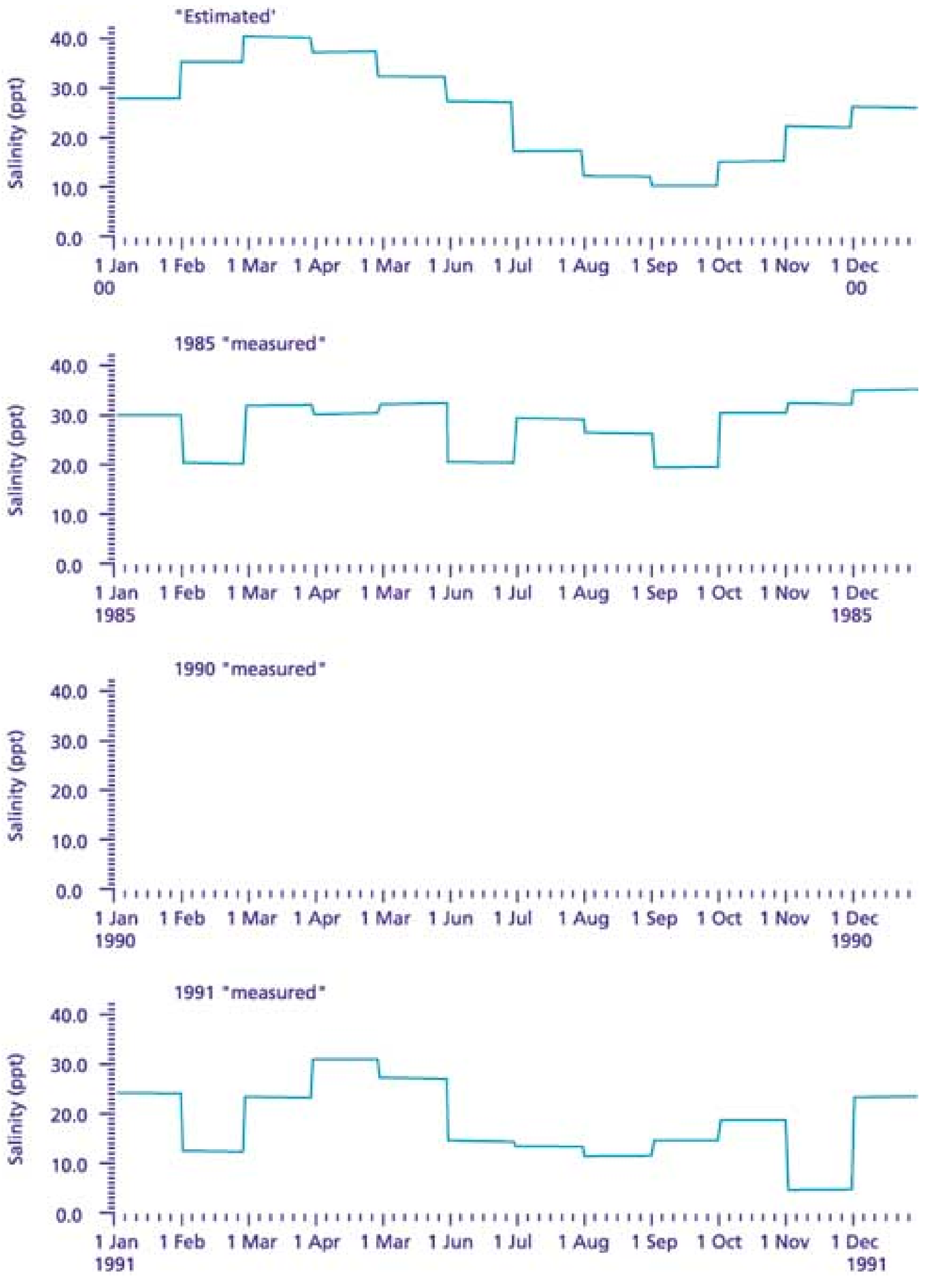
A range of hydrologic tools are available, including:

- monthly simulation models for the River Murray (MDBC)
- daily simulation models for the River Murray downstream from Yarrawonga (being developed by the MDBC), and monthly models upstream from Yarrawonga (Figure 2.5)
- daily data archives (DENR)
- Murray Mouth estuary model and Coorong model (Gary Tong, International Fluid Dynamics)
- Murray Mouth modelling (University of South Australia).

The river is a heavily regulated system supplying a heavy demand for water to entrenched user groups. However, there is room for significant modification and flexibility to simulate key parts of the natural hydrological regime to meet ecological needs and improve the sustainable management of the water resource.

FIGURE 2.5 PELICAN POINT SALINITY – BOUNDARY CONDITIONS FOR LONG-TERM MODEL

(SOURCE: COMPUTATIONAL FLUID MECHANICS INTERNATIONAL)



GEOMORPHOLOGY OF THE LOWER MURRAY LAKES AND COORONG

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BACKGROUND AND CURRENT STATUS

Geomorphically the lower Murray lakes and Coorong area is naturally very dynamic. A major impact of river regulation has been to reduce that dynamism; the tendency has been to maintain an unnatural constancy in the system. In order to provide environmental benefits, future management operations of the barrage system should be undertaken in the context of improving the variability of the area to accommodate both short-term and longer-term natural changes.

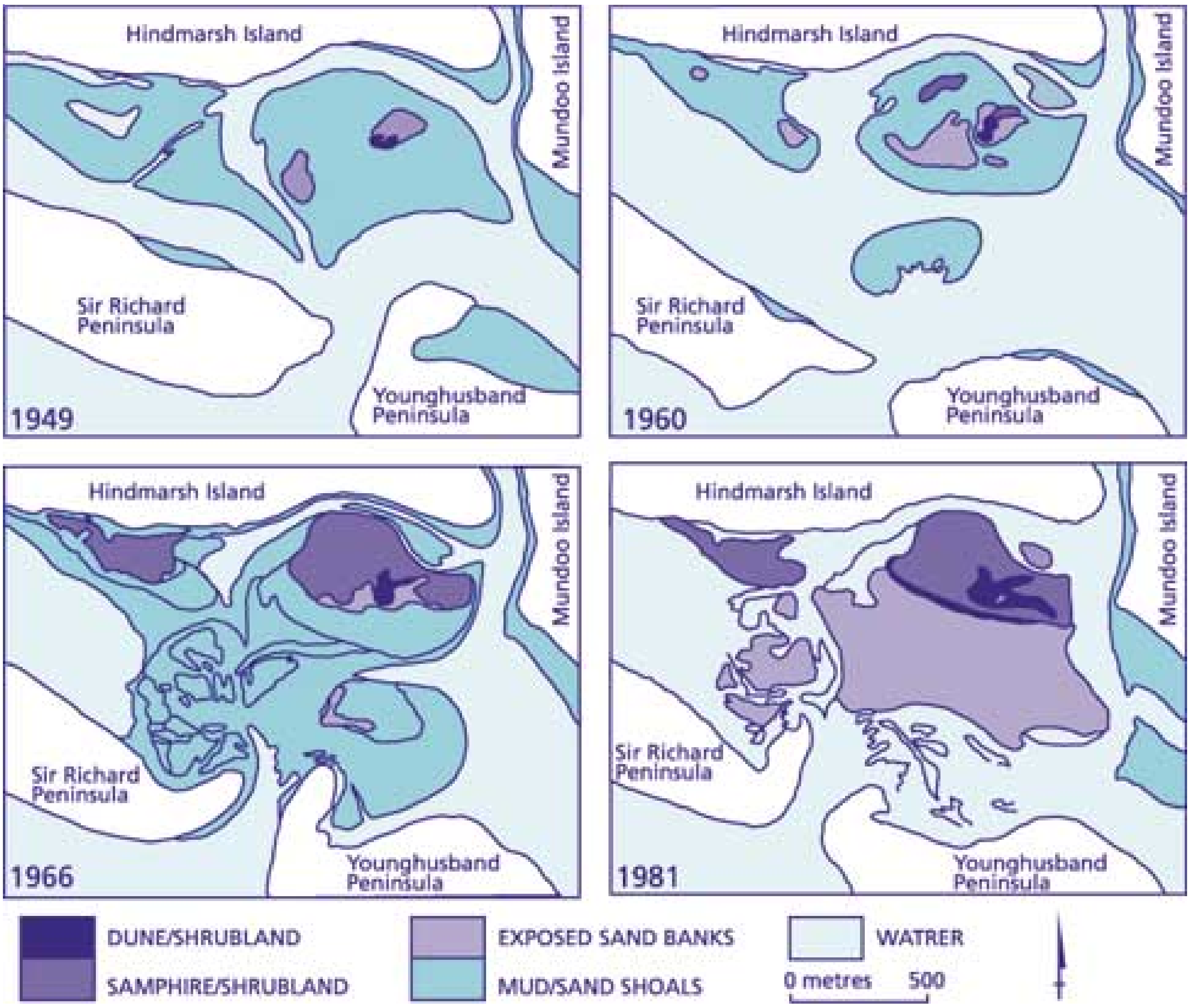
The region is not only affected by river flows. It is also affected by aeolian processes, tidal oscillations, storm surges, wave action on lake and ocean shores, wind-induced lake level changes and variations in local sea level due to global sea level changes and long-term land subsidence. Furthermore, human influences impact on many of these processes.

The natural River Murray estuary, which comprises terminal lakes Alexandrina, Albert and the Coorong Lagoon, is a Holocene feature, occupying Quaternary interdune areas and formed as a result of drowning by the eustatic sea level rise (from -150 m) that accompanied global deglaciation from 17 000 years to 7000 years BP. The location of the estuary also reflects subsidence of the lakes region in relation to the Mt Lofty Ranges and the Robe–Naracoorte area of south-eastern South Australia.

The last interglacial shoreline parallels the modern shoreline several kilometres inland, and most of the barrage system has been built on this substrate. The northern half of Hindmarsh Island formed during the last interglacial times (125 000 years BP) when longshore transport was dominantly from the southeast, effectively pushing the

FIGURE 2.6 DEVELOPMENT OF THE MURRAY MOUTH FLOOD TIDAL DELTA

(SOURCE: BOURMAN & HARVEY 1983)



course of the River Murray westward, partly explaining the large bend in the River Murray at Goolwa (Ngarrindjeri for 'elbow').

The modern coastal barrier system (Sir Richard Peninsula and Younghusband Peninsula) formed from 7000 years ago when sea level rose following glacial melt. The development of Sir Richard Peninsula completed the elbow of the main Goolwa Channel. Subsequently, the barriers have migrated landward, sporadically exposing lagoonal sediments on the ocean beaches. During the Holocene about 5000 years BP, an extensive sand flat with associated dunes formed immediately inland of the coastal barrier.

Aeolian processes are of significance, with at least six generations of Late Pleistocene dune systems in the region. For example, during the last glacial period when the climate was drier, colder and windier; a system of parallel, west-east trending, yellow-red desert dunes developed around the lakes.

Aeolian processes remain important with occasionally up to 5000 tonnes of sand being in motion along the modern shoreline (Bourman 1986). During mouth migration, dunes up to two metres high have been formed and vegetated in 12 months, directly inland from the mouth (Bourman & Harvey 1983). In the Coorong, sand is blown directly from barrier dune systems into the lagoons, clogging channels.

The position of the Murray Mouth is extremely dynamic, migrating over 1.6 km since the 1830s, with migrations of up to 6 km over the past 3000 years (Bourman & Harvey 1983; Harvey 1996) (Figure 2.6). Movements of 14 metres in 12 hours have been observed. These documented changes reveal the geomorphic dynamism and fragility of the Murray estuary and highlight the need to minimise future human impacts.

KEY ISSUES

Natural changes

There are some natural, ongoing geomorphic changes which will have impacts on the long-term flow management of the lower Murray system. Natural changes are operating, trending towards returning the artificial freshwater lake system back into an estuary. Differential levels of the sea relative to the lakes are likely to decrease as a result of the factors described below.

Accelerated Greenhouse-induced global sea-level rise

Predictions of accelerated Greenhouse-induced global sea-level rise of the past seem to have been downgraded. The range of Intergovernmental Panel on Climate Change (IPCC) best current estimates for global sea-level rise (eustatic) are now 1 to 2.5 mm/yr (IPCC, 1996). Calculations of the sea-level trend for Victor Harbor is +0.6 mm/yr, which can be revised downwards to +0.5 mm/yr based on expected neotectonic movements in the region (Harvey 1996).

Recent work at Port Pirie suggests a possible rate of local eustatic sea-level rise of no more than 0.29 mm/yr (Barnett et al 1997; Harvey et al 1997).

Despite these low rates of predicted, climatically-induced sea-level rise, it should be noted that there is evidence that when climate change occurs, it may change extremely rapidly. A rapid melting of the West Antarctic ice sheet would result in major marine incursions into the Lower Lakes region.

Tectonic movement

Tectonic dislocation of the last interglacial shoreline of 125 000 years ago indicates that Hindmarsh Island and the barrage system is subsiding at a rate of 0.02 mm/yr. The level of the last interglacial shoreline is 6 m AHD at Victor Harbor, 2 m AHD on Hindmarsh Island, 2 m AHD at Mark Point, 3 m AHD at Salt Creek, 8 m AHD at Robe (Woakwine Range) and 18 m AHD near Mount Gambier. This indicates tilting down towards the Murray Mouth area from both westerly and south-easterly directions.

Coastal erosion

Erosion has been well documented on Sir Richard Peninsula, with the neck of land at the proximal end of the barrier (immediately upstream of Goolwa Barrage) narrowing (Bourman & Murray-Wallace 1991). This section of the spit is important because it forms a barrier between the sea and the freshwater upstream of the Goolwa Barrage. Aboriginal middens (2000 to 3000 years old) on sand dunes have been eroded and reincorporated into the modern beach sediments, back barrier lagoonal sediments approximately 6000 years old have been exposed on the modern beach face, and surveyed roads and a European beach shelter now occur in the subtidal zone (Bourman 1979; Bourman & Murray-Wallace 1991). Sir Richard Peninsula is affected by high energy waves, but the small tidal range and limited surge effects, together with the dissipative effect of the offshore topography, suggest that there is little likelihood of oceanic breaching of the barrier. Even during the 1981 blockage of the Murray Mouth, when a storm surge resulted in washover of the barrier near the western end of Barkers Knoll on Younghusband Peninsula, a new channel was cut but silted up rapidly. The rates of change are not extremely rapid and there is no imminent danger of a breakthrough given wise management of the area.

Nevertheless, it is an area that should be monitored closely. A rise in sea level, related in part to enhanced 'Greenhouse' influences or the continuance of the long-term tectonic subsidence of the Murray Mouth area (Sprigg 1952), could exacerbate this problem.

Geomorphic impacts of river and lake regulation

The significant geomorphic impacts of river and lake level regulation include:

- the development of prograding shorelines in sheltered areas
- accelerated shoreline erosion in exposed localities
- accelerated rates of sedimentation in the lakes
- a change in the character of the sediments deposited and the acceleration of salinity in soils associated with salinisation of depressions and blocked drainage channels.

The most important geomorphic impact of river regulation has been the growth and consolidation of the flood tidal delta (Bird Island) landward of the Murray Mouth (Bourman & Harvey 1983) (Figure 2.6).

Prograding shorelines

These have developed on sheltered coasts and in former estuaries such as those of the Finniss River and Currency Creek where digitate deltas have formed. The progradation is closely related to the colonisation of the shoreline by freshwater plants (reeds and rushes), which aid the trapping of sediments (Bourman 1974). No detailed studies have been undertaken on the rates of sedimentation, although comparison of 1945 aerial photographs with modern ones should produce reasonably reliable estimates. Prograding shorelines do not appear to present major problems to managers except that freshwater plants may dominate in former saline environments.

Eroding shorelines

These occur predominantly (but not exclusively) on exposed coasts, especially where fluviatile clays overly marine sands. The marine sands were deposited as an extensive sand flat approximately 5000 to 6000 years ago in relation to a slightly higher (approximately 1 m) sea level than at present. This marine sand is in turn overlain by some 20–30 cm of dark fluvial, lacustrine clay. The subdued conditions of sedimentation of the sand flat suggest that the sand horizon is at a uniform elevation, and that the sand horizon occurs within and below the current range of lake levels. Wherever this situation occurs, the rate of shoreline erosion does not appear to be slowing down, as might be expected with movement towards a new equilibrium condition.

Often human-induced geomorphic change occurs rapidly in the first instance but slows down and eventually a new equilibrium condition is established. However, in this case, because of the disposition of the easily-eroded sand horizon, within the zone of lake water levels, a new equilibrium condition will not be achieved until the eroding shoreline reaches harder material. Given the widespread occurrence of this vulnerable sand flat around the lake shores and the need to sacrifice large areas of land before a new equilibrium could be achieved, there appears to be little alternative but to try to protect the shoreline from erosion by physical means. The stability and aesthetics of these physical structures could be improved by fencing off stock, planting reeds and revegetating the riparian fringe.

The eroding shorelines have contributed to the accelerated sedimentation (Bourman & Barnett 1995) and the deterioration in water quality in the lakes, as fine sediments and stored salt have been incorporated into the lakes following shoreline erosion. The increased rates of sedimentation are discussed below. Coulter (1992) noted maximum rates of erosion of 12 m/yr, with an average of 1 m/ yr. The costs of land and production losses since barrage construction were calculated at $4.2 million in 1992 (Coulter 1992).

Accelerated sedimentation in lakes

The amount of clastic sediment reaching the coast may have been greater in the past. Sprigg (1952) attributed the higher quartzose contents in beach sediments near the Murray Mouth to terrestrial sediment inputs from the river, but it could also have been derived from offshore sources during the post-glacial rise in sea level (Bourman & Murray-Wallace 1991). If there has been a reduction in the delivery of coarse sandy material to the coast, it could reflect the impacts of river regulation upstream, where coarse sediment is trapped by weirs and dams (Thoms & Walker 1992; 1993). There may be some longer-term impacts of coastal stability due to decreased sediment input from the River Murray. Johnston (1917), noting the gentle gradient of the river and the settling impact of the terminal lakes, wrote that 'It is probable, therefore, that the water which reaches the Murray Mouth is quite free of sediment'. The greatest amount of sediment in suspension, measured by Johnston in 1915, was one in 4200 parts at Morgan. Johnston (1917) also noted that considerable quantities of sand blown from Sir Richard Peninsula into the Goolwa Channel have been transported through the mouth and onto the offshore bar.

Johnston (1917) also reported on the observations of a Lieut. Goalen who stated in 1876 that 'The matter which discolours the water sometimes for miles seaward of the mouth is so impalpable that it cannot sink if there is the slightest motion in the water — that contained in a bucketful is not more than sufficient to slightly stain a handkerchief'. The matter referred to is almost certainly phyto-plankton, and it is interesting to note that it was occurring more than 120 years ago.

Accelerated sedimentation in Lake Alexandrina has been accompanied by minor increases in organic carbon, total phosphorus and copper concentrations (Barnett 1993; 1994). While these can mostly be related to either early diagenic processes or fluctuating algal populations in the lake, the addition of organic matter, nutrients and trace elements due to European settlement cannot be overlooked. There has been an increase in the sedimentation rate in Lake Alexandrina over the past 100 years, perhaps related to accelerated lakeshore erosion. Barnett (1993) demonstrated a long-term (over thousands of years) sedimentation rate of 0.5 mm/yr in the central channel of the lake and a much greater shorter-term (over tens of years) rate of 1.7 mm/yr. As stated above, the cause of the increased sedimentation is probably related to accelerated lake shore erosion. The implications of this increased rate of sedimentation is that greater amounts of sediment, much of which is very fine-grained, has been put in motion in the lake waters, increasing turbidity and the potential for increased nutrient storage in the lakes.

Change in the character of the sediments deposited

Generally there has been a change in the character of the sediments deposited towards finer particles which can adsorb phosphorus. Accelerated sedimentation has occurred upstream of the barrages. For example, sedimentation upstream of Goolwa Barrage has occurred at a rate of 4.5 mm/yr over the past 50 years (Bourman & Barnett 1955), with a change from bioclastic sands to muds. The upstream weirs also cut off the supply of coarser sediments, with only the finer, clay-sized materials which carry nutrients being transported through the upstream barrier systems in suspension.

Acceleration of salinity

Raised water tables associated with artificially-elevated lake levels (and probably in association with regional vegetation clearance) has raised the salinity of soils, with associated salinisation of depressions and blockage of natural flow paths/drainage channels. A distributary system of channels formerly discharged river floodwaters across Hindmarsh Island, sometimes forming wetlands where the discharge was blocked by sand dunes on the south side of Hindmarsh Island. Elsewhere the floodwaters discharged directly to the sea.

Artificial blockage of these channels has occurred on Hindmarsh Island by road causeway construction. Even when there is no flood overflow into the channels, runoff from local rainfall accumulates in the channels. This water cannot flow away, evaporates and increases the salinity of the channels. Local landholder Kym Denver is making steps towards resurrecting the seaward flushing of these channels. This process should be encouraged. The operation of the barrages has minimal impact on this process, except that maintaining a water level at +0.75 m AHD should encourage through-flow, provided that the channels are cleared. These channels should be operated to maximise biotic exchanges between the estuary and the lakes.

Saline depressions occur in many localities on Hindmarsh Island and it is likely that their current level of salinity is related to elevated water table levels consequent upon permanent raising of the lake level to +0.75 m. However, vegetation clearance on the island has also probably contributed to the salinisation of the depressions. Lowering of the lake levels may reduce the level of salinity in the depressions, but this is difficult to justify given the lack of detailed knowledge about the character and formation of these saline depressions, and given the unknown contribution of vegetation clearance and irrigation activities to their salinity levels.

From a geomorphological point of view there is no obvious reason to oppose the proposal to build levees to stop marine incursions across the island spillways. These are already artificial barriers to flow and maintain the lake level at the prescribed +0.75 m. There is little doubt that they would be effective in limiting saline incursions into the freshwater lakes. On the other hand, there may be a danger of increased flooding risk during a major flood event down the Murray system. It is suspected that in the original design of the system these lower levels were built to accommodate the discharge of high flood events. Today, with increased water abstraction from the system, the high flood events may occur less frequently.

Despite the fact that there is little objection on purely geomorphic grounds to the proposal to build higher levees on some of the causeways, the levees would change the salinity levels of the overflow regions, which may be important for fish passage and habitat for waders (Paton ibid).

Development of Bird Island

Ecologically, the most important geomorphic impact of flow restriction and regulation has been the development of Bird Island by the growth and consolidation of the former flood tidal delta immediately inland from the Murray Mouth. This is particularly related to the lack of discharge through the Mundoo Barrage. The barrages were not completed until 1940, but the Mundoo Channel immediately upstream from Bird Island was closed by a barrage with timber sluiceway in 1915 to restrict salt water ingress into Lake Alexandrina. The continuing growth of Bird Island and the sedimentation in the surrounding channels has the potential to result in more frequent and permanent blockages of the Murray Mouth. The island is approximately 1 km in diameter and sand dunes on the island stand well above the level of the 1956 flood (Bourman & Barnett 1995).

Flood-tidal delta formation was detailed by Bourman and Harvey (1983) (Figure 2.6). Historical surveys and photographic sequences of the mouth area were summarised by Harvey (1983), and Carruthers (1992) reported on the progressive vegetation colonisation of Bird Island. The growth of Bird Island is described and documented in a series of aerial photographs in Bourman and Barnett (1995). Together these studies highlight the rapid growth and consolidation of Bird Island in the area of the Murray Mouth since barrage completion. A combination of no river flow and subdued meteorological and oceanic conditions led to the closure of the Murray Mouth in April 1981 (Bourman & Harvey 1983) (Plate 3). A channel was dredged by the then Department of Engineering and Water Supply (E&WS) to re-open the mouth (Shanks 1981) in order to prevent flooding of large areas of land, homes and shacks on the shores of the lakes and channels. The mouth has been close to closure on many occasions in the past (Marsh pers comm) and up until 1981 there had been sixteen times when river flow was stopped for 100 or more consecutive days by barrage closure (Shanks 1981). During the drought of 1967–68 the barrages were closed for 529 days, but the mouth did not close completely as it did in 1981 when the barrages were closed for only 196 days, suggesting that conditions other than lack of river discharge (high tides, storm surges) are important in maintaining the opening to the sea.

The cost of re-opening the mouth has been estimated at $50 000 (Victor Harbor Times (June 1, 1983). The Murray Mouth Advisory Committee in 1987 considered dredging a channel at a cost of $225 000 as a possible option for mouth maintenance. Other options included allowing a river outflow of at least 20 000 ML a day for one month, the construction of groynes ($500 000), installation of drift fencing on Younghusband Peninsula ($15 000) and artificial closure of the mouth to prevent sand movement into the lagoon.

The mouth threatened to close several times since 1981 and again in late 1996, when soundings at the mouth were as shallow as 1.5 m, but the sedimentation process was interrupted by an unseasonal summer storm which drove sea water through the mouth (Marsh pers comm).

Reduction of River Murray estuary

The River Murray estuary has been heavily modified by progressive river regulation. There have been 20–30 periods of no flow after barrage construction, when the barrages have been closed for 100 or more consecutive days. There has been a reduction in the water flow available for flushing of mouth by as much as 75 % compared to natural conditions (Close 1990; Newman ibid).

The barrages have also resulted in a physical restriction of the area of tidal influence. Furthermore, during periods of low or no flow, it has been noticed that the mouth restriction increases as the tidal influence diminishes. Winter tides are generally higher than summer tides and calm meteorological conditions lead to decreasing tidal amplitudes through the mouth which may ultimately result in the blockage of the mouth.

The progressive restriction of the lagoon and channels near the mouth can be related to:

- The total flow through the Murray system has been reduced to one-third of the median flow, with the frequency of no flow at the mouth increased from one in twenty to one in two (Close 1995).

- The reduction in the size of the estuary has reduced the size of the tidal prism by around 90% of its original pre-barrage size. In 1914 the lake area affected by tides was 97.3 km2 (75 000 hectares), with a spring tidal prism of 20 000 ML (Walker 1990). These figures indicate that the original tidal prism produced a twice-daily exchange of similar magnitude to the flows of 20 000 ML/day for a month or more which would now be required to substantially clear the mouth of accumulated deposition (Harvey 1988).
- Storm surges, which have become more important in clearing the mouth with the reduction in river outflows, occur with variable frequency. Thus periods will occur when storms are less likely to occur, increasing the risk of mouth closure. A threatened closure in December 1996 was averted by an unseasonal summer storm surge (Marsh pers comm). Chappell (1991) showed that in the seven months prior to mouth closure in 1981 only 28 storms capable of moving sand at the mouth occurred, compared with an average of 44 storms for similar periods during 1940–90.
- The volume of water discharged through the Mundoo Barrage has become negligible. Mundoo Barrage is operated infrequently, as the gates are cumbersome to operate, making it extremely difficult to respond to rapid changes in conditions induced by wind. The structure consists mostly of causeway with a small number of discharge gates. Even when the gates are fully open, there is a restriction of flow as the barrage gates only cover 20% of the natural channel width. As a result, flows through the Mundoo Channel are greatly reduced in volume and frequency from pre-barrage flows.
- The pattern of flow discharges through the estuary channels has been altered. Under natural conditions the Holmes Creek or Mundoo Channel accommodated 10–20% of the total flow of the River Murray. The Goolwa Channel has always been the major channel, carrying 60–70% of flows, with the balance of 10–20% of flows passing the remaining three openings (McIntosh 1949; Johnston 1917). Today the main flow is still through the Goolwa Channel, but virtually no water passes through the Mundoo and Boundary Creek barrages (see Figure 2.2).
- A flow shadow has formed on the southern side of Hindmarsh Island. Plumes from the changing flood tidal delta landward of the mouth have become progressively vegetated and stabilised, eg Bird Island. Much of the island now stands above the flood height of the 1956 flood (Bourman & Harvey 1983) and would not be removed even by a major flood. It has also permanently reduced the tidal prism and the flow capacity at the Murray Mouth.
- The sand spit produced during the westward migration of the Murray Mouth is protecting the ocean side of Bird Island from coastal processes. The progradation of Bird Island towards the Murray Mouth continues and increases the possibility of more frequent and permanent closures of the mouth, which is undesirable on many counts.

ECOLOGICAL NEEDS

From a geomorphological perspective, there are four key ecological needs which require addressing, as listed below:

- limit sedimentation inside the Murray Mouth
- limit shoreline erosion in lakes Alexandrina and Albert and rehabilitate areas experiencing these pressures
- reduce the rate of sedimentation in the lakes
- reduce the effects of this sedimentation by addressing turbidity levels.

OPPORTUNITIES FOR IMPROVEMENT

Options for rehabilitation measures to address the key geomorphological issues are outlined below.

Short-term

Salinity

- Reduce the effects of salt concentration in the artificially blocked drainage lines on Hindmarsh Island. This could be achieved by clearing the channels, facilitating the through-flow of river water. Options for improvement require further investigation.
- Identify options to reduce salinity problems in the depressions on Hindmarsh Island affected by artificially raised water tables.

Sedimentation

A combination of measures may be required to reduce sedimentation caused by shoreline erosion. Such measures must take into account the impact of wind-generated lake setups. Physical structures will probably be necessary to protect erosion control measures. These should be used in combination with grazing controls and revegetation with appropriate native species to maximise stability and habitat value and to minimise visual impact.

- Remove sediment and nutrients from the Lower Lakes by promoting the flushing of sediments through the Murray Mouth when turbidity levels are high. To ensure the sediments and nutrients are not transported into the Coorong Lagoon, it is suggested that this flushing take place during summer when low tides predominate or during periods of low tide and calm seas.
- Improve the water quality of Lake Alexandrina through reduced sediment inputs by reducing the effects of lakeshore erosion and establishing sites of nutrient storage (reed beds). Management options in this area may need to incorporate the temporary lowering of lake levels to allow farmers to undertake remedial work along eroding lakeshores.

Medium-term

- Minimise the chances of mouth closure by clearing sediment from the channels upstream and downstream of the barrages. As Mundoo Channel has the steepest gradient to the sea, Mundoo Barrage should be opened first and more frequently to maximise flow velocities. The barrage opening should be enlarged to increase flow volumes and scouring effects.

A detailed study is required of the size of the flows that can be generated, the optimum size of opening in the Mundoo Barrage and the optimum operating strategy to maximise scouring effects at the Murray Mouth. Some initial dredging of the Mundoo, Holmes Creek Channel may be required. Clearly, a detailed hydrological and ecological study is needed. The recommended automation of the barrage (in association with other benefits such as fish migration) will facilitate short-term responses that are essential in operating this barrage.

The danger of flooding downstream of the barrage and the impacts on upstream irrigators in Mundoo Channel would need to be investigated

This option is essential for maintenance of an estuarine environment and flow through the Murray Mouth in the medium to long term. Without action, the frequency of mouth closures will increase, with associated losses to fishing, recreation and tourism. The cost of re-opening the mouth to prevent serious flooding is also significant, with estimates of up to $1 million in machinery and expertise given in late 1996 (Jensen pers comm).

Long-term

- Enlarge the diversity of habitat in the estuary by increasing the size of the tidal prism and the flushing effects of tides at the mouth. An option for management is to relocate the barrage system to Wellington or to Pt Sturt–Pt McLeay.

These options are further explored and integrated with other recommended actions in Part 3.

AQUATIC AND RIPARIAN VEGETATION

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BACKGROUND AND CURRENT STATUS

Salinity is the overriding factor determining the productivity and species composition of the plant communities associated with the junction of fresh and saline water. The original flora of the Lower Lakes and Coorong would have been dominated by those species able to tolerate both saline surface waters and high root zone salinities.

Previous work relevant to this region of South Australia (Brock 1979; Renfrey et al 1989; Margules et al 1990; Mensforth 1996), including the Coorong and the area around Hindmarsh Island, suggests characteristic communities associated with surface water salinity tolerances (Table 2.2).

The soil salinities associated with the freshwater species ranged from 190 to 2150 µS/cm, and >50,000 µS/cm (1:5 extract) for the halophytic species.

These data suggest that the saline tolerant plant communities *(Ruppia spp – Isolepsis spp, Sarcocornia quinqueflora – Distichlis distichophylla, Halosarcia sp – Distichlis distichophylla)* would have dominated the more saline areas. The transition zone between fresh and saline water would have been dominated by *Paspalum distichum, Schoenoplectus littoralis, Melaleuca halmaturorum, Juncus pallidus, Juncus kraussi, Bolboschoenus medianus,* and on the higher ground by two species of *Gahnia (G filum* and *G trifida)*. The freshwater areas would have included emergent vegetation such as *Typha domingensis, Phragmites australis* and possibly members of the genus *Baumea* and other members of the Cyperaceae (eg *Eleocharis* spp and *Schoenoplectus pungens*). The submerged and semi-emergent vegetation would have included species such as *Triglochin procerum, Villarsia reniformis,Vallisneria americana* and *Myriophyllum* spp, as well as species belonging to the genus *Potamogeton*.

The current distribution of species along the salinity gradient created by the presence of the barrages reflects this range of tolerances. Thus the more saline and permanent waters of the Coorong and Murray estuary are

TABLE 2.2 SURFACE WATER SALINITY TOLERANCES OF PLANT COMMUNITIES IN THE LOWER LAKES AND COORONG

Dominant species and plant associations	Surface water salinity (ppm)
Sarcocornia quinqueflora – Distichlis distichophylla	0.38 – 42.40
Halosarcia sp – Distichlis distichophylla	23.9 – 56.5
Ruppia spp – Isolepsis spp	36.9 – 56.5
Paspalum distichum – Schoenoplectus littoralis	0.01 – 18.69
Melaleuca halmaturorum	0.2 – 17.3
Juncus pallidus – Bolboschoenus medianus	0.84 – 17.12
Typha domingensis – Berula erecta	0.01 – 0.53
Typha domingensis – Phragmites australis	0.01 – 0.51
Phragmites australis	0.01 – 0.51
Hydrocotyle verticillata – Paspalum distichum	0.01 – 0.49
Muehlenbeckia florulenta	0.38 – 0.50
Myriophyllum salsugineum	0.38 – 0.50
Schoenoplectus littoralis	0.43 – 0.49
Bolboschoenus medianus – Triglochin procerum	0.49 – 0.50
Vallisneria americana	0.45

dominated by three species of *Ruppia* and *Lamprothamnium papulosum*. The saline but less permanently inundated soils of the coastal region are dominated by *Sarcocornia quinqueflora, Halosarcia* sp, *Wilsonia* spp, *Suadea australis* and *Selliera radicans,* as well as the more terrestrial members of the Chenopodiaceae family (eg *Enchylaena tomentosa*).

The current distribution of the emergent vegetation on the upstream freshwater side of the barrages is dominated by those species which require a freshwater environment and include *Typha* spp, *Phragmites australis* and *Bolboschoenus medianus,* which often form dense and apparently monospecific stands. The dense and extensive nature of these stands often obscures the smaller species which add to the biodiversity of the area. For example, *Utricularia* spp, *Wolfia* spp, *Lemna* spp, *Spirodella* spp and many of the shade-loving stoneworts (*Nitella* spp and *Chara* spp), as well as some of the herbland species such as *Triglochin striatum* occur beneath the canopy of these extensive stands. Indeed Blanch (1997) lists more than 200 species associated with the sub-littoral, littoral and lower floodplain of the Lower Murray between Blanchetown and Wentworth during collections made between 1993 and 1996.

Prior to river regulation much of plant biodiversity appears to have been concentrated on the floodplain and the temporary wetlands rather than in the main channel where the persistent rise and fall of water levels probably inhibited the establishment of the flora (Blanch 1997). It is worth noting that the explorer Sturt comments on the extreme variability of the water clarity which 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 (< 25 NTU), Harris (1963) described a rich aquatic flora 20 km upstream of Blanchetown which extended out into the main channel 6 to 10 metres. Whether this was because of exceptionally clear Murray water or whether there was some other reason is unknown.

The submerged vegetation in the Lower Lakes is now restricted to inshore areas, whereas anecdotal evidence suggests that these species were once more widely spread throughout the lake basins. Although it is not possible to come to any definitive process-orientated description of why the Lower Lakes or the main channel of lower Murray lack a significant submersed flora, speculation should include the idea that turbidity, water levels and flow were always variable on both annual and inter-annual scales and this has persisted since regulation, although at different scales.

KEY ISSUES

The four key issues influencing the productivity, distribution and floristic composition of the aquatic and riparian vegetation are:

- salinity
- turbidity
- water regime
- wind and wave action.

Salinity

The barrages split the water mass into two distinct zones juxtaposed to each other and artificially maintained. The transition from seawater to freshwater now usually occurs within a very confined distance and is maintained irrespective of river flows.

This management protocol has effectively removed those habitats which represent the transition from saline to freshwater characteristic of undisturbed estuaries. As a consequence, the flora adapted to this transition zone is poorly represented and restricted to those areas where it can survive despite competition from those species better adapted to a permanent freshwater environment.

In addition, those species which have now established themselves throughout the freshwater lakes as a consequence of 50 years of freshwater impoundment are also able to tolerate periods of relatively high salinities. *Phragmites, Typha* and *Bolboschoenus* can tolerate salinities between one-third and two-thirds of seawater. Furthermore, their underground rhizomes are able to survive long periods of high soil salinities as the soil dries out, yet will re-sprout as the soil profile freshens as a result of freshwater inputs.

Turbidity

The lack of many submerged plant species in the Lower Lakes appears to be correlated with the reduced penetration of light as turbidities have increased as Darling flows make a significant contribution to the lower Murray water budget (Mackay et al 1988; Mackay 1990). This and the labile nature of the bottom sediments restricts the vegetation to the near shore areas, where it is subject to wave and wind action and where individuals are susceptible to desiccation and uprooting.

The light required to maintain positive growth in *Vallisneria americana* has been investigated by Blanch et al (1997). They showed that if the average midday irradiance between the water surface and the sediment surface is > ca 30 mmol/m2/s, then the plant will be able to maintain a positive growth rate. However, if the average water column irradiance falls below this level, then the species is unable to survive. At turbidities of ca 500 NTU this critical level of light penetration will occur at a depth of between 20 and 30 cm. For a turbidity of 209 NTU, the survival limit would be at a depth of 60 cm, and for 90 NTU plants could survive to a depth of 110 cm.

At average intensities of 110 µmol/m2/s, the leaf recruitment is much greater than leaf senescence, but as the average intensity falls to 35 µmol/m2/s, leaf senescence outstrips leaf recruitment. In addition, the longer the duration of top flooding with turbid water, the less likely is the survival of the plants.

The origins of the turbidity in the lakes and Coorong is unclear. In addition to the turbidity due to the particulates advected downstream in the main river, and their re-suspension due to wind and wave action, an additional source may occur in the lakes. This is due to a combination of significant bank erosion as a consequence of wave action and wind-blown soil erosion directly entering the lakes. The particles are kept in suspension by turbulent water movement. There is evidence to suggest that particulate matter is discharged through the barrages and enters the Coorong, where it can be resuspended via wind action at the surface (Tucker 1996).

Water regime

The water regime of the Lower Lakes and Coorong aims to maintain a relatively static level of 0.75 cm AHD but features frequent major rapid water-level changes of more than one metre due to wind-induced seiching. Major fluctuations in water levels may cause water stress to those plants high on the littoral elevation gradient. Although many aquatic plants can withstand sudden inundation, few can withstand sudden desiccation. Experimental work with *Bolboschoenus* suggests that if the fall in water level is ca two cm per day for 30 days (a total fall in water level of 60 cm), plants can extend their roots to maintain contact with the receding water table (Blanch et al 1997). However, the optimal rate will depend upon the hydraulic characteristics of the soil (eg sand, loam or clay).

Alternatively, rising water levels may drown emergent species by restricting access to atmospheric carbon dioxide and oxygen or by restricting light energy. Denton and Ganf (1994) have shown that if *Melaleuca halmaturorum* seedlings are top-flooded for more than three weeks they do not survive. Blanch et al (1997) have shown that *Bolboschoenus* must have at least 10% of its leaf surface area above the water surface, otherwise it will die. Other work has demonstrated that if those species which pump air into the sediments (eg *Phragmites* spp and *Typha* spp) are top-flooded, rhizome growth will be restricted. Cooling (1997) has demonstrated that the critical water depth for *Vallisneria reniformis* is ca 60 cm, whereas if *Baumea juncea* is top-flooded growth ceases but it can recover following draw down.

Wave action and wind

A major factor influencing the establishment of aquatic plants is the stability of the sediment. Continual wave action caused by either natural (wind) or artificial (boats) means is always a problem, particularly in the establishment phase of an aquatic plant community. This is often exacerbated by grazing of both domestic stock and water birds.

Supplementary issues

Unpublished work obtained from the river between Blanchetown and Nildottie during the summers of 1995 and 1996 demonstrated that concentrations in the river water of inorganic phosphorus and nitrogen were often below the limits of routine chemical analysis. Furthermore, Brookes, Ganf, Burch, Baker and Geary (unpub, University of Adelaide and Australian Water Quality Centre) showed via a series of bioassay experiments that both nitrogen and phosphorus limited phyto-plankton growth. Similarly, transplant experiments with *Vallisneria americana* during 1995 in the region of Lock 1 demonstrated a significant increase in growth on the addition of nutrients. These data strongly suggest that during the period of investigation nutrient limited growth of both macrophytes and phytoplankton occurred in the main river. It is unknown whether similar nutrient limitation occurs in the Lower Lakes. However, it is reasonable to suppose that after fifty years of sedimentation from river flows and surrounding land, internal stores of phosphorus and other nutrients will have built up. This process of nutrient accumulation poses a potential problem to the system.

The data suggest that phosphorus concentrations are a function of the origin of the water (Darling v Murray) and this will vary from year to year (Burch pers comm). The literature suggests that to induce P-limitation, the concentration of inorganic phosphorus should not exceed 10 mg/m3 on average for the entire growing season or absolutely for 50% of the growing season (Reynolds 1992). The bioavailability of the phosphorus depends upon the water source and will vary from 20% to 80% (Oliver 1993). Further investigation is required to determine whether the primary source of nutrients is the lake catchment region rather than inputs from the river.

ECOLOGICAL NEEDS

In order to manage the vegetation communities of the Lower Lakes and Coorong with the objective of maintaining the diversity and range of habitat types which existed prior to regulation, there are a number of ecological needs which would need to be met:

- re-establish a salinity gradient to promote species diversity (active management would be required to promote native species and community establishment while controlling weed invasion)
- reduce turbidity levels in the Lower Lakes to enhance growth and recruitment of aquatic and riparian vegetation
- establish a water regime allowing for optimum survival and growth of a diversity of flora.

OPPORTUNITIES FOR IMPROVED ENVIRONMENTAL CONDITIONS

Salinity

The management objective should be to create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients. It is important to maintain the salinity gradient of estuarine to hypermarine along the Coorong, as Paton (1997) has demonstrated that the performance of the important food source *Ruppia tuberosa* is dependent upon salinity. To return to pre-barrage vegetation communities, one solution would be to remove the barrages and permit the salinity gradient to re-establish itself. However, this is not practical and even if it were, there is no certainty that the flora would revert to something resembling the historical associations. It is more likely to provide fertile ground for the invasion and establishment of exotic weed species.

The greatest potential for reinstatement of estuarine vegetation communities would be to ensure that any future manipulation or re-construction of the barrages maintains a salinity gradient over an ecologically sound distance, which is in tune with the seasonal fluctuations in salinities afforded by river discharges.

Turbidity

To produce minimum illuminance conditions, there are a number of suggested approaches to reducing turbidity in the Lower Lakes and Coorong. These include:

- directing turbid water over the barrages and out to sea with minimum interaction with the Coorong (note that this would have minimum impact in the marine zone, where turbid river water quickly disperses and mixes)
- ensuring that there is an adequate re-vegetation of the lakes shore and restriction of grazing and cultivation of the riparian zone. This may include revegetation with species such as *Typha* and *Phragmites* as a first step, but could also include *Cyperus gymnocaulus* and other bank stabilising species (eg *Eleocharis acuta*)
- ensuring that the catchment is adequately vegetated to prevent wind borne soil particles entering the lakes
- implementing shoreline protection including erosion control works.

Water regime

To provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem, the water management regime should incorporate the following requirements:

- the rate of fall should not exceed ca two cm per day for no longer than 30 days
- seedlings should not be top-flooded for more than two weeks
- average water column irradiances given for *Vallisneria americana* should be used as a guideline for the duration and depth of flooding
- at least 10% of emergent leaf area should be maintained at the maximum operating height.

Any successful management through water manipulation will need to take into account and try to minimise wind-induced seiche movements.

Wave action and wind

To reduce desiccation and physical damage of aquatic plants and damage to riparian vegetation, wave and wind action needs to be minimised. Options to consider include:

- Drop the water level at the rates referred to above, thus increasing the littoral zone available for plants. It is likely that those plants that invade these temporary areas are likely to be the herbland species which have a relatively small biomass. Although these plants may act as a suitable food source for birds, it should also be recognised that the larger, more permanent emergent reeds and rushes act as very significant nutrient sinks. Any removal of these species may well result in further nutrient enrichment of the water column, with an increase in the probability of phytoplankton blooms.

- Any structure (either artificial or natural, eg re-vegetation of reed beds or trees in the riparian zone) which creates a wind break reducing the fetch and lessening the impact of wind-driven turbulence, would provide an advantage for the riparian and aquatic plant communities. There is a need to evaluate the effectiveness of options in reducing wind and wave action.

Supplementary issues

Options to reduce the internal store of phosphorus in the lakes and to reduce the risk of cyanobacterial blooms need to be considered. Any flushing of the lakes would be an advantage. However, while the impact on the high-energy, high-volume marine environment would be negligible, this discharge should not be allowed to impact on the restricted environment of the Coorong.

BIRD ECOLOGY IN THE COORONG AND LAKES REGION

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BACKGROUND AND CURRENT STATUS

The wetlands of the Coorong, Murray Mouth region, lakes Albert and Alexandrina, including the ocean beach, constitute a Wetland of International Importance under the Ramsar Convention. The primary reason for the initial nomination was the diversity and abundance of waterbirds that used these wetlands. The nomination also acknowledged the diversity of wetland habitats (freshwater, estuarine, marine and hypermarine) and singled out the hypermarine southern Coorong for special mention, indicating that this was a particularly good example of this type of wetland.

Over 85 species of waterbirds have been recorded from the Coorong and Lower Lakes wetlands, including various grebes, cormorants, ducks, geese, swans, pelicans, egrets, herons, ibis, spoonbills, gulls, terns and waders. These species are not evenly distributed over the region. Certain wetland systems are favoured by different species of birds (eg the exposed mudflats and shallows of the Coorong and Murray Mouth estuary are favoured haunts of waders). Within these wetlands, selected areas consistently attract substantial numbers of waterbirds.

These locations have been identified and recently mapped as part of the Coorong and Lower Lakes Ramsar Management Plan (Berggy et al in press). The significance of the area for waterbirds is easily established by comparing the numbers and diversity of birds that use these wetlands with other wetland regions in Australia. In terms of species richness and overall numbers of waterbirds of all kinds, the Coorong and Lower Lakes rank within the most important six waterbird sites in Australia. On a state basis, the area is a stronghold for more than half of the waterbirds that occur in South Australia.

The extensive mudflats and shallow waters of the Coorong and Murray Mouth estuary are particularly important for waders. The Coorong and estuary wetlands (mudflats) rank among the top three sites in Australia for seven species of wader (Lane 1987):

- banded stilt
- red-necked stint
- sharp-tailed sandpiper
- curlew sandpiper
- red-necked avocet
- black-winged stilt
- red-capped plover.

Coupled with the ocean beach, the region also ranks in the top two sites for pied oystercatchers and sanderlings. For a further three species, the Coorong is ranked in the top six sites and for another three species it is ranked in the top thirteen most important sites in Australia.

To reinforce the importance of the region as a whole for waders, the fringing wetlands and marshes associated with Lake Alexandrina (and to a lesser extent Lake Albert) also rank amongst the top 20 sites in Australia for seven of these species.

According to Lane (1987), significant recordings of bird use in the Coorong include:

- 77 000 banded stilts
- 40 000 curlew sandpipers
- 64 000 red-necked stints
- 56 000 sharp-tailed sandpipers.

These numbers probably represent in excess of 20% of the total Australian populations for these species. The latter three species are listed on the CAMBA and JAMBA international treaties. For a range of other species the peak numbers recorded in the Coorong probably represent between 5% and 10% of the estimated Australian populations.Various waterfowl also occur in large numbers in the Coorong and lakes wetlands. Up to 60 000 grey teal and over 60 000 hoary-headed grebes have been recorded in just the Southern Lagoon of the Coorong in some years, and up to 50 000 black swans may also be present in the region as a whole in some years. Other species that exist in large numbers (>1000) include:

- australian pelican
- australian shelduck
- pacific black duck
- chestnut teal
- cape barren goose
- fairy tern
- crested tern
- whiskered tern.

Cape barren geese usually congregate on adjacent pastures rather than in or on the wetlands themselves. As yet there are no complete or accurate counts of the numbers of waterbirds using the freshwater wetlands associated with the lakes, but ibis, cormorants, coots, moorhens, swamphens and several other species of duck are also likely to have population sizes in the thousands. These

TABLE 2.3 SCIENTIFIC BIRD NAMES

Common Name	Scientific Name
cape barren goose	Cereopsis novaehollandiae
australian shelduck	Tadorna tadornoides
pacific black duck	Anas superciliosus
grey teal	Anas castanea
chestnut teal	Anas castanea
australian pelican	Pelecanus conspicillatus
red-necked stint	Calidris ruficollis
sharp-tailed sandpiper	Calidris ferruginea
black-winged stilt	Himantopus himantopus
banded stilt	Cladorhynchus leucocephalus
red-necked avocet	Recurvirostra novaehollandiae
pied oystercatcher	Haemotopus longirostris
red-capped plover	Charadrius ruficapillus
sanderling	Calidris alba
fairy tern	Sterna neries
crested tern	Sterna bergii
caspian tern	Sterna caspia
black swan	Cygnus atratus
hoary-headed grebe	Poliocephalus poliocephalus

freshwater swamps and reedbeds are important habitats for a range of species, including the rarely encountered australasian bittern.

The numbers of waterbirds using the Coorong and lakes region fluctuate seasonally and from year to year. Numbers of waterbirds are generally much higher during summer and autumn than over winter and spring. For example, counts of waterbirds in the southern Coorong showed a ten-fold change in abundance during 1984-85. In winter and early spring 14 000–18 000 waterbirds were present but the numbers rose to over 160 000 in summer and autumn (Paton unpub). The increase in numbers was due to the annual influx of waders (both Palaearctic and Australian species), grebes and ducks.

The actual numbers that use the wetlands over summer and autumn also vary from year to year and appear to be related to the extent to which other freshwater wetlands still retain water. In dry summers and during prolonged droughts many more birds appear to congregate around the Lower Lakes and Coorong, indicating the importance of these wetlands as drought and summer refuges.

Relative to the numbers of birds recorded using the region, only a few species breed in substantial numbers. In the Coorong there are large nesting colonies (several thousand birds) of crested terns and australian pelicans. Both of these species mainly forage for food outside the Coorong (pelicans catch carp in the Lower Lakes, crested terns fly over Younghusband Peninsula and catch marine fish). Other species nesting in smaller but still significant numbers (hundreds of nests) in the southern Coorong are fairy and caspian terns (also piscivorous species). Their use of the southern Coorong is possibly influenced by the presence of many small islands coupled with the abundance of small fish (hardyheads) in the Southern Lagoon. Most of the other waterbirds using the Coorong do not breed in the area. However, black swans, a variety of ducks, cormorants, ibis and herons nest around the shores of the Lower Lakes.

The extent of the different habitats within the region has undoubtedly changed since the introduction of the barrages. Prior to the construction of the barrages, water levels in the lakes would have fluctuated depending on flows down the River Murray. Incursions of marine water would have extended further up the river when the river was not flowing. Estuarine type wetlands would have been more extensive prior to the construction of the barrages, while freshwater wetlands, particularly reedbed, were probably less prominent than they are today.

With the construction of the barrages, estuarine type habitats more suitable for waders have declined and have been replaced by freshwater habitats more suitable for other waterbirds. The current operating policy of maintaining a relatively constant water level reduces the amount of shoreline around the lakes which is seasonally exposed when water levels drop. This reduces opportunities for wading birds. Historically, swamp paperbarks *(Melaleuca halmaturorum)* were more widely distributed around the lakes than today. These provided important nesting sites for a range of waterbirds and added to the diversity of riparian vegetation.

The Technical Working Group established to assist with the development of the Coorong and Lower Lakes Ramsar

PLATE 4 PELICANS, EWE ISLAND (PHOTOGRAPH: ANNE JENSEN)

Management Plan (Berggy et al in press) concluded that in general the numbers of almost all species of waders and waterbirds using the wetlands of the Coorong and Lower Lakes were declining and that the decline had been particularly noticeable over the last 20 years (also see Paton et al 1989). The group acknowledged that many of these declines were taking place over a much wider area than the Coorong and Lower Lakes region itself, and that these declines were linked to loss and degradation of habitat nationally (and possibly internationally). However, the group indicated that there was little if any monitoring taking place and hence a lack of reliable quantitative data on which to support such a conclusion. However, for a range of species, particularly waders and some ducks, the declines of total populations, particularly in the regions between the barrages and the Murray Mouth, were considered to be substantial and greater than the overall decline in these species.

KEY ISSUES

Changes in water management brought about following the installation of the barrages and upstream controls on river flows have contributed to these declines in waterbird populations. Particular threats include:

- lakeshore erosion
- changes in water quality, particularly turbidity
- increased sedimentation
- the effects of carp on aquatic vegetation (and turbidity)
- rapid changes in water level
- potential disturbance by increased human activity on and around the wetland.

These threats influence waterbird numbers largely through changes to the quality and quantity of suitable habitats and are ongoing threats.

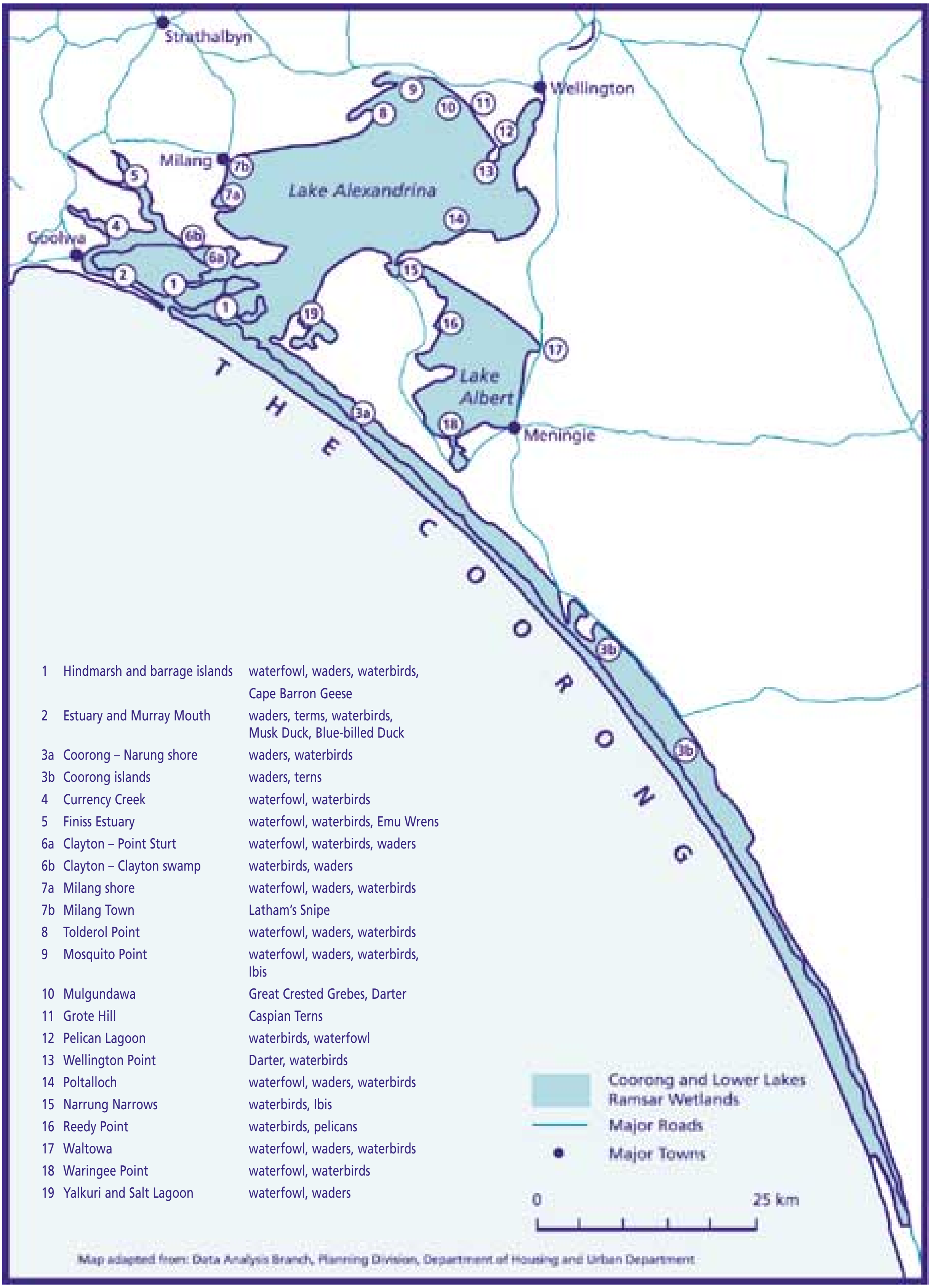
Lakeshore erosion

Of all the habitats used by waterbirds in the region, the relatively steep eroding banks of the Lower Lakes are the least preferred and are rarely used by waterbirds. The extent of eroding shorelines has increased dramatically (Eckert pers comm) since the installation of the barrages, which has allowed the water levels in the lakes to be maintained at a consistently high and more or less constant level. These eroding shores may also contribute to increased sedimentation and turbidity.

The maintenance of relatively constant levels in the lakes may also limit the amount of seasonally exposed lake floor and so lead to reduced habitat opportunities for waders.

FIGURE 2.7 COORONG AND LOWER LAKES RAMSAR WETLAND AREA – KEY TO CRITICAL BIRD HABITATS

(SOURCE: DHUD)



Turbidity

Increasing turbidity levels impact on bird populations by decreasing food sources and limiting their hunting ability. The sources of turbidity in the Lower Lakes and Coorong include particulates in river inflows, regional catchment erosion and feeding activity by carp.

Increased turbidity may have contributed to reductions in grebes, other diving birds, as well as herons, egrets, cormorants and terns, all of which hunt largely by sight. Increased turbidity may have also reduced the productivity of any remaining submerged aquatic plants (Ganf ibid). Similarly, turbidity may have increased in the Coorong lagoons over time, affecting the quantity of light and hence productivity of submerged aquatic plants in these regions as well (Paton et al unpub; Paton 1997).

Increasing sedimentation

Changes in the quantities and timing of releases of water over the barrages may have influenced the availability and or productivity of the mudflats used by waders and some waterfowl (grey teal, black swans, australian shelduck). Increased levels of sedimentation, particularly large quantities of sand, in the region of the Murray Mouth estuary and the dynamics of sand movements in the region (Bourman ibid) may have rendered some of the mudflats in this region less suitable for aquatic plants and invertebrates, smothering them or alternatively restricting tidal volumes and so reducing the extent to which more distant mudflats are tidally flushed and/or exposed. There are no specific data to support this contention but it is a logical biological outcome following the extensive and relatively rapid rates (Bourman ibid) at which sand has been deposited in the region. This could also reduce the areas of habitat suitable for some of the aquatic plants that grow in channels and the Northern Coorong Lagoon, affecting both aquatic invertebrate abundances and fish, which in turn reduces the carrying capacity of the area for birds.

European carp

European carp are now abundant in the Lower Lakes and are believed to contribute to increased turbidity and degradation of aquatic plant communities (Roberts et al 1995). The loss of aquatic (submerged) plants within the lakes has been cited as the likely factor contributing to the recent and substantial declines in musk ducks and blue-billed ducks (Soon 1992). Loss of these aquatic plants may also affect invertebrate food resources used by other birds.

Rapid changes in water level

The effect of rapid changes in water level on habitat quality is best illustrated by examining the performances of the key aquatic plant in the southern Coorong, *Ruppia tuberosa*. This 'annual' plant grows around the ephemeral shoreline of the Southern Lagoon and produces large quantities of seeds and turions which are consumed by some of the waterbirds and waders. The plant also provides resources and habitats for aquatic invertebrates (chironomid larvae, ostracods, etc) which in turn provide food for birds and the abundant small-mouthed hardyhead *(Atherinosoma microstoma)*, an important resource for some of the waders, terns, grebes, herons and cormorants (Paton 1982; 1986; Molsher et al 1994; Brooks et al 1995; Paton et al unpub).

Water levels in the Southern Lagoon fluctuate seasonally by about one metre, with rainfall (and/or groundwater) and evaporation considered to be the major contributors to this seasonal pattern (Tong pers comm). As a consequence, extensive areas of mudflats (typically several hundred metres wide around most of the shores of the Southern Lagoon) are exposed during late summer and autumn. It is on these mudflats that *Ruppia tuberosa* grows. Seeds and turions germinate or sprout in late autumn and winter when water levels rise (often in association with rainfall and local runoff) (Paton 1997 unpub).

The plants grow through winter and spring and, provided water levels are maintained for long enough, will flower in late spring and produce seeds and then turions before water levels drop again. Examination of the performance of this plant shows that it performs best in water depths that range from about 0.3 m to 0.8 m during winter and spring (Paton 1997). In shallower water plants are limited by periodic desiccation due to day-to-day fluctuations in water levels brought on by changes in the direction and strength of the wind. In water deeper than about 0.8 m the plants perform poorly, presumably because insufficient light penetrates the turbid water. Although some seedlings may survive at these depths they generally do not grow and most eventually die without reproducing. The operation of the barrages thus has a bearing on the ability of *Ruppia tuberosa* to complete its reproductive cycle through the affect on water levels.

The water levels in the southern Coorong have a slightly higher head than the water levels in the Murray Mouth region, such that the level of water may be a metre higher than sea level during late winter and spring. Thus when the barrages are not open, water from the Southern Lagoon slowly shifts northwards but when the barrages are open the water levels are higher in the northern Coorong. This essentially plugs the Coorong, reduces the movement of water northwards and so water levels in the Southern Lagoon are higher.

However, if the barrage gates are closed over a relatively short period of time, the water level in the Southern Lagoon can drop rapidly (as it did in December 1990), such that the beds of *Ruppia* are suddenly exposed to desiccation and both seed and turion production are prevented. Prior to the construction of the barrages changes in water levels in the northern Coorong would have been more gradual as flows down the Murray subsided gradually and not abruptly.

A gradual change in water depth may provide *Ruppia* plants with the time to package resources into turions, with the plants using any of a number of cues to switch from sexual reproduction (seeds) to asexual reproduction (turions). Changes in light intensity (caused by slowly dropping water levels) and/or changes in day length (anticipating reduced water levels well in advance) might have normally triggered turion production during summer and into autumn. Prior to the construction of the barrages and locks, flows of water into the northern Coorong may have extended for a longer period of time and further into late summer and autumn. This would have given this annual plant a longer period of time in which to complete its cycle.

Impacts of human activity

A further and increasing threat to the 'quality' of the habitats in the region is linked to increases in human recreational activity. Human activity ranging from walking along the shoreline to use of canoes, power boats and jet skis could all disturb birds while they are foraging on nearby mudflats and in shallow water. That disturbance if frequent may greatly reduce the time the birds spend foraging, may force them to abandon preferred areas, may contribute to reductions in aquatic and or riparian plants and may be critical for some of the waders, particularly those that are attempting to fatten prior to migrating northwards.

ECOLOGICAL NEEDS

To maintain and protect the diversity of avifauna unique to the Lower Lakes and Coorong, it is essential that management of the system addresses these ecological needs:

- buffer the abrupt changes in water levels in the southern Coorong
- allocate more water downstream of the barrages, extending the period of flow and mitigating the rate of recession of water levels in the Coorong
- reduce sedimentation of the mouth
- increase the size of the tidal prism
- increase the spatial extent of wader habitat by increasing the tidally exposed mudflats
- reduce turbidity in the lakes to improve the growth of submerged plants
- reduce sediment transport into the Coorong
- protect saline wetland habitat for waders
- enlarge the area of estuarine habitat and create additional estuarine habitat around the lakes
- reduce carp numbers and human disturbance.

The first task is to restore and rehabilitate the estuarine habitat that existed between the barrages and the Murray Mouth until recently, by flushing out some of the coarser marine sands that have been deposited in the estuary region.

OPPORTUNITIES FOR IMPROVEMENT

Management opportunities for improvement can be divided into short-, medium- and long-term options, which are detailed below.

Short-term

The management objective should be to reduce the abrupt changes to water levels in the Coorong. This could be achieved through the short-term, minor changes to the operation of the barrage gates. This would involve opening gates progressively, perhaps starting a little earlier than currently happens, keeping some of the gates open for a longer period into summer. When the gates need to be closed, the gates could be closed progressively, perhaps starting earlier than is currently the case but extending the period over which the gates are closed. Closing the Tauwitchere Barrage last might slightly prolong water level recessions in the Coorong, because of its proximity to the northern Coorong (relative to other barrages).

Medium-term

The priority medium-term action is to improve the ‘fine’ control of barrage releases by automating some of the gates. The proportion of gates needing to be automated for optimum environmental benefits is unknown, however even if only a small percentage can be modified initially, that will still be of some benefit. Automatic gates (even a few on each of the barrages currently serviced with power) will clearly improve the ability of barrage operators to deliver the short-term management objectives.

Additional medium-term actions should consider allocating more water for environmental use downstream of the barrages, enabling the barrage operators to extend the period of flow over the barrages until later in the year and/or to allow water levels to be dropped more gradually downstream of the barrages during late summer or autumn.

The third priority medium-term action should aim to reduce the sedimentation taking place adjacent to the mouth and to scour out this region with a view of increasing the tidal prism and increasing the potential wader habitats in the regions. This may involve increasing the frequency and volume of water released through Mundoo Channel, possibly requiring additional gates to be added to that barrage. To achieve this objective, substantial quantities of water may need to be released for an extended length of time. This action may only be feasible when there is a substantial flow of water coming into the lakes for sufficient time. There may also be benefits to release the water strategically for parts of the day when tides are lowest and winds are favourable.

A similar scouring effect may be required to remove sand accumulating in the Coorong estuary channels between the mouth and Tauwitchere. That may require the strategic release of high flows over the Tauwitchere Barrage (while the others are not opened).

The second reason for recommending increased volumes and strategic opening of the Mundoo Barrage is to promote reductions in turbidity in the lakes. This would favour various submerged aquatic plants and increase their productivity, which indirectly is likely to increase the numbers of invertebrates, fish and birds in the lakes. The use of Mundoo Barrage could thus be considered to help flush/remove suspended material from the lakes, to help reduce turbidity. This may require the gates at Mundoo to be opened strategically during windy weather, when the quantity of suspended material is higher.

The choice of Mundoo Barrage over the others for this purpose is because of its proximity to the Mouth and hence reduced risks of the suspended material being deposited or remaining in suspension in the Coorong, in the northern channels or other parts of the estuary. To maximise the effectiveness of this action, the gates should be opened during windy weather when sediment has been resuspended, and during a falling tide to maximise the probability that this turbid water will be flushed straight out to sea with minimal impact on the marine environment (Ganf ibid).

Another medium-term management action worth considering is reducing the water levels in the lakes to help protect the habitat of the constructed and natural saline wetlands around the lake shores, used by waders, from influxes of freshwater when water levels are surcharged to 0.85 m prior to the barrages closing for summer. If water levels are not dropped then the height of the levee banks could be raised slightly to help protect the fringing saline habitats during times when the water level of the lake is maintained near 0.85 m. However, some temporary drop in water level below current operating levels is required if any additional mud flats are to be exposed around the shoreline.

Dropping the level (or allowing the level to drop below 0.65 m), particularly during the summer/ autumn period, might also expose some of the lake floor, providing additional mudflats and shallow water suitable for wading birds around the perimeter of the lake. Drops in level of 10–20 cm may be sufficient to increase the area of suitable foraging habitat for waders.

Reduced water levels might also reduce erosion pressure on exposed shores. Lowering water levels in the lakes may also assist remedial action on those shores that are currently eroding. However, given that many of these eroding shores are already steep, dropping water levels even by substantial amounts (0.5 m) may not be sufficient to provide any real benefits simply because of the large wind-induced water level changes and erosive strength of the wind-induced waves.

Long-term

To establish a larger estuarine area the long-term option of shifting the barrages to a point further upstream is likely to benefit waders by providing opportunities for tidally-exposed estuarine mudflats to re-establish in the area immediately above the current barrages. At the same time this would reduce the freshwater habitats around the current lakes at the expense of the more freshwater-dependent waterbirds.

Depending on the frequency and volumes of water that would be released over a weir at Wellington if it replaced the current barrages, substantial parts of the northern and central lakes may not change greatly. An agreement would be required to ensure that freshwater flows were maintained into the new estuarine zone. A broader, more natural estuarine zone might establish over the southern parts of Lake Alexandrina.

Such a drastic change to this wetland system might challenge the obligations for maintaining ecological character under the Ramsar convention. Nevertheless, it would clearly improve the functioning of the mouth region with clear benefits to biota and biotic processes in this part of the wetland.

Other approaches to management

There are a series of other management actions that should be implemented. Although they complement any adjustments to water regimes in the study area, they should be implemented irrespective of any adjustments to the operation of the barrages. In particular, there should be urgent remedial work on locations around the lakes currently experiencing or at risk of shore erosion to stabilise the shore (use of protective structures, destocking, and revegetation), as well as broader regional revegetation programs aimed at reducing impacts of dryland salinisation and possible sources of sediments to the lakes.

As Darling water is more turbid than Murray water, there may be benefits in reducing the amounts of Darling water entering the system, particularly if any build up in sediments and fine suspended material currently in the lakes cannot be flushed out to sea.

The presence of carp in the lakes remains a major obstacle to reducing turbidity and to stimulating the re-establishment of submerged aquatic plants. Although suitable techniques may not yet be available, implementing programs to reduce the carp numbers would be beneficial. Some commercial fish species, if they can be introduced into the lakes in adequate numbers, may help to reduce densities of carp by preying on fry and eggs (Pierce pers comm; Geddes ibid).

Impacts

In general the short- and medium-term actions of adjusting the operation of the barrages and installing automatic gates should have minimal impacts and are consistent with delivering other environmental benefits. Implementing these proposals, however, may lead to greater fluctuations in water levels in the lakes and/or periods when the Lower Lakes might have a lower mean level than the current 0.75 m AHD level. Lower lake levels and possibly greater fluctuations in water levels (more frequent in time and over a greater amplitude) may have some impacts on users such as irrigators and some short-term impacts on freshwater habitats (eg reedbeds).

If lake levels were permanently lowered the freshwater fringing vegetation (reeds) would presumably shift towards the new water level but once established might assume similar dimensions to the current system. Lower water levels might also reduce groundwater mounding in adjacent areas but lead to increased incursions of saline groundwater into the lakes. Revegetation programs if implemented at appropriate scales and in time would limit such influxes.

The lifespan of the barrages is unknown but they will eventually require replacement. Therefore, evaluation of the benefits and impacts of shifting the location of the control structure is warranted. Removing the barrages and replacing them with a weir at Wellington would probably be the most financially viable alternative. How this will affect waterbird habitats is not known and appropriate assessment of the risks of further impact on the ecosystem should be conducted.

FISH AND INVERTEBRATES

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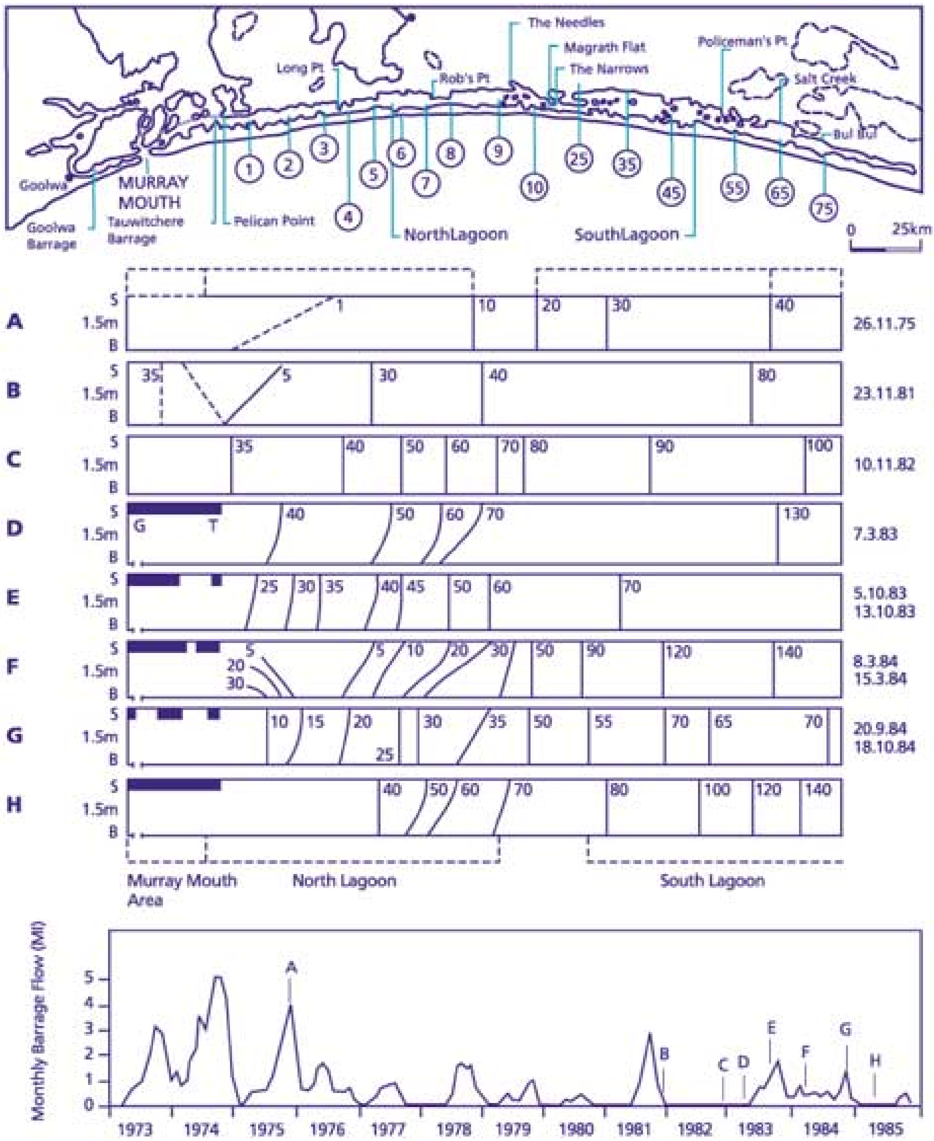
BACKGROUND AND CURRENT STATUS

The macroinvertebrates of the Coorong Northern Lagoon and Murray Mouth are an estuarine assemblage that is similar to that of other southern Australian estuaries. However, only 21 macroinvertebrate species were collected by Geddes and Butler (1984), compared to over 100 species in many other estuaries in south-eastern Australia. Major groups include Amphipods and Gastropods (particularly *Hydrobia*) that are highly abundant in macrophyte beds *(Ruppia megacarpa)*, and polychaetes and bivalves that are abundant in the soft sediments in the central parts of the lagoons.

The Southern Lagoon is characterised by a restricted hypermarine fauna. The chironomid *Tanytarsus barbitarsus* is abundant as are the hardyhead fish *Atherinosoma microstoma* (Geddes 1987). A limited array of crustaceans including ostracods, cyclopoid and harpacticoid copepods and the salt lake isopod *Haloniscus* searlei along with saline water dipteran larvae such as ephydrids and ceratopogonids also occur. Along with the seeds and turions of *Ruppia tuberosa*, these invertebrates and the hardyhead provide forage for the aquatic birds that feed in the Southern Lagoon of the Coorong (Paton ibid).

The fauna is adapted to extreme fluctuations in salinity with tolerances from 2–5 ppt to 50–60 ppt (Geddes & Hall 1990) (Figure 2.8). Even so, in periods of low flow

FIGURE 2.8 LONGITUDINAL AND VERTICAL SALINITY PATTERNS IN THE COORONG AT IRREGULAR INTERVALS BETWEEN 1975 AND 1985 (SOURCE: GEDDES & HALL 1990)



and associated high salinity, the distribution of the estuarine fauna covers only part of the Northern Lagoon. The high productivity of the macrophyte beds and the open water of the Northern Lagoon supports a highly productive macroinvertebrate fauna. The Southern Lagoon has extensive beds of *Ruppia tuberosa, Lepilaena* and *Lamprothamnion*. These plants require particular combinations of salinity depth and light (Paton ibid). Salinity is also important in the distribution of chironomids and hardyheads, with upper salinity limits of about 100 ppt. At periods of lowered salinity the estuarine fauna may move into the Southern Lagoon. Periods of extended low flow result in high salinity in the Southern Lagoon and the southern parts of the lagoon may have salinities beyond the tolerance of the hypermarine fauna (Geddes 1995).

The fish of the Coorong lagoons (Table 2.4) include species that move between the sea and the Coorong, such as mulloway and australian salmon, and species that are resident in the Coorong, including black bream, green back flounder, river garfish, yellow eye (coorong) mullet, and congolli. For mulloway and australian salmon, the Coorong is a juvenile nursery. The truly estuarine species breed in the Coorong, where freshwater inflows and

TABLE 2.4 FISH OF THE COORONG (SOURCE: GEDDES & HALL 1990)

(1) Species of commercial and/or recreational importance

Scientific Name	Common Name	Estuarine Dependency
Argyrosomus hololepidotus	mulloway	spawns in marine zone; juveniles estuarine; adult marine
Acanthopagrus butcheri	black bream	spawns in estuary; juveniles estuarine; adults estuarine
Rhombosolea tapirina	greenback flounder	spawns in estuary/ocean; juveniles estuarine
Hyporhamphus regularis	river garfish	all stages estuarine
Pseudaphritis urvilli	congolli or tupong	all stages freshwater/estuarine may need to spawn in estuary
Aldrichetta forsteri	yellow-eye mullet	all stages marine/estuarine
Arripis trutta esper	australian salmon	all stages marine

(2) Species of little of no direct commercial or recreational importance

Scientific Name	Common Name	Estuarine Dependency
Retropinna semoni	australian smelt	as with congolli
Gobius bifrenatus	bridled goby	all stages estuarine
Atherinosoma microstoma	small-mouthed hardyhead	all stages marine and hypermarine
Engraulis australis	southern anchovy	unknown
Lizagobius galwayi	blue spot goby	unknown
Spratelloides robustus	blue sprat	unknown
Hyperlophus vittatus	sandy sprat	unknown
Galaxias maculatus	common galaxias	freshwater – may spawn in either river or estuary

estuarine salinities may trigger reproduction and promote recruitment. There is evidence that freshwater inflow promotes reproduction and recruitment in black bream and greenback flounder (Pierce pers comm). The pattern of mulloway catches follows the pattern of freshwater outflows at the barrages (Figure 2.9). The estuarine species and mulloway are tolerant of freshwater salinities, but they cannot tolerate salinities above about 50–60 ppt (Geddes & Hall 1990).

The fish populations are in their healthiest state when there is good access between the Coorong and the sea, and when salinities are estuarine in the Northern Lagoon. There is evidence that some species, including mulloway, do well in the freshwater environment of Lake Alexandrina when they can gain access via locks, levees or the barrages (Pierce pers comm). This additional foraging habitat improves their condition for spawning and enhances recruitment success later in their life cycle. This access is opportunistic and related to the operation of the locks and barrage gates. Recently some experimental management of the locks and barrage gates to promote fish passage has been undertaken (Pierce pers comm).

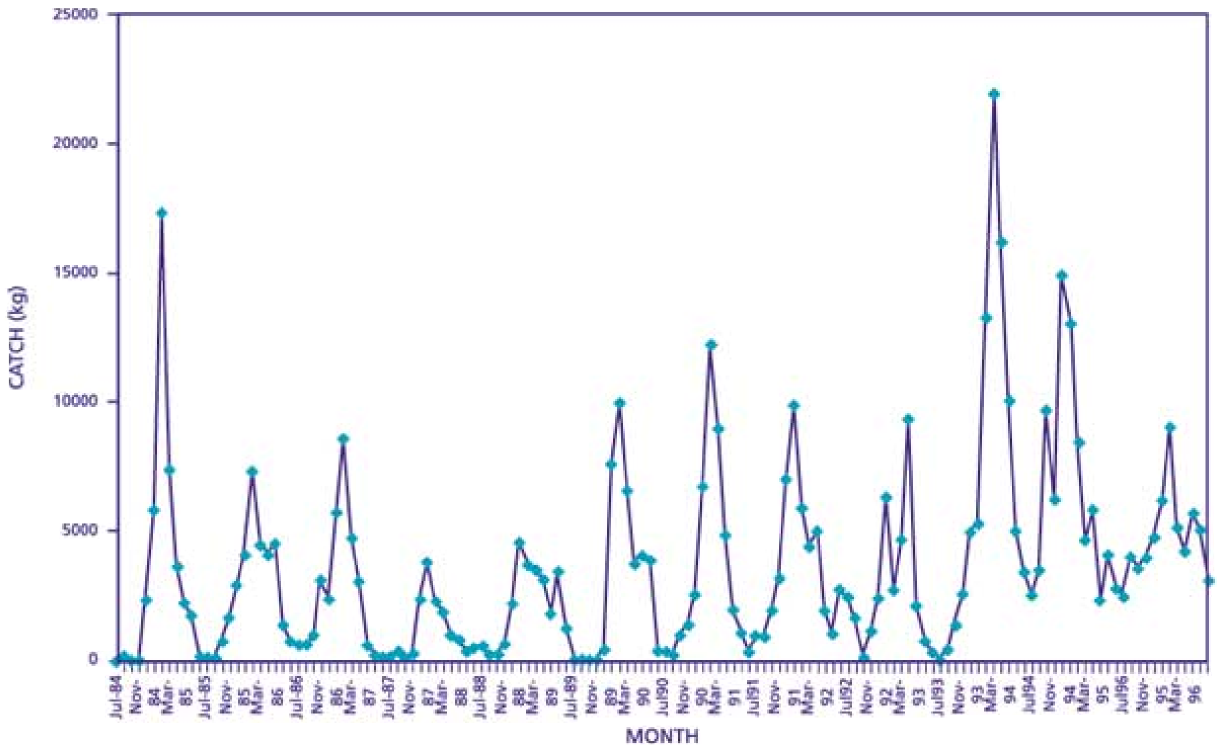
The importance of access to Lake Alexandrina via channels/creeks across Tauwitchere Island has been emphasised by professional fisher Gary Hera-Singh in a submission to the scientific panel Appendix IX). At times of high flow and/or high tides these channels are one of the few remaining links between the estuary and Lake Alexandrina, apart from the barrage openings. This may be particularly important for obligate migratory species such as the common galaxias and congolli. The fishery for all of the commercial species of fish is said to have been diminished substantially by loss of estuarine habitat (Hera-Singh pers comm, Appendix IX).

The Lower Lakes and Coorong region has in the past supplied as much as 50% of South Australia's scalefish production and currently harvests 7% of the state's capture fisheries production, including Australia's largest and most effective carp fishery. As well as being important for the commercial fishing industry, the region is also significant for its use by recreational fishers (15 000–20 000/year) (Pierce pers comm).

KEY ISSUES

The barrages scientific panel identified six key issues (see Part 1). Two of these, the reduced estuary area and changed water regimes, have direct relevance to the macroinvertebrates and fish of the Murray estuary and Coorong. Changed water regimes have also reduced access of fish to Lake Alexandrina, because of the barrier of the barrages, and to the Southern Lagoon,

FIGURE 2.9 TOTAL COMMERCIAL CATCHES OF MULLOWAY IN SOUTH AUSTRALIA 1951 – 85 AND RIVER LEVEL ABOVE LOCK 1 (SOURCE: GEDDES & HALL)

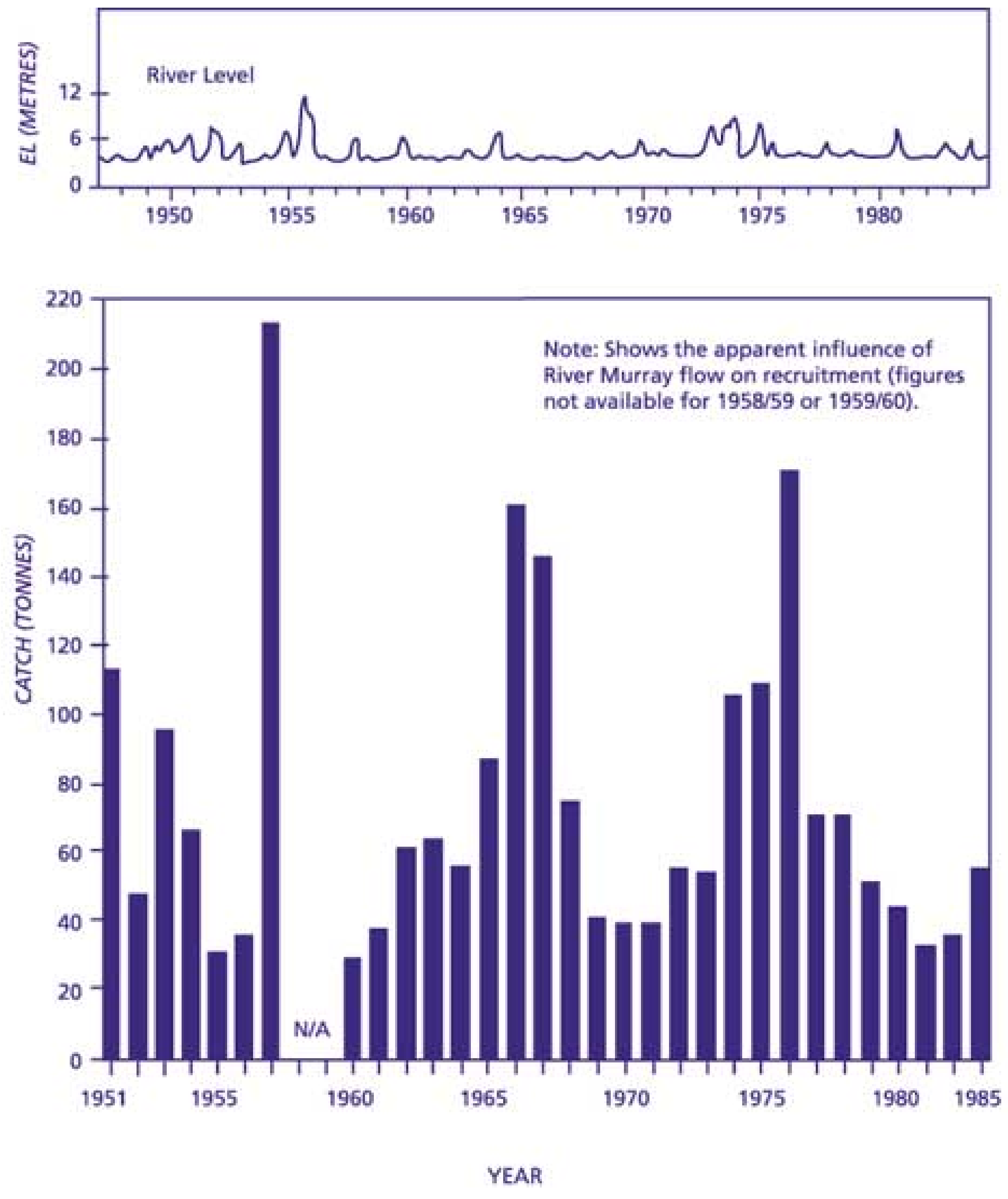


because of higher average salinities associated with reduced inflows from the River Murray.

Reduced estuarine area

In pre-regulation and pre-barrage times the Lower Lakes, Murray Mouth and Coorong lagoons operated as one extensive estuary system. The barrages have separated the now freshwater lakes from the Murray Mouth. The reduction in the area of highly productive estuarine habitat has affected the abundance of commercial and non-commercial fish species. The extent of estuarine conditions in the Coorong lagoons has also been restricted. Salinities in the northern and southern lagoons are controlled primarily by outflow from the barrages (Geddes 1987). With reduced outflows, salinity in the

FIGURE 2.10 INCREASE IN COORONG MULLOWAY CATCHES AS A RESPONSE TO A REINSTATED NATURAL WINTER FLOW REGIME (SOURCE: SARDI)



Coorong has risen. Estuarine salinities have not been recorded in the Southern Lagoon since the Murray floods of 1975 (Geddes & Butler 1984). When the barrages are closed for extended periods there may be no areas at all of estuarine conditions, but rather the mouth zone becomes a marine tidal system.

Changed water regime

The regulation of River Murray flows has led to reduced outflows at the barrages, especially at times when moderate flows would have operated (Newman ibid). There are now many periods of barrage closure and no outflow. Outflow from the Murray Mouth to the sea is important to many aspects of fish ecology. It provides nutrients to increase productivity in the system and promote survival of larval and juvenile fish. The outflow of water from the Murray Mouth is also a cue to attract large mulloway in spawning condition and to encourage juvenile mulloway, australian salmon and other species to enter the Coorong.

Changed flow regimes through the barrages at different times of the year are being investigated by SARDI. Through recommendations made by local fishers (together with fish passage research), minor freshwater inflow increases have been implemented over winter since 1994. The result has been attraction, feeding and maintenance of mulloway stocks over the full year, as can be clearly seen in Figure 2.10. Note that the most recent annual data are not finalised, but preliminary analyses demonstrate a similar pattern (for example a minimum of 5 tonne of this species alone taken monthly in the winter commercial fishery). The causal nature of the relationship is demonstrated in the recent (August 1997) stoppage of increased flows, resulting in a noticeable reduction in fish numbers only seven days after the reduced flows (Pierce pers comm). While mulloway, a top predator (150 mm to over 20 kg), benefit from this flow increase, flounder and bream are also seen to be more active in the presence of this stimulus (Pierce pers comm).

We can predict that over spring/summer/late autumn, use of attractant flows and proactive gate operation will allow fish passage. However, in the event of a significant storm, fish passage through the barrages is not possible as they would be severely buffeted (for example at Tauwitchere and Ewe Island barrages). Instead, computer operated barrages would open the sheltered Boundary Creek site where major aggregations of particularly sub-adult fish will be found and enticed into freshwater and out again (Pierce pers comm).

Current management of floodwaters restricts the recruitment of many estuarine fish species. Floodwaters are typically 'captured' in upriver weir pools, or behind the barrage network, which means from the perspective of an estuarine fish freshwater inflows are shut off almost instantly. Recruitment of most estuarine fish species worldwide is linked to the post-flood productivity with spawning linked to the final outflows (Kennish 1990). Estuarine species such as greenback flounder and bream are currently often found in advanced reproductive stages, but instead of receiving smooth flow cues to successful spawning, they usually suddenly find all inflows shut off over a one-day period. These fish then disperse and subsequent sampling fails to find evidence of significant recruitment. For example, bream catches were consistently around 100+ tonnes/year in the 1970s, but are now around 3 tonnes/year and consistently declining (Pierce pers comm). Natural flow reductions in less modified systems than the River Murray are spread over longer periods. Smoothing of the reduced flows over the barrages would more closely replicate the natural conditions expected by fish adapted to a natural estuarine ecosystem. This flow management regime is recommended to smooth and extend flows for the period September to January (Harbison 1974; Weng 1970) for bream, for greenback flounder as well as for other estuarine species (Hall pers comm).

ECOLOGICAL NEEDS

The changes in water regime and the presence of the barrages have both led to a reduced extent of the estuarine system, now approximately 11% of the former area (Bourman ibid). Along with the changes, there has been an increase in the extent of the freshwater environment behind the barrages and an increase in the spatial and temporal occurrence of hypermarine conditions in the Southern Lagoon. There has been the establishment of unvarying marine salinities for long periods in the remnant estuary when the barrages are closed.

Clearly, management of the region needs to enhance the environment for estuarine macro-invertebrates and for estuarine-marine fish. To enhance the environment for estuarine macro-invertebrates and for estuarine-marine fish, the following are key ecological needs.

Maximise estuarine area

The area which is estuarine may be defined on salinity criteria or on the basis of access between marine and freshwater habitats. It might best be considered as that part of the environment that supports an estuarine biota. The estuarine area can be maximised by extending the area of the Coorong that has salinities between freshwater and about 50 ppt. This will depend upon the extent of outflow from the barrages and the way in which that outflow is managed. Substantial outflows can control salinities in the Coorong lagoons, and small outflows can be managed so as to maximise their effect on salinity in the Murray Mouth region. The estuary can be increased by removal or relocation of the barrages to re-include the Lower Lakes in the estuary. Alternatively, if access to the lakes is provided for estuarine species that are able to use that habitat, then the lakes, even in the present freshwater condition, can become a functional part of the estuary.

In attempting to maximise the estuarine area the following two limitations need to be recognised:

- Peak outflows must not be sacrificed for the sake of extended flows. Large numbers of mulloway are attracted to the Murray Mouth at high flows, and peak flows also possess hydraulic benefits in retaining mouth depth and channel capacity.
- Avoid implementing a fixed flow regime. Variation is inherent to the productivity of the system. For example, enhanced productivity, as seen through prey species such as shore crabs, mullet and hardyheads, can fail to be made available to higher trophic levels through fixed flow regimes.

Increase fish passage between the Northern Lagoon estuarine zone and the sea via the Murray

Mouth

Several species of fish move between the Coorong and the sea during their lifecycle. The best known is the mulloway, which spawns in the sea (offshore from the Murray Mouth). Larvae and juveniles then spend several months at sea before migrating into the Coorong where they spend four to five years. Upon reaching sexual maturity, they migrate out of the Murray Mouth to sea for spawning. This outward migration occurs in November–December, and the inward migration occurs ten months later in October–December.

Australian salmon also move through the Murray Mouth. Yellow-eye mullet may also move in and out of the mouth (Hall 1984), although studies by Harris (1968) suggest that they breed in the Coorong in the months February to May.

Provide conditions suitable for spawning and larval/juvenile survival in the Coorong and Murray Mouth regions

Inflows of freshwater into the Coorong lagoons promote spawning success in estuarine species such as black bream and greenback flounder. Further studies are needed to provide an understanding of spawning in these species. Greenback flounder are thought to spawn from July to September and black bream from November to March. Flows should be maintained during the spawning season of these species. It is also important that flows are not shut off suddenly, but the recession of flow should be gradual to replicate conditions for fish spawning under natural estuary conditions (Pierce pers comm).

Provide fish passage through the barrages

Some species require access between freshwater and estuarine/marine water to complete their lifecycle. These include congolli and common galaxias. The barrier of the barrages has had a substantial impact on the population numbers of these species. Other species that may have used the lakes when they were an open estuarine system prior to the construction of the barrages include freshwater eels and lampreys.

In addition to these species that require fresh and estuarine/marine habitat, many of the estuarine/marine species may be able to use the freshwater habitat of the lakes during pre-adult growth (Pierce pers comm).

In order to meet these ecological needs, future management of flows at the barrages should incorporate the following features:

- Manage existing structure with a view to maximising freshwater flows to the Coorong, especially during low flow seasons.
- Manage outflow from the barrages at low flow to maximise the extent of estuarine/brackish water in the Murray Mouth region. This may involve maintaining gates open at the further ends of the barrages at Goolwa and Tauwitchere.
- Provide outflows at times of spawning of estuarine species (such as black bream and greenback flounder) to maximise spawning success.
- Ensure that the recession of flows is gradual to replicate conditions in a natural estuary.
- Promote flows through the Murray Mouth at critical times for fish migration.
- Retain at least two open gates at both Tauwitchere and Goolwa sites over winter to enhance recruitment of native Coorong fishes over the winter period.

- Smooth and extend the spring flood recession flow to the Coorong to mimic natural conditions particularly over the period September to January.
- Experimentally manage barrage outflow (with automation preferable) so they are timed to increase tidal ebb flows and thus increase the net flow impact on channel formation. Benefits to fish include maintenance of deeper water habitats as well as migratory access to and within the Coorong.
- Provide increased passage into the lakes from the estuary by automation of 22% of barrage gates and using them under fine control to promote fish passage (see Appendix VII).
- Provide environmental flows to maintain limited flow through barrages throughout the year and especially in October to May. These flows do not need to be even and should aim to replicate natural historical flows as clearly as possible. The exact management of these flows requires further research on the spawning and larval/juvenile recruitment of fish species in the Coorong.
- Consider removal/relocation of barrages to enlarge marine/estuarine habitat. Substantially more information on the ecology of the system and the biology of the fish species would be required before this major change to the system could be proposed.

OPPORTUNITIES FOR IMPROVED ENVIRONMENTAL CONDITIONS

A range of management options are suggested below in the context of time scales and extent of associated impacts (see Part 3). These options aim to improve conditions for fish and invertebrates, and are integrated with other environmental needs in Part 3.

AIM: Maximise estuarine area

Short-term, minor

- Manage the outflow from the barrages by selecting the place and timing of gate opening to maximise the extent of estuarine/brackish conditions in the Murray Mouth area, especially at times of low flow.
- Maximise the transfer of freshwater to the Coorong particularly during times of seasonal low flow in January and May. This would involve managing the timing, sequence and duration of barrage gates opening and closing.

Short-term, major

- Maximise the environmental benefits of outflow from the barrages by automating approximately 22% of the gates of all five barrages allowing for finer control of barrage operation (see Appendix VII). This will allow for control of flows to promote fish spawning, fish passage across the barrages and the transfer of water to the Coorong for maintenance of estuarine conditions in the Northern Lagoon.
- Make diluting flows available to the Coorong at periods of seasonal low flow, for example by operating the Lower Lakes at lower lake levels.

Medium-term, minor

- Maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages.

Medium-term, major

- Make additional water available for the Coorong environment by operating the lakes at lower levels and allocating water saved to the estuary.

Long-term, major

- Consider removal of present barrages and investigate options for new structures at Wellington or Pt Sturt. This would greatly enlarge the estuary and return it to its historical form. More information on hydrology, geomorphology and biology of the system is needed before this major change could be implemented.
- Develop Lake Albert as a managed estuarine system to increase the size of the estuary, which may involve a control structure at the Narrows and a channel from Lake Albert to the Coorong. Again more information on hydrology and ecological systems would be needed before this management proposal could be implemented.

AIM: Promote fish movement through the Murray Mouth

All of the above management strategies will promote freshwater flushing through the Murray Mouth. Consideration would need to be given to flow management in the months of likely high fish migration in and out of the mouth (October to December). However, further research is required to determine an optimal environmental flow regime and details of associated water management requirements.

Medium-term, minor

- Manage flows in association with tidal movements to maximise the tidal prism in the Murray Mouth area.

Medium-term, major

- To promote flushing of the Murray Mouth, widen Mundoo Barrage and automate gates.

AIM: Promote fish passage between Murray Mouth and Lake Alexandrina.

Short-term, minor

- To promote fish passage, change details of present operation of locks, levees and barrage gates. Note that the access to Lake Alexandrina via the creek systems across low-lying islands presently is an important connection between the Murray Mouth and Lake Alexandrina that needs to be better understood. Experiments on fish passage via locks and barrage gates is currently being undertaken by Bryan Pierce of SARDI.

Short-term, major

- In order to meet the requirements for fish passage as they relate to lunar cycles, tidal cycles and attractant flows, a suggested approach to management involves automating 22% of gates to allow for finer operation.

Medium-term, minor/major

- Provide flows for fish passage and attractant flows by managing Lake Alexandrina and River Murray flows to provide flows for these ecological needs at the barrages.

Long-term, major

- Allow access to an enlarged estuarine environment by removing the barrages.

PHYTOPLANKTON IN THE LOWER LAKES OF THE RIVER MURRAY

P Baker, Australian Water Quality Centre

BACKGROUND AND CURRENT STATUS

Phytoplankton composition and abundance has been monitored by SA Water in the Lower Lakes at Goolwa, Milang and Meningie since the 1950s. In recent years, the strategy of monitoring has changed to focus upon the detection of dominant and problem species which are likely to impair the quality of water used for domestic, recreational and agricultural purposes. Most attention has focused on recent toxic blooms in primarily located in Lake Alexandrina and Lake Albert, with most attention on recent toxic blooms on Lake Alexandrina.

Aspects of the limnology of Lake Alexandrina have been examined by Geddes (1984a; 1988) and a model has been proposed identifying the factors that may be responsible for dominance of different phytoplankton groups. Turbidity is recognised as a key factor in the availability of light and nutrients, which in turn determines phytoplankton community structure. Total biomass is also determined by flushing and sedimentation rates, as well as grazing by zooplankton.

Under conditions of high turbidity, low light availability and high nutrient levels (nitrogen and phosphorus), algal diversity may be limited and the filamentous chlorophyte *Planctonema lauterbornei* is the dominant phytoplankton species in Lake Alexandrina, often exceeding densities of 105 cells/mL (Geddes 1988; SA Water unpublished data). This is often associated with periods of high flow and high suspended load in the incoming River Murray water. Conversely, low flow and low suspended load in the river is associated with low turbidity, relatively high light availability and moderate to low nutrient levels. These conditions favour the growth of cyanobacteria, particularly *Nodularia spumigena*, *Anabaena* spp and *Aphanizomenon* sp.

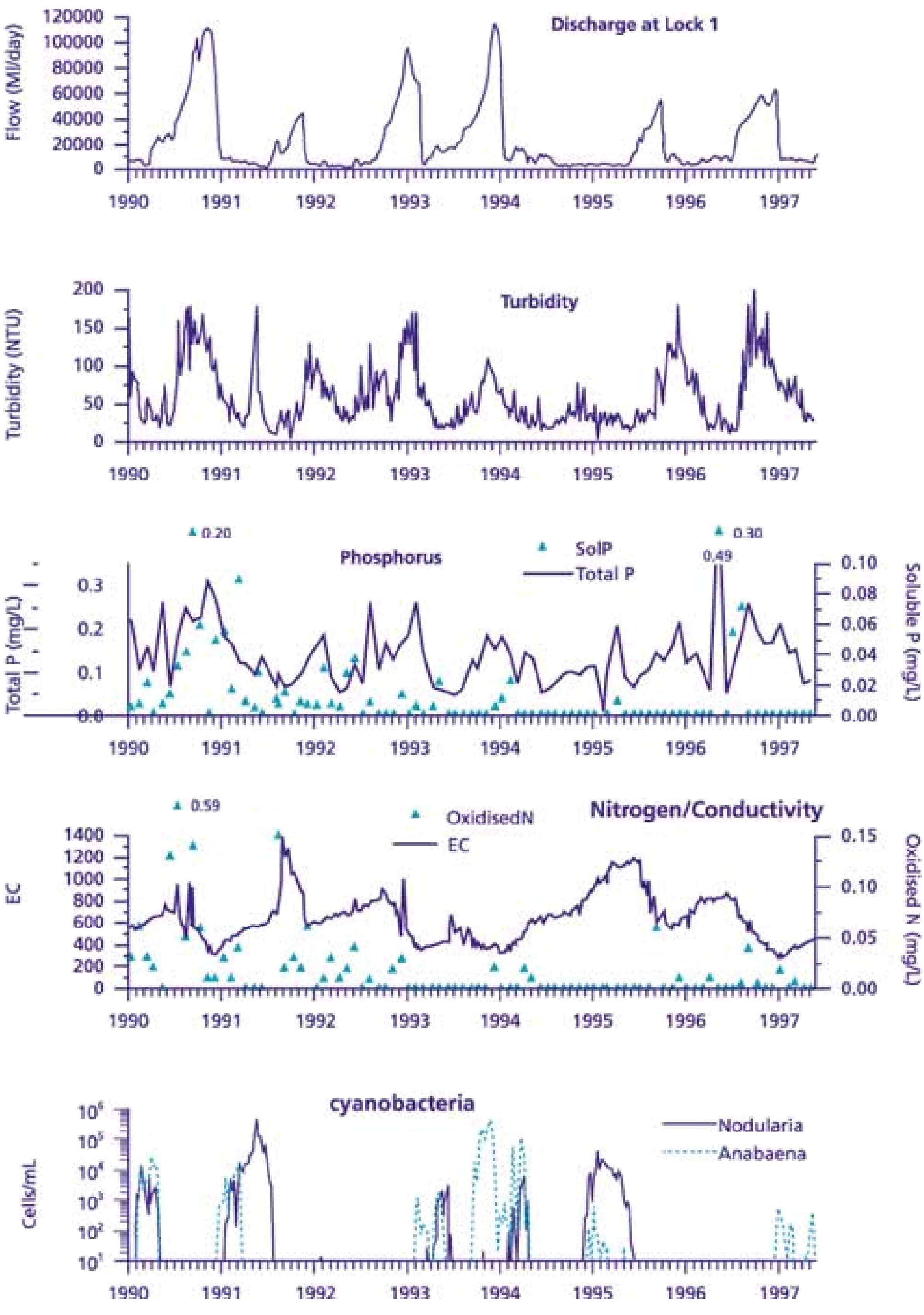
The ability of cyanobacterial cells to regulate their buoyancy and position in the water column provides a significant advantage over other phytoplankton species, which tend to settle out during periods of low turbulence (Reynolds 1987). Cyanobacteria are able to exploit turbid conditions to monopolise the available light at the water surface, but this may only occur when stability of the water column is maintained for extended periods. In the Lower Lakes, the occurrence of cyanobacterial blooms has been consistent with extended periods of calm weather, low turbulence and low turbidity (Steffensen 1995).

Flow data from Lock 1 and physical, chemical and phytoplankton data from Milang, Lake Alexandrina for the period 1990 to 1997 are presented in Figure 2.11 (SA Water unpublished data). The occurrence of *Nodularia* blooms in summer/autumn of 1990, 1991 and 1995 was associated with periods of low flow (<10 000 ML/day), turbidity less than 50 NTU, conductivity 400–1100 EC and variable nutrient concentrations (TP, SRP, Oxidised N). Blooms were reported in Lake Albert in the same years and also in 1992. High concentrations of *Anabaena* spp. were present in both lakes in 1990 and 1991. A monospecific bloom of *Anabaena circinalis* in both lakes in spring 1993 decreased significantly in biomass from December to February 1994 during a high flow event (>100 000 ML/day). The bloom was again prominent in March and April 1994 as flows and turbidity declined. In 1991, an extensive bloom of *Nodularia* persisted from February to July, while a bloom of *Anabaena circinalis* was recorded from November 1993 to March 1994. Both blooms were found to be toxic and duly recognised as a threat to public water supplies, agriculture and recreation. Cyanobacterial blooms have not occurred since 1990 at times of high flow and when abiogenetic turbidity was greater than 100 NTU.

The turbidity of River Murray inflows is influenced greatly by their source. It has been established that releases from the Darling River into the Murray River at Wentworth introduce a very high load of suspended fine clays (Woodyer 1978). Median turbidities for the period 1980–85 in the Darling River at Burtundy were 88 NTU, compared with 30 NTU in the River Murray at Euston, upstream of the Murray–Darling confluence (Sullivan et al 1988). At Milang, turbidity ranged from 14 to 390 NTU during the same period, with the highest values directly attributable to the River Darling flood of 1983–84. High turbidities (>150 NTU) and elevated nutrients at Milang in 1990 (Figure 2.11) can also be attributed in part to a proportionately high release of River Darling water to the lower River Murray (SA Water unpublished data). Blooms of *Nodularia* have occurred following seasons of both high flow and high nutrient input (1990–91) and low flow and low nutrient input (1994–95).

The influence of wind on the open shallow lake (average depth 2.9 m) appears to be significant in destabilising thermal stratification in the water column and producing fluctuating turbidity and nutrient levels. Recent studies also indicate that both nitrogen and phosphorus water quality in the lower River Murray may be limiting for phytoplankton growth during periods of low flow (Geary et al 1997). Therefore, it might be hypothesised that cyanobacterial growth in the Lower Lakes in

FIGURE 2.11 WATER QUALITY AT MILANG AND LAKE ALEXANDRINA 1990–97 (SOURCE: SA WATER)



summer/autumn months is dependant upon internal recycling of phosphorus from the sediments. Sedimentation rates and nutrient loadings in the Lower Lakes have not been determined in relation to flow regulation. However, analysis of sediment cores collected in Lake Alexandrina by Barnett (1994) showed that the sediment accumulation rate and phosphorus concentration was higher in core sections corresponding to the last 100 years, compared with those dated over the past 7000 years.

The first reported cyanobacterial bloom *(Nodularia spumigena)* in Lake Alexandrina occurred over one hundred years ago (Francis 1878). It was considered at that time to be caused by a combination of low flow and an extended period of warm, calm weather. The impact of European settlers on water quality and quantity in the Murray–Darling Basin would have been minimal at this time and algal blooms might therefore be regarded as a natural occurrence. There is a general consensus, however, that the incidence of cyanobacterial blooms in the Lower Lakes has increased with time (five out of eight years since 1990) and that this is a symptom of gradual eutrophication of the Lower Lakes from anthropogenic sources (Codd et al 1994).

Cyanobacterial toxicity has been associated with blooms of both *Nodularia spumigena* and *Anabaena circinalis* in the Lower Lakes. Supply from Milang Pump Station was temporarily closed during the 1991 bloom and alternative domestic supplies were provided. Health risk alerts were issued with respect to domestic, recreational and agricultural use. No stock deaths attributable to these blooms were reported. Epidemiological evidence from recreational water exposure studies at Goolwa in 1995 demonstrated increased symptom occurrence associated with increased contact with water containing cyanobacteria (Pilotto et al 1997). The economic cost of cyanobacterial blooms in the Lower Lakes has not been determined, but future estimates should include the cost of monitoring and analysis, provision of emergency water supplies, preparation of contingency and management plans, public awareness campaigns, public health issues, research and impacts on agriculture and tourism. There have been no reported effects on the natural environment as a direct result of cyanobacterial blooms in the Lower Lakes.

The hepatotoxins produced by *Nodularia spumigena* are known to produce chronic liver damage and to promote tumor growth, 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). From a public health perspective, current knowledge would suggest therefore, that blooms of Nodularia might pose a more significant risk than blooms of *Anabaena circinalis.*

Although there is no information available on changes to the phytoplankton composition in the lakes since barrage construction, the occurrence of at least some freshwater species is assumed to be a direct consequence of the altered water regime freshening of the lakes. A lack of base-line data has also prevented “an assessment of changes in biodiversity of phytoplankton communities or impact on the food chain that has resulted from the altered water regime. Geddes (1984b) however, found no apparent relationship between phytoplankton biomass and the density or composition of filter-feeding zooplankton in Lake Alexandrina, and suggested that detritus and bacteria may be the major food source of the zooplankton, rather than the phytoplankton.

There is evidence to suggest that growth of at least one cyanobacterial species, *Nodularia spumigena,* is predisposed to a wide salinity tolerance, ranging from that of the brackish natural estuary which existed at the time of the 1878 bloom, to that in the now existing freshwater lakes (0.16–1.7 ppt). This species has been described mostly from brackish and saline waters, with development of blooms reported at salinities varying from 7–10 ppt in the Baltic Sea (Kononen 1992), 15–20 ppt in Orielton Lagoon, Tasmania (Jones et al 1994) and 3–30 ppt in the Peel-Harvey Estuary, WA. (Hodgkin et al 1985). Hobson (1996) found that the optimum salinity for growth in a laboratory culture isolated from Lake Alexandrina was 10–13 ppt. Laboratory studies have demonstrated that the optimum salinity for germination of *Nodularia* akinetes produced by a strain from the Peel–Harvey estuary was between 0-10 ppt (Huber 1985) and that akinete production of *Nodularia* isolated from Orielton Lagoon was positively correlated with increasing salinity up to 35 ppt (Jones et al 1994). *Anabaena circinalis* is a common bloom-forming species in the River Murray and other freshwater habitats, and may be a more recent (post-regulation) phenomenon in the Lower Lakes.

It is unknown whether changes have occurred at the autotrophic level in the Coorong estuary and Coorong lagoons since the construction of the barrages. There are no reports of initiation and growth of cyanobacterial blooms in the Coorong, although trailing scums from lake blooms discharged through the barrages were observed by local fishermen in 1991 as far downstream as Dodds Landing in the Northern Lagoon. The occurrence of dinoflagellate blooms ('red tides') has also been observed in the Coorong estuary and may be associated with the mixing of saline water with freshwater inflows from the lakes. Certain species are known to produce toxins, but no information is available on the frequency of these blooms and their environmental effects in the Coorong.

The ecological significance of cyanobacterial blooms is largely unknown. The toxins produced by some cyanobacteria, including *Nodularia spumigena* are potent inhibitors of protein phosphatases and may affect a range of higher plants and animals. Toxic effects have been observed on other phytoplankton and aquatic macrophytes (Kirpenko 1986), which could have significant consequences on primary production (Lindholm et al 1992). Thick scums often accumulate along littoral zones and may shade aquatic plants and benthic algae and also restrict access by fish and birds to reproduction and feeding areas.

It is likely that aquatic invertebrates and fish have developed defence mechanisms or avoidance strategies to co-exist with cyanobacteria and their toxins. There are conflicting data on toxicity to invertebrates, but inhibitory effects have been reported on some species (Carmichael 1992). The specific contribution of toxins to fish kills in natural waters is unclear, as is the mode of toxin action; whether via food or the gills. In many instances, oxygen depletion in the water due to decay of algal blooms may have been the cause of fish kills. Mortality of small fish, crabs and benthic invertebrates in the Peel–Harvey Estuary was considered to be caused by deoxygenation below the water surface during *Nodularia* blooms (Hodgkin et al 1985). Larger fish may be able to avoid severely affected areas of blooms, but it has been suggested that the *Nodularia* blooms in the Peel–Harvey Estuary have had a major inhibitory effect on feeding, respiratory movements, oral brooding and egg development of fish (Potter et al 1983).

There is clear evidence of bio-accumulation of cyanobacterial toxins in shellfish, but it is not known whether fish can accumulate toxins. Falconer et al (1992) demonstrated significant accumulation of *Nodularia* toxin (nodularin) in the intestinal tract of mussels *(Mytilus edulis)* collected from the Peel–Harvey Estuary during a bloom and Negri and Jones (1995) found that the freshwater mussel *Alathyria condola* accumulated high levels of PSP toxins when fed the neurotoxic cyanobacterium *Anabaena circinalis* under laboratory conditions. Poisoning of birds and animals is occasionally associated with blooms, but these incidences might be considered inadvertent and not necessarily an ecological consequence (Yoo et al 1995).

KEY ISSUES

The increased frequency of algal blooms is clearly an important water quality issue in the Lower Lakes, particularly with regard to risks to human health and impacts on recreation and agriculture. Direct effects on ecosystem biodiversity and function have not been demonstrated, although there is evidence from studies elsewhere that the quality of aquatic habitat may be temporarily reduced and some loss of native fauna may be incurred. The management of algal blooms for the purpose of maintaining the ecosystem of the Lower lakes and Coorong may therefore be considered a low priority relative to other environmental issues.

Management of algal blooms has been addressed under a separate agenda and has resulted in the development of an Algal Management Strategy for the Murray–Darling Basin (Murray–Darling BasinCommission Ministerial Council 1993).

Of the five identified regions for assessment (prograding lakeshores, eroding lakeshores, Coorong estuary, Coorong Northern Lagoon, Coorong Southern Lagoon) (Figure 1.3), both freshwater lake-shore regions were identified as the primary areas of concern. The causes of increased algal bloom frequency that might be linked to flow regulation include:

- increased nutrient loadings to the lakes by sedimentation processes, arising from reduced flow-through rates in winter/spring
- reduced turbidity in the lakes attributable to reduced inflow rates in summer/autumn
- increased nutrient loadings to the lakes from shoreline erosion caused by higher lake operating levels
- increased residence time of water in the lakes arising from reduced flow-through rates in summer/autumn. Significant cell growth and accumulation may occur, which may then be redistributed by wind action to leeward shorelines
- change to freshwater habitat favouring freshwater algal species. This includes the bloom-forming (and toxic) cyanobacterial species *Anabaena circinalis, Microcystis aeruginosa* and *Cylindrospermopsis raciborskii.*

ECOLOGICAL NEEDS

The causes of cyanobacterial blooms in the Lower Lakes have not been clearly elucidated, but it appears that a combination of low inflow from the River Murray and persistent periods of calm weather are significant factors in the short term and sedimentation of phosphorus on the lake-bed in the long term.

In order to decrease the frequency of cyanobacterial blooms in the Lower Lakes, the following management objectives should be adopted:

- a reduction in nutrient loading to the lakes from sedimentation processes
- a reduction in nutrient loading into the lakes from shoreline erosion
- the provision of adequate flows (in summer/autumn) to reduce residence time, and maximise throughflows.

OPPORTUNITIES FOR IMPROVEMENT

A decrease in the frequency of algal blooms in the Lower Lakes may be achieved by addressing the relevant ecological needs through implementation of certain operating strategies at the barrages.

- Reduce residence time, maximise throughflows and minimise biomass accumulation by providing flushing flows for short critical periods (probably in summer/autumn). Higher flows through the lake may also increase mixing of the water column with subsequent reduction in cyanobacterial growth rates. Proposed changes to flow regulation should reflect the transient nature of algal blooms and be able to provide rapid responses to fluctuating conditions. In the short term (1–3 years), alterations might be implemented at the barrages to allow flexibility in the operation (timing, frequency or duration) of gate opening and to allow adjustment of water levels outside the current operating range of 0.60–0.85 m EL.

The success of this strategy may be compromised by localised concentrations of cyanobacterial scum around lake shorelines. The accumulation of cyanobacterial cells is also likely to exceed the maximum possible flushing rate (50 000 ML/day) and period of flushing under existing operating rules, assuming a growth rate of say 0.2 doublings/day.

- Reduce nutrient loadings to the lakes by transporting sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina. Enlargement of Mundoo Barrage in the medium term (3–10 years) may allow this process to be carried out with minimum impact on the Coorong, by creating a direct flow path to the sea.
- Control shoreline erosion and subsequent nutrient input to the lakes by operating the lake at lower levels. The establishment and protection of riparian vegetation around lake shorelines should also be promoted as an additional measure for prevention of erosion and also to create buffer zones to act as nutrient sinks.

The long-term option of re-creating an estuarine environment in Lake Alexandrina and Lake Albert with the construction of a barrage at Wellington on the River Murray offers advantages and disadvantages with respect to minimising cyanobacterial blooms. The incidence of blooms of the toxic freshwater species *Anabaena circinalis* may be reduced, but blooms of *Nodularia spumigena* could quite likely increase as a result of moderate to large increases in salinity (say 1–20 ppt). Germination rates of akinetes of *Nodularia spumigena* may not be greatly affected by moderate increases in salinity (up to 10 ppt), but this requires further investigation.

Toxic blooms of *Nodularia spumigena* are considered to pose a higher public health risk than those of *Anabaena circinalis* in drinking water, but both species are likely to produce allergenic effects on contact from washing and recreation. In the event that alternative domestic water supplies are provided to the community surrounding Lake Alexandrina, it might be argued that the restoration of the lakes to their original estuarine state would not introduce an additional public health risk. The creation of a barrage in Lake Alexandrina at Point Sturt in lieu of their current location, may eliminate blooms of *Anabaena* in the Goolwa/Hindmarsh Island region where much recreational activity is based. The use of the Milang Pumping Station for domestic supplies would then still be an option.

The potential for development of *Nodularia* blooms in the Coorong should also be considered as a possible outcome of freshening by environmental flows from the barrages. A contributing factor may also be the observed transport and deposition of river sediments and adsorbed nutrients across the barrages into the Coorong estuary and Northern Coorong Lagoon (Tucker 1996).

It is probable that cyanobacterial blooms will continue to be a common occurrence in the Lower Lakes due to internal recycling of the large phosphorus store in the sediments. Some degree of control may be possible in the long term by managing water regimes to decrease residence time of water in the lakes, so that the rate of sedimentation and phosphorus loading in the lakes is also decreased. Flushing flows could be allocated to transport a larger proportion of the phosphorus load from the river straight to the ocean. When algal blooms do occur, their social and economic impact may be reduced in the short term by providing flushing flows at critical periods to reduce residence time and to minimise accumulation of cell biomass.

A reduction in nutrient load to the lakes and a decrease in algal bloom frequency in the long term may also be possible by controlling the rate of shoreline erosion. Options to achieve this objective may involve temporary operation of the lakes at a lower level to allow construction of protective structures along shorelines, supplemented by encouragement for the growth of riparian vegetation.

PART 3:

OPPORTUNITIES FOR IMPROVED ENVIRONMENTAL CONDITIONS

PLATE 5 EXPERT PANEL AT LAKE ALBERT (PHOTOGRAPH: ANNE JENSEN)

ECOLOGICAL NEEDS AND OPPORTUNITIES FOR IMPROVED HYDROLOGICAL MANAGEMENT

Several significant ecological needs and opportunities for management actions to improve environmental conditions have been identified by the scientific panel. These have been linked to each of the five broad environmental regions (Figure 1.3). These opportunities have been identified by the scientific panel after considering the current management of the barrages and reviewing scientific, engineering and social information relevant to modified management of the barrages.

Fifteen key ecological needs have been identified. These are presented in Table 3.1 with the critical actions required to address these needs.

Fifteen opportunities to improve environmental conditions by changing hydrological management were identified (Table 3.2). These primarily relate to the management of the barrages, but other changes to upstream flow management were also identified.

Complementary opportunities to change local land or water management practices were also identified and these are discussed in the section 'Complementary management opportunities'. Opportunities have been identified as major or minor over three time scales: short-, medium- and long-term.

Three time scales have been used:

- short-term (1–3 years)
- medium-term (3–10 years)
- long-term (> 10 years).

These have been used to take account of investment planning, infrastructure design and planning, and social and economic adjustment if required.

Opportunities have been split between major and minor categories on the basis of the:

- cost of capital works and/or the cost of changed management
- off-site social and economic costs.

The time scales give no consistent indication of the timing of positive environmental benefits flowing from the management actions. In some cases positive impacts will be very rapid and in others there may be a significant lag between action and environmental response. The latter applies particularly to those responses highly dependent on the occurrence of higher river flows.

Table 3.2 summarises the opportunities to improve environmental condition by changed hydro-logical management.

Options for rehabilitation measures to address the key issues are outlined as follows.

Universal outcomes

A number of universal outcomes are assumed for all options. These are listed below and are not repeated for all variations of options. They include opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong, as the important food source *Ruppia tuberosa* is dependent upon salinity
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem
- maximise estuarine area
- reduce abrupt changes to water levels in the Coorong
- maximise the transfer of freshwater from the lakes to the Coorong
- promote freshwater flushing through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- to reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- ensure sediments and nutrients are not transported into the Coorong Lagoon
- to limit the potential for algal blooms, control the water regime, particularly temperature stratification, mixing and turbidity, to decrease the accumulation of cell biomass.

Short-term opportunities

Minor short-term options, to be undertaken within three years, include:

- changing the timing, sequence and frequency of opening and closing gates in the existing structures and operating within the current range of lake levels
- development of specific arrangements for maximising the ecological benefit of the non-consumptive proportion of entitlement flows to South Australia

- modification of the proposed levees across the island spillways to allow interface of fresh and salt water.

Major short-term options, which will involve greater expense or potential impacts, include:

- automation of approximately 22% of barrage gates across all five structures and finetuning of gate operation within current lake levels
- investigation of the options for operating over a wider range of lake levels
- negotiating different monthly or daily flows in the pattern of delivery of entitlement flows to produce flow patterns at the barrages to meet ecological needs.

The environmental outcomes which could be achieved by these management measures are outlined below.

Recommended action

A1 Change the timing, sequence and frequency of opening and closing of barrage gates within current operating range of lake levels (0.60-0.85 m EL) to optimise the ecological, social and economic benefits

Current operation

The current operating rules are primarily determined by the aim of maintaining an average lake level of 0.75 m EL. Additional factors are:

- ease of operation of various barrages
- limited staff resources
- distance from staff bases to barrages
- economic limits on staff over-time at weekends
- hydraulic capacity of channels
- risk of marine intrusions
- capacity of barrage structures for rapid adjustment
- short-term effects of wind on lake levels
- extreme weather events.

The combined effects of these factors is a tendency to operate barrages in the following order of preference and frequency of opening:

- Goolwa
- Tauwitchere
- Ewe Island.

Boundary Creek and Mundoo barrages are rarely opened, due to the required removal of the road platform, thus disrupting through traffic across the barrages from Pelican Point to Goolwa ferry. These barrages are only opened when favourable tides, weather conditions and extended (high) summer flows are available in the system. Typically, this would be when River Murray flows exceed 80 000 ML/d at the South Australian border. Boundary Creek Barrage is operated at least once per year and this has been the case for the last ten years. The operation of Mundoo Barrage does not prevent through traffic to Pelican Point once the water ways have been opened. The deck units are reinstated and the stop logs stored along one edge of the decking. This does restrict access for large vehicles whilst water ways are open.

While the general guidelines for operating the barrages are documented, the observations and trigger factors involved in daily operation of the barrages to maintain the 0.75 m EL are known to personnel within SA Water but are apparently not recorded in published form. It is recommended that these daily guidelines be articulated, both to ensure that this knowledge is not lost with change of personnel. It is also required to provide a factual basis for negotiation of altered operational rules to meet environmental needs.

Opportunity

The suggested alterations to current operating conditions include the following (some of which are already being practised informally):

- attractant flows for fish passage
- brief openings of limited gates at key points of tidal cycle for fish passage
- minor flows (few gates at key sites) maintained through long periods of barrage closure
- altered opening and closing sequences to maximise fresh water exchange into the Coorong
- preferential opening of Mundoo Barrage during high flows to increase scour velocities through the Murray Mouth zone
- operation of closures to reduce rapid falls in water level in the Coorong.

Issues arising

Operation of the barrages affects water levels, irrigation operations and native fisheries upstream to Mannum and even as far as Blanchetown.

TABLE 3.1 ENVIRONMENTAL NEEDS AND CRITICAL OUTCOMES TO MEET NEEDS

Environmental needs	Critical outcomes required to meet needs
Protect aquatic plants in Coorong and maximise mudflat habitat	Prevent abrupt Coorong level changes
Maximise estuarine area	Maximise water mixing into Coorong Provide flows during low flow periods Increase river outflows
Limit deposition at mouth	Increase volume and velocity of flows at mouth
Increase fish passage through the river mouth	Maintain mouth passage
Provide fish passage through barrages	Provide attractant and passage flows through the barrages
Protect and enhance saltmarsh habitat around lakes	Reduce fresh water overwash from lakes Allow interface of fresh and salt water across islands
Increase diversity of riparian vegetation	Protect, maintain and encourage regeneration or revegetation to re-establish diverse riparian communities
Reduce sediment transport into Coorong	Reduce inputs, divert to sea
Reduce nutrient in lakes	Reduce inputs by increasing riparian vegetation to filter in-flows * and fencing/stock management to increase buffer zone * Increase through-put by maintaining critical flows over period of high risk of blooms
Maintain a diverse water quality regime in the estuary and Coorong	Manage to maintain a range of salinities, from fresh to hyper-saline
Reduce exotic fish in lakes	Provide water regimes and manage fish effort to favour native fish Capture fish when trapped in estuary, manage fishing effort to target exotics*
Increase aquatic vegetation	Reduce impact of exotic fish in lakes Provide water regime to ensure minimum light and level requirements for aquatic plants
Reduce area of dryland salinity	Provide water regime to minimise impact on groundwater
Reduce lakeshore erosion	Reduce or buffer erosive power of waves, stabilise and protect shorelines to allow establishment of riparian vegetation*
Reduce lake water turbidity	Reduce sediment inputs, increase wind buffers, reduce fetch at key locations

* Management actions other than modification to hydrological regimes (Addressed in section Complementary Management Opportunities)

TABLE 3.2 HYDROLOGICAL MANAGEMENT OPPORTUNITIES

Time scale	Scope of works	Code link to Table 3.5	Hydrological management opportunities
Short-term (1–3 years)	Minor	A1	Change the timing, sequence and frequency of opening and closing of barrage gates within current operating range of lake levels (0.60–0.85 m EL)
		A2	Develop specific arrangements for maximising the ecological benefit of the non-consumptive proportion of entitlement flows to South Australia
		A3	Assess proposal to build levees on island spillways to minimise impacts on the interface between fresh and salt water
	Major	B1	Automate approximately 22% of gates across all five barrages and finetune timing sequence and frequency of opening and closing of automated barrage gates according to environmental guidelines within the current range of lake levels
		B2	Investigate operating automated gates at a greater range of lake levels (ie higher or lower than current 0.60–0.85 m EL)
		B3	Negotiate different monthly and/or daily flows in the pattern of delivery of entitlement flows to provide seasonal flows at barrages
Medium–term (3–10 years)	Minor	C1	First revision of operating rules for automated gates and flow allocations on basis of adaptive management monitoring results
	Major	D1	Modify Mundoo Barrage to increase scour capacity and to operate preferentially to limit sedimentation in the Murray Mouth zone
		D2	Trial operation of lakes at a wider range of levels (ie outside 0.6–0.85 m EL)
		D3	Automate more barrage gates as determined by adaptive management monitoring results and operate at a wider range of lake levels according to environmental guidelines
		D4	Increase environmental flows to meet ecological needs in the Lower Lakes and Coorong through ongoing basin-wide water allocation reviews
Long–term (> 10 years)	Minor	E1	Second revision of operating rules for automated gates and revise flow allocations on basis of adaptive management monitoring results
	Major	F1	Relocate the barrages upstream to Wellington and invest evaporative savings into environmental flows for the lakes and Coorong, to maintain a larger estuarine area
		F2	Increase the estuary area by converting Lake Albert into an estuarine zone, eg by constructing a barrage at Narrung Narrows and a channel from Marnoo swamp into the Coorong
		F3	Relocate the barrages upstream to Point Sturt and invest evaporative savings into environmental flows for the lakes and Coorong, to maintain a larger estuarine area

Expected outcomes

The following outcomes are expected from changing current barrage gate operations:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- maximise the transfer of freshwater from the lakes to the Coorong
- promote freshwater flushing through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- maintain open passage particularly in period of likely high fish migration in and out of the Murray Mouth (October to December)
- provide flows for fish passage and attractant flows at the barrages, particularly in winter
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- ensure sediments and nutrients are not transported into the Coorong Lagoon
- limit the potential for algal blooms, control the water regime, particularly temperature stratification, mixing and turbidity, to decrease the accumulation of cell biomass.

Recommended action

A2 Develop specific arrangements for maximising the ecological benefit of the non-consumptive proportion of entitlement flows to South Australia

Current operation

Under the Murray–Darling Basin Agreement South Australia receives an 'entitlement flow' of 1850 GL per annum, as twelve monthly minimum monthly flows. While this is guaranteed there is provision for reduction in drought years. In reality the median flow to SA is approximately 4047 GL per annum and we receive the entitlement flow or less only about 30 % of the time. This means that about 70 % of the time we receive greater flows than 1850 GL per annum.

Opportunity

The new Water Resources Act (1997), requires water allocation plans to be developed for all prescribed water resources. These plans must assess the water needs of ecosystems and provide water for these needs above what is required for consumptive use. The responsibility will rest with the River Murray Catchment Water Management Board appointed late September 1997.

South Australia's position under the recently agreed Murray–Darling Basin 'cap' on further water diversions from the river has implications for this opportunity. The position is that 573 GL per annum is allocated for irrigation use and 180 GL per annum for SA Water, and that all water above this is effectively water for ecological purposes. This should be formalised as part of the water allocation plan for the River Murray prescribed watercourse.

The Lower Murray Flow Management Working Group (1997) has reported on opportunities to manipulate weir structures from Lock 10 to the barrages during entitlement flows to improve riverine littoral habitat and wetlands connected at pool level. This current scientific panel process for the barrages will provide detail on opportunities to improve or maintain the environmental values of the Lower Lakes and Coorong. Both of these sets of needs and opportunities should be recognised in the water allocation plan in the form of operational rules to maximise environmental benefit from the water allocated to the environment. For example, a few gates could remain open for fish passage during periods of barrage closure. Assuming a flow of 250 ML/d per gate, a flow of say 75 GL would allow 10 gates to remain open for a month for fish passage. Further investigation will be required to determine the volume, timing and frequency of flows required.

Other potential benefits of an allocation for environmental purposes include maintenance of mudflats for waterbirds, buffering of abrupt water level changes in the Coorong, and extension of estuarine habitat. Flows could be allocated to limit sedimentation in the mouth zone and to promote fish passage through the mouth channel. However, the effectiveness of these options will be limited by the relatively small volumes available and the limited flexibility of opening and closing of gates.

Expected outcomes

The expected outcomes from the development of special arrangements to maximise environmental benefits include opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- maximise the transfer of freshwater from the lakes to the Coorong
- allocate environmental flows to the Coorong at periods of seasonal low flow
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages
- promote freshwater flushing through the Murray Mouth and promote fish passage between Lake Alexandrina and the estuary
- improve habitat quality through flushing of the lakes
- to reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- ensure sediments and nutrients are not transported into the Coorong Lagoon
- to limit the potential for algal blooms, control the water regime, particularly temperature stratification, mixing and turbidity, to decrease the accumulation of cell biomass
- reduce the internal store of phosphorus in the lakes
- reduce the risk of cyanobacterial blooms
- provide flushing flows for short critical periods to decrease the risk of blooms (probably in summer/autumn).

Recommended action

A3 Assess proposal to build levees on island spillways to minimise impacts on the interface between fresh and salt water

Current operation

Two extended low-lying areas on Ewe Island and Tauwitchere Island act as spillways when water levels exceed 0.85–0.9 m EL. The natural habitat of the island is salt marsh, which requires inundation by a mixture of fresh and salt water, and acts as a buffer between the two water bodies, slowing the water exchange across tussocky marsh with ill-defined channels.

This buffering effect has been weakened by recent drainage works on the freshwater side, designed to enhance access to fresh water for irrigation of pastures and to flush out salt from saline soils. When marine incursions occur due to high tides, winds or storms, the salt water now has much more efficient flow paths into the fresh water body, causing water quality problems for irrigators. Once a salt slug is trapped in the Goolwa Channel, this can be drawn into the Currency Creek reach when the Goolwa Barrage is opened, causing problems for irrigators.

The proposal to build levees to prevent marine incursions is designed to protect water quality for lake diverters. However, the proposed levees will prevent this important interface of fresh and salt water, to the detriment of the salt marsh habitat and associated fauna. The levees will also prevent fish passage through this region, which is an extremely important by-pass for the barrier presented by the barrages.

It is recommended that the proposal for the levees be assessed to ensure minimum impacts on fish passage and maintenance of the salt marsh habitat. Opportunities should also be investigated to divert saline drainage water from the Angas–Bremer basin to sustain saltmarsh communities on the western shores of Lake Alexandrina. The impacts of the drains on the water balance and marsh habitat should also be examined.

Expected outcomes

Assessment of this proposal should lead to outcomes which:

- ensure that management maintains a salinity gradient over an ecologically sound distance, which is in tune with the seasonal fluctuations in salinities afforded by river discharges
- allow fish passage across salt marsh and freshwater wetland habitats
- minimise impacts of drainage and levee construction on saltmarsh habitats.

Recommended action

B1 Automate approximately 22% of gates across all five barrages and finetune timing, sequence and frequency of opening and closing of automated barrage gates according to environmental guidelines within the current range of lake levels

Opportunity

The number of gates proposed to be automated in each barrage is summarised in Table 3.3 and Appendix VII. These gates should then be operated according to the recommended environmental guidelines (part 2; Ganf; Paton; Geddes ibid) within the current range of lake levels.

Automation of the gates will greatly improve the flexibility of barrage operations, allowing short-term, rapid response operation at all five structures with minimal staff resources. The benefits outlined for option A1 can be achieved more rapidly over the full length of the barrages. (Note that a power supply will be required at the Boundary Creek and Ewe Island sites). Much greater flexibility and shorter response times would greatly improve benefits from minor opening and closing sequences. For example, if the gates were only opened for 20 minutes at the top of the tide to allow fish passage, 720 gates could be opened for fish passage for 30 days using an allocation, as there would be very little water passed through the gates.

Issues arising

In order to ensure the fish are not targeted by recreational and commercial fishers at the point of passage, some form of regulation of fishing may be required. Commercial and recreational harvest is currently excluded from a zone on either side of all barrages. The Inland Fisheries Management Committee has accepted that with gate automation this matter will be immediately revisited, both to ensure fish passage benefits meet sustainability and equitability criteria, and to ensure that production benefits demonstrably exceed harvest.

Expected outcomes

The expected outcomes from automation of barrage gates and finetuning of gate operation are to:

- improve the 'fine' control of barrage releases to deliver the short-term ecological management objectives
- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- maximise the transfer of freshwater from the lakes to the Coorong
- promote freshwater flushing through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- remove sand accumulating in the Coorong estuary channels between the mouth and Tauwitchere
- meet the requirements for fish passage as they relate to lunar cycles, tidal cycles and attractant flows
- maintain open passage particularly in period of likely high fish migration in and out of the Murray Mouth (October to December)
- provide flows for fish passage and attractant flows at the barrages

TABLE 3.3 PROPOSED AUTOMATION OF BARRAGE GATES

Barrage	Gates to be automated (total gates)	Modification required
Goolwa	20 (128)	replace logs with radial gates, automate
Mundoo	15 (26)	replace logs with radial gates, automate
Boundary Creek	5 (6)	replace logs with radial gates, automate
Ewe Island	30 (111)	automate radial gates
Tauwitchere	60 (322)	automate radial gates
Total	130 (593)	21.9% of gates automated

- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- ensure sediments and nutrients are not transported into the Coorong Lagoon
- limit the potential for algal blooms, control the water regime, particularly temperature stratification, mixing and turbidity, to decrease the accumulation of cell biomass
- reduce the internal store of phosphorus in the lakes
- reduce the risk of cyanobacterial blooms.

Recommended action

B2 Investigate operating automated gates over a greater range of lake levels (ie higher or lower than current 0.60-0.85 m EL)

Opportunity

This option has the potential to generate a greater range of habitat conditions in the region, and has a high priority for investigation of its feasibility. Using the fine-control capability of the automated gates and the wider operational range of lake levels, the management objectives could include:

- attractant flows for fish passage
- brief openings of limited gates at key points of tidal cycle for fish passage
- minor flows (few gates at key sites) maintained through long periods of barrage closure
- altered opening and closing sequences to maximise fresh water exchange into the Coorong
- preferential opening of Mundoo Barrage during high flows to increase scour velocities through the Murray Mouth zone
- operation of closures to reduce rapid falls in water level in the Coorong
- maximisation of the estuarine habitat
- maintenance of fish passage through the Murray Mouth
- increased diversity of riparian vegetation
- flushing of lakes to reduce turbidity and nutrient loadings, while reducing sediment transport into the Coorong
- provision of a water regime to favour native fish and reduce exotic fish species
- enhancement of aquatic vegetation communities
- protection and enhancement of salt marsh habitat.

Issues arising

The maximum level of 0.85 m cannot be exceeded unless the existing spillway sill levels (0.85–0.9 m) are raised. The minimum level of 0.6 m relates to the requirements of gravity irrigators near Mannum, who would be unable to operate if levels fall below this (for significant periods). During extended dry conditions the level sometimes falls below this by usage and evaporation. These impacts would have to be assessed as part of the evaluation.

Expected outcomes

If this option proves to be feasible, it could provide opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- maximise the transfer of freshwater from the lakes to the Coorong
- promote freshwater flushing through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- remove sand accumulating in the Coorong estuary channels between the mouth and Tauwitchere
- meet the requirements for fish passage as they relate to lunar cycles, tidal cycles and attractant flows
- maintain open passage particularly in period of likely high fish migration in and out of the Murray Mouth (October to December)
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- ensure sediments and nutrients are not transported into the Coorong Lagoon
- limit the potential for algal blooms, control the water regime, particularly temperature stratification, mixing and turbidity, to decrease the accumulation of cell biomass

- reduce the internal store of phosphorus in the lakes
- reduce the risk of cyanobacterial blooms
- control shoreline erosion and subsequent nutrient input to the lakes
- reduce turbidity to produce minimum illuminance conditions for plant growth
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem
- reduce desiccation and physical damage of aquatic plants and damage to riparian vegetation, by minimising wave and wind action
- promote reductions in turbidity in the lakes to increase the productivity of various submerged aquatic plants which indirectly is likely to increase the numbers of invertebrates, fish and birds in the lakes
- reduce risks of the suspended material being deposited or remaining in suspension in the Coorong, in the northern channels or other parts of the estuary
- reduce the water levels in the lakes to help protect the habitat of the constructed and natural saline wetlands around the lake shores, used by waders, from influxes of freshwater when water levels are surcharged to counteract summer evaporation
- drop lake levels, particularly during the summer/autumn period, to expose some of the lake floor, providing additional mudflats shallow water suitable for wading birds around the perimeter of the lake
- reduce water levels to reduce erosion pressure on exposed shores and to assist remedial action on those shores that are currently eroding.

Recommended action

B3 Investigate the benefits of different monthly and/or daily flows in the pattern of delivery of entitlement flows to provide seasonal flows at barrages and negotiate changes if appropriate

Current operation

The entitlement allocation 1850 GL per annum is currently delivered in a pattern of flows which reflects the needs of water users (Table 3.4). This pattern, which is described in a schedule attached to the River Murray Waters Agreement, can be re-negotiated within the total volume and the system delivery capacity. Part IX Division 2 of the Agreement permits the Commissioners for South Australia to request a variation in the distribution of water to South Australia, provided that the total amount of water received is not increased.

Opportunity

Small changes in the delivery pattern could provide significant benefits to the Lower Lakes and Coorong ecosystems, as well as to the upstream river habitat. For example, 1000 ML/d transferred from winter to summer would allow four gates to be opened for the day, or at least 72 automated gates to be opened for 20 minutes at the top of the tide during periods when the barrages are often closed for several months. This amount could be provided by minor deductions from flows across several months. Further negotiations would be required to determine the minimum and optimum environmental requirements, and the capacity for re-negotiation of delivery patterns.

TABLE 3.4 PATTERN OF DELIVERY OF SOUTH AUSTRALIA'S FLOW ENTITLEMENT
(SOURCE: OHLMEYER 1991)

Month	Total Volume (ML)	Daily Flows (ML/day)
January	217 000	7000
February (leap year)	194 000 (194 000)	6930 (6690)
March	186 000	6000
April	135 000	4500
May	93 000	3000
June	90 000	3000
July	108 500	3500
August	124 000	4000
September	135 000	4500
October	170 500	5500
November	180 000	6000
December	217 000	7000
Total	**1 850 000**	

Expected outcomes

The expected outcomes from changed seasonality in the pattern of flows at the barrages include opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- maximise estuarine area
- promote freshwater flushing and fish movement through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- allocate more water for environmental use downstream of the barrages
- extend the period of flow over the barrages until later in the year
- allow water levels to be dropped more gradually downstream of the barrages during late summer or autumn
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- promote the flushing of sediments through the Murray Mouth when turbidity levels are high
- ensure the sediments and nutrients are not transported into the Coorong Lagoon
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem.

Medium-term opportunities

Minor medium-term options, to be undertaken within ten years, include action to:

- revise operating rules and water allocations on the basis of adaptive management monitoring results.

Major medium-term options, which will involve greater expense or potential impacts, include action to:

- modify Mundoo Barrage to increase scour capacity and operate preferentially to limit sedimentation in the Murray Mouth zone
- trial operation of the lakes over a wider range of levels
- automate more barrage gates as determined by adaptive management monitoring results and operate according to environmental guidelines over a wider range of lake levels
- increase environmental flows for the barrages through ongoing basin-wide water allocation reviews.

The environmental outcomes which could be achieved by these management measures are outlined below.

Recommended action

C1 First revision of operating rules for automated gates and flow allocations on basis of adaptive management monitoring results

Opportunity

In the medium term, it will be necessary to revise the operating rules and flow allocations in relation to adaptive management monitoring results, and to adapt operational guidelines as appropriate to maximise environmental benefits and minimise any social costs.

Expected outcomes

The expected outcomes from finetuning of operational guidelines include opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- extend the period of flow over the barrages until later in the year
- allow water levels to be dropped more gradually downstream of the barrages during late summer or autumn
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages
- promote freshwater flushing through the Murray Mouth, maintaining access for fish
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages

- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- promote the flushing of sediments through the Murray Mouth when turbidity levels are high
- ensure the sediments and nutrients are not transported into the Coorong Lagoon
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem.

Recommended action

D1 Investigate structural and operational modifications to Mundoo Barrage to increase scour capacity and operate preferentially to limit sedimentation in the Murray Mouth zone and implement if appropriate

Current operation

The Mundoo Barrage currently consists of a long solid causeway with a short section of 26 gates towards the eastern side of the channel. The gated length is approximately 20% of the natural channel width. Thus, even when the gates are fully opened, there is still an 80% reduction of flow capacity in the channel. Extensive siltation has occurred downstream and upstream of the structure since its construction.

Prior to construction of the barrages, the Mundoo Channel carried up to 20% of flows to the Murray Mouth (Bourman ibid). The creation of Bird Island between the mouth of the Mundoo Channel and the Murray Mouth dates from after construction of the barrages and is suggested to be linked to the overall reduction of flows to the mouth, and particularly to the reduction of flows through the Mundoo Channel (Bourman ibid). Without active intervention, it is predicted that Bird Island will coalesce with Hindmarsh Island in the foreseeable future (Bourman ibid).

Opportunity

Widening of the Mundoo Barrage is expected to increase the flow capacity of the channel and provide the capacity to scour the mouth zone more effectively. With a wider opening and automated gates, medium to high flows could be selectively directed to limit the rate of sedimentation on Bird Island.

Other benefits of this option include the ability to use the shortest, steepest channel to flush the lakes, to reduce turbidity and nutrient levels, reduced sediment transport to the Coorong, and maintenance of the mouth channel for fish passage.

Issues arising

It should be noted that this channel is the most susceptible to marine incursions from storms, requiring a rapid response facility to shut the gates prior to high salt water levels.

There are two irrigators drawing water from upstream of the Mundoo Barrage and their needs should be taken into account in determining operating guidelines.

The widening of the Mundoo structure may not significantly increase the flow capacity of this channel, as channel capacity is limited downstream of the barrage by silting and it is suspected that it may also be limited upstream of the barrage. An hydraulic investigation and evaluation of the channel is required as part of a feasibility study of this option.

Expected outcomes

Increased scour capacity in the Mundoo Channel should provide opportunities to:

- reduce the sedimentation taking place adjacent to the mouth
- scour out this region with a view of increasing the tidal prism and increasing the potential wader habitats in the regions
- increase the frequency and volume of water released through Mundoo Channel
- reduce risks of the suspended material being deposited or remaining in suspension in the Coorong, in the northern channels or other parts of the estuary
- promote fish movement through the Murray Mouth
- promote freshwater flushing through the Murray Mouth, maintaining access for fish.

Recommended action

D2 Trial operation of the lakes at a wider range of levels (ie outside 0.60-0.85 m EL)

Opportunity

The feasibility of operating the lakes at higher or lower levels (B2) should be trialled.

The option of operating the lakes at a greater range of levels offers a long list of environmental benefits. It should be emphasised that many of the variations sought are short-term seasonal variations, allowing room for negotiation to accommodate users' needs.

Naturally fluctuating water levels over a wider range, eg with spring-early summer peak levels and lower winter levels, would favour native plants and animals over introduced species. Lower levels in winter-early spring could reduce the amount of freshwater splash onto saltmarsh zones.

Lower levels and/or simulated tidal fluctuations in late summer/early autumn could increase mudflat habitat for migratory waders during their moulting and fattening phase prior to migration to the northern hemisphere.

Lake levels could be lowered at key times to provide a flow over the barrages to allow fish passage, or to flush through the Murray Mouth, or to provide freshwater into the Coorong.

Operation of lake levels should take into account depth and light requirements for survival and growth of native aquatic plants. These needs include observation of depth limits for light penetration, access to air and prevention of desiccation.

For prevention of lakeshore erosion, short-term lowering of lake levels may be necessary for access to the shore to build protective structures.

Issues arising

The trials must include provisions to minimise the impacts on users. The physical constraints of the barrage structures must be taken into account.

Fluctuating levels of the order indicated during a normal irrigation season (October to April) would cause significant operational problems for irrigators, especially those who irrigate by gravity in the reclaimed swamps between Wellington and Mannum. Typically, the spring fresh of above entitlement flows would have receded by November/December and maximum use would be required of the storage capacity of the lower reach, including the lakes.

Navigational requirements must be taken into account.

Expected outcomes

Operation of the lakes at a wider range of levels should provide flexibility to:

- promote the flushing of sediments through the Murray Mouth when turbidity levels are high
- minimise the chances of mouth closure by clearing sediment from the channels upstream and downstream of the barrages
- reduce turbidity to produce minimum illuminance conditions by directing turbid water over the barrages and out to sea with minimum interaction with the Coorong
- reduce the internal store of phosphorus in the lakes
- reduce the risk of cyanobacterial blooms
- improve aquatic habitat through flushing of the lakes
- reduce the sedimentation taking place adjacent to the mouth
- promote reductions in turbidity in the lakes to increase productivity of various submerged aquatic plants, which indirectly is likely to increase the numbers of invertebrates, fish and birds in the lakes
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- limit the potential for algal blooms, control the water regime, particularly temperature stratification, mixing and turbidity
- improve the water quality of Lake Alexandrina by reducing the effects of lakeshore erosion and establishing sites of nutrient storage (reed beds)
- allow temporary lowering of lake levels to allow farmers to undertake remedial work along eroding lakeshores
- control shoreline erosion and subsequent nutrient input to the lakes
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem
- reduce desiccation and physical damage of aquatic plants and damage to riparian vegetation, by minimising wave and wind action
- reduce the internal store of phosphorus in the lakes
- reduce the risk of cyanobacterial blooms
- reduce the water levels in the lakes to help protect the habitat of the constructed and natural saline wetlands

around the lake shores, (used by waders) from influxes of freshwater when water levels are surcharged to 0.85 m prior to the barrages closing for summer

- drop lake levels, particularly during the summer/autumn period, to expose some of the lake floor, providing additional mudflats shallow water suitable for wading birds around the perimeter of the lake
- reduce water levels to reduce erosion pressure on exposed shores and to assist remedial action on those shores that are currently eroding.

Recommended action

D3 Automate more barrage gates as determined by adaptive management monitoring results and operate at a wider range of lake levels according to environmental guidelines

Opportunity

This medium-term option expands the short-term option of automation for greater effects, subject to monitoring results to determine which gates should be automated as a priority.

Expected outcomes

Increased management control and flexibility is expected to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong, as the important food source *Ruppia tuberosa* is dependent upon salinity
- reduce the abrupt changes to water levels in the Coorong
- maximise estuarine area
- promote freshwater flushing and fish movement through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- promote the flushing of sediments through the Murray Mouth when turbidity levels are high
- ensure the sediments and nutrients are not transported into the Coorong Lagoon
- make additional water available for the Coorong environment by revision of operating guidelines and allocation options, and allocating water saved to ecological needs.

Recommended action

D4 Increase environmental flows to meet ecological needs in the Lower Lakes and Coorong through ongoing basin-wide water allocation reviews

Opportunity

This option seeks a new allocation of water for environmental purposes, to be obtained through water savings upstream. This could be negotiated within the current environmental flows evaluation as an allocation outside the South Australian entitlement, in high flow events (eg >15 000 ML/day). It is likely that ongoing basin-wide water allocation reviews may provide further opportunities.

Any allocation which was gained could then be assigned for specific purposes, which could be reviewed annually. These could include flushing of the lakes to improve water quality, flows for fish passage at the barrages, flushing of the Murray Mouth Channel, or maintenance of estuary habitat.

Expected outcomes

Increased environmental allocations for the barrages could provide opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- maximise estuarine area
- promote freshwater flushing and fish movement through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary
- allocate more water for environmental use downstream of the barrages

- extend the period of flow over the barrages until later in the year
- allow water levels to be dropped more gradually downstream of the barrages during late summer or autumn
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- promote the flushing of sediments through the Murray Mouth when turbidity levels are high
- ensure the sediments and nutrients are not transported into the Coorong Lagoon
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem.

Long-term opportunities

Minor long-term options, to be undertaken beyond ten years, include to:

- revise operating rules and water allocations on basis of adaptive management monitoring results.

Major long-term options, which will involve greater expense or potential impacts, include to:

- relocate the barrages upstream to Wellington and invest evaporative savings into environmental flows to maintain a larger estuarine area
- increase estuarine area in Lake Albert, eg by constructing a barrage at Narrung and a channel between southern end of Lake Albert and the Coorong
- relocate the barrages upstream to Point Sturt–Point McLeay and invest evaporative savings into environmental flows to maintain a larger estuarine area.

The environmental outcomes which could be achieved by these management measures are outlined below.

Recommended action

E1 Second revision of operating rules for automated gates and revise flow allocations on basis of adaptive management monitoring results

Opportunity

In the long term, it will be necessary to revise again the operating rules and flow allocations in relation to monitoring results, and to adapt operational guidelines as appropriate.

Expected outcomes

The revisions are expected to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- reduce abrupt changes to water levels in the Coorong
- extend the period of flow over the barrages until later in the year
- allow water levels to be dropped more gradually downstream of the barrages during late summer or autumn
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages
- promote freshwater flushing through the Murray Mouth, maintaining access for fish
- maintain estuary habitat in seasonal low flow periods by allocating environmental flows for flows through the barrages
- reduce turbidity and nutrient loadings, transport sediments and associated nutrient loads through the barrages and out to sea with flushing flows through Lake Alexandrina
- promote the flushing of sediments through the Murray Mouth when turbidity levels are high
- ensure the sediments and nutrients are not transported into the Coorong Lagoon
- provide a varied water regime with a range of conditions to support a diverse and balanced ecosystem
- make additional water available for the Coorong environment by revision of operating guidelines and allocation options, and allocating water saved to ecological needs.

Recommended action

F1 Investigate costs and benefits of relocating the barrages upstream to maintain a larger estuarine area as part of the scheduled maintenance review

Opportunity

Assuming that the ageing barrage structures will require replacement in the longer term, consideration has been given to options for relocation rather than reinstatement at the current site. Given current predictions for sea-level rise and the geomorphological trend of sinking at the current site, relocation may become a necessity (Bourman ibid).

There would be several significant benefits associated with relocation of the barrages to Wellington. It is assumed that operation of a barrage at Wellington would include the following features:

- river water would continue to flow into the lakes
- the existing barrages would no longer be used as control structures
- the lakes would be allowed to operate as an estuary, with tidal influence on water levels
- alternative freshwater sources would be provided for regional water users currently diverting from the lakes
- lake levels would no longer be required to be relatively static.

Under these conditions, an estuarine system could be allowed to re-establish. However, it should be noted that the freshwater system which has established in the Lower Lakes over the past 50 years would gradually be replaced by estuarine plant communities. The impacts of this major changeover in habitat conditions are difficult to predict in detail.

If the lake can be operated at more widely fluctuating water levels, it may be possible to achieve a regime which reduces the extent of shoreline erosion.

It should be emphasised that there would be little ecological benefit if insufficient water is allowed to flow from the river into the estuary, resulting in a predominantly marine environment in the Lower Lakes.

An operating regime would be required for the river reach upstream of the new barrage to maintain water quality and levels for gravity irrigators.

Issues arising

It is acknowledged that many social and economic impacts must be taken into account in considering this option. However, present and future environmental problems occurring with the current system of operation of the barrages and Lower Lakes, and associated impacts on water quality, may necessitate a major review of operations in any case. Creation of an estuarine environment in Lake Alexandrina and Lake Albert could result in an increase in blooms *Nodularia spumigena* in a brackish/saline water environment.

Expected outcomes

Operation of Lake Albert as an estuary include opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- ensure that any future manipulation or re-construction of the barrages maintains a salinity gradient over an ecologically sound distance, which is in tune with the seasonal fluctuations in salinities afforded by river discharges
- enlarge the diversity of habitat in the estuary by increasing the size of the tidal prism and the flushing effects of tides at the mouth
- reduce abrupt changes to water levels in the Coorong
- establish a larger estuarine area to benefit waders by providing opportunities for tidally-exposed estuarine mudflats to re-establish in the area immediately above the current barrages
- an agreement would be required to ensure that freshwater flows were maintained into the new estuarine zone
- a broader, more natural estuarine zone might establish over the southern parts of Lake Alexandrina
- improve the functioning of the mouth region with clear benefits to biota and biotic processes in this part of the wetland
- create an enlarged estuarine environment around the natural delta
- promote freshwater flushing and fish movement through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary.

Recommended action

F2 Investigate the option of increasing the estuary area by converting Lake Albert into an estuarine zone, eg by constructing a barrage at the Narrung Narrows and a channel from Marnoo swamp into the Coorong

Opportunity

Consideration has been given to any options which could increase the area of the estuarine zone, currently severely restricted to the channels downstream of the barrages, and limited by the reduced river outflows.

There would be several significant environmental benefits associated with conversion of Lake Albert into estuarine habitat. It is assumed that operation of a barrage at Narrung would include the following features:

- river water would continue to flow into Lake Albert
- Lake Albert would be allowed to operate as an estuary, with tidal influence on water levels
- alternative freshwater sources would be provided for regional water users currently diverting from the lake
- the lake level would no longer be required to be relatively static.

Under these conditions, an estuarine system could be allowed to re-establish. However, it should be noted that the freshwater system which has established in Lake Albert over the past 50 years would gradually be replaced by estuarine plant communities. The impacts of this major changeover in habitat conditions are difficult to predict in detail.

It should be emphasised that there would be little ecological benefit if insufficient water is allowed to flow from the river into the estuary, resulting in a predominantly marine environment in Lake Albert.

If the lake can be operated at more widely fluctuating water levels, it may be possible to achieve a regime which reduces the extent of shoreline erosion.

Expected outcomes

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong, as the important food source *Ruppia tuberosa* is dependent upon salinity
- ensure that any future manipulation or re-construction of the barrages maintains a salinity gradient over an ecologically sound distance, which is in tune with the seasonal fluctuations in salinities afforded by river discharges
- reduce abrupt changes to water levels in the Coorong
- establish a larger estuarine area to benefit waders by providing opportunities for tidally-exposed estuarine mudflats to re-establish in the area immediately above the current barrages
- an agreement would be required to ensure that freshwater flows were maintained into the new estuarine zone
- create an enlarged estuarine environment.

Issues arising

It is acknowledged that many social and economic impacts must be taken into account in considering this option. However, present and future environmental problems occurring with the current system of operation of the barrages and Lower Lakes, and associated impacts on water quality, may necessitate a major review of operations in any case. The reaction of regional groundwater to a changed water regime would need to be assessed. The feasibility of this option should be fully investigated.

Recommended action

F3 Relocate the barrages upstream at Point Sturt and invest evaporative savings into environmental flows for the lakes and Coorong, to maintain a larger estuarine area

Opportunity

An alternative option for barrage relocation is between the main body of Lake Alexandrina and the sand barrier islands in the natural estuary, along a line between Point Sturt and Point McLeay. While this would require a more expensive structure, the major water body could be retained for freshwater supply to the region. This option could be operated in conjunction with a barrage at Narrung (option F2) or with Lake Albert continuing as a freshwater lake.

There would be similar significant benefits associated with relocation of the barrages to Point Sturt as for the Wellington option. It is similarly assumed that operation of a barrage at Point Sturt would include the following features:

- river water would continue to flow into the estuary
- the existing barrages would no longer be used as control structures
- the new estuary zone would be allowed to operate as

an estuary, with tidal influence on water levels

- alternative freshwater sources would be provided for regional water users currently diverting from this area
- lake levels in the new estuary would no longer be required to be relatively static.

Under these conditions, an estuarine system could re-establish. However, it should be noted that the freshwater system which has established in this zone over the past 50 years would gradually be replaced by estuarine plant communities. The impacts of this major changeover in habitat conditions are difficult to predict in detail.

It should be emphasised that there would be little ecological benefit if insufficient water is allowed to flow from the river into the estuary, resulting in a predominantly marine environment in the new estuary.

Issues arising

It is acknowledged that many social and economic impacts must be taken into account in considering this option. However, present and future environmental problems occurring with the current system of operation of the barrages and Lower Lakes, and associated impacts on water quality, may necessitate a major review of operations in any case. Creation of an estuarine environment in Lake Alexandrina and Lake Albert could result in an increase in blooms *Nodularia spumigena* in a brackish/saline water environment. The feasibility of this option should be fully investigated.

Expected outcomes

If the barrages were relocated, benefits would include opportunities to:

- create a flow regime which maintains a viable estuarine habitat and maintains a range of salinities along appropriate gradients
- maintain the salinity gradient of estuarine to hypermarine along the Coorong
- ensure that any future manipulation or re-construction of the barrages maintains a salinity gradient over an ecologically sound distance, which is in tune with the seasonal fluctuations in salinities afforded by river discharges
- enlarge the diversity of habitat in the estuary by increasing the size of the tidal prism and the flushing effects of tides at the mouth
- reduce abrupt changes to water levels in the Coorong
- establish a larger estuarine area to benefit waders by providing opportunities for tidally-exposed estuarine mudflats to re-establish in the area immediately above the current barrages
- an agreement would be required to ensure that freshwater flows were maintained into the new estuarine zone
- a broader, more natural estuarine zone might establish over the southern parts of Lake Alexandrina
- improve the functioning of the mouth region with clear benefits to biota and biotic processes in this part of the wetland
- create an enlarged estuarine environment around the natural delta
- promote freshwater flushing and fish movement through the Murray Mouth, and promote fish passage between Lake Alexandrina and the estuary.

Effectiveness of management options

The management opportunities across all regions for all time scales are summarised in Table 3.5. This table shows that the most effective actions which satisfy the most ecological needs would be:

- D2 – trial operation of lakes across a wider range of levels
- F1 – relocate barrages upstream to Wellington and allocate water savings for environmental flows to maintain estuary
- B1 – automate approximately 22% of barrage gates across all five structures and operate according to environmental guidelines
- F3 – relocate barrages upstream to Point Sturt and allocate water savings for environmental flows to maintain estuary.

Complementary management opportunities

There are a series of other management actions, not related to flow management at the barrages, that should be implemented. Although they complement any adjustments to water regimes in the study area, they should be implemented irrespective of any adjustments to barrage operation.

In particular, there should be urgent remedial work on locations around the lakes currently experiencing or at risk of shore erosion to stabilise the shore (use of protective

TABLE 3.5 LOCATION OF ENVIRONMENTAL NEEDS SATISFIED BY EACH HYDROLOGICAL MANAGEMENT OPPORTUNITY (LOCATION CODES IN EACH CELL SHOWN BELOW TABLE)

	Hydrological management opportunities (by code from Table 3.2)														
Environmental needs	A1	A2	A3	B1	B2*	B3	C1	D1	D2	D3	D4	E1	F1	F2	F3
Protect aquatic plants in Coorong and maximise mudflat habitat	CN CS	CN CS	E	CN CS	CN CS	CN CS			CN CS	CN CS	CN CS	CN CS	CN CS		CN CS
Maximise estuarine area	CN E	CN E	E	CN E	CN E	CN E			CN E	CN E	CN E	CN E	CN E	CN E	CN E
Limit deposition at month				CN E				CN E					CN E		CN E
Increase fish passage through the river mouth	CN E	CN E	E	CN E	CN E	CN E	C N E	CN E	CN E	CN E	CN E	CN E	CN E		CN E
Provide fish passage through barrages	LE LP E	LE LP E		LE LP E	LE LP E	LE LP E	LE LP E		LE LP E	LE LP E	LE LP E	LE LP E	LE LP E	LE LP E	LE LP E
Protect and enhance saltmarsh habitat around lakes			E		LP				LP				LP	LP	LP
Increase diversity of riparian vegetation					LP LE				LP LE						
Reduce sediment transport into Coorong	CN E			CN E				CN E							
Reduce nutrient in lakes		LE LP		LE LP	LE			LE LP	LE						
Maintain a diverse water quality regime in the estuary and Coorong	E CN CS	E CN CS	E	E CN CS	E CN CS	E CN CS	E C N CS	E CN CS	E CN CS	E CN CS	E CN CS	E CN CS	E CN CS	E CN CS	E CN CS
Reduce exotic fish in lakes					LE LP				LE LP				LE LP		LE LP
Increase aquatic vegetation					LE LP				LE LP						
Reduce area of dryland salinity					LE LP				LE LP				LE LP		LE LP
Reduce lakeshore erosion					LE				LE				LE		
Reduce water turbidity					LE LP			E CS N	LE LP						
Total number of environmental needs satisfied	14	14	5	18	25*	12	8	14	25	12	12	12	20	9	19

LE = lake with eroding shoreline; LP = lake with prograding shoreline; E = estuary; CN = Coorong Northern Lagoon; CS = Coorong Southern Lagoon* These are recommended investigations. Outcomes will only be derived after trial operation under D2.

TABLE 3.6 NON-HYDROLOGICAL OPPORTUNITIES FOR IMPROVED MANAGEMENT OF LOWER LAKES AND COORONG

Opportunity	Options	Scope	Time scale	Linkages
Regional revegetation	See Coorong and Districts Local Action Plan	Major	Medium - long	CARE program Coorong and Districts Soil Conservation Board
Lakeshore erosion	Protective structures Revegetation Improved stock management	Minor	Medium - long	CARE program Coorong and Districts Soil Conservation Board
Control of European carp	Trapping when stranded in estuary behind barrages	Minor	Short - medium	Fishing industry
	Increasing the abundances of native fish species	Minor	Medium - long	Fishing industry SA Water MDBC SARDI

structures, destocking, and revegetation), as well as broader regional revegetation programs aimed at reducing impacts of dryland salinisation and possible sources of sediments to the lakes.

Shoreline erosion

Any structure (either artificial or natural, eg revegetation of reed beds or trees in the riparian zone) which creates a wind break reducing the fetch and lessening the impact of wind-driven turbulence, would provide an advantage for the riparian and aquatic plant communities. Suggested actions include:

- control shoreline erosion and subsequent nutrient input to the lakes
- reduce sedimentation caused by shoreline erosion
- take into account the impact of wind-generated lake setups
- physical structures will probably be necessary to protect erosion control measures.

Riparian buffer zones

The establishment and protection of riparian vegetation around lake shorelines should be promoted for prevention of erosion and also to create buffer zones to act as nutrient sinks. Erosion controls works should be used in combination with grazing controls and revegetation with appropriate native species to maximise stability and habitat value and to minimise visual impact.

Carp

The presence of carp in the lakes remains a major obstacle to reducing turbidity and to stimulating the re-establishment of submerged aquatic plants. Although suitable techniques may not yet be available, implementing programs to reduce the carp numbers would be beneficial. Some commercial fish species, if they can be introduced into the lakes in adequate numbers, may help to reduce densities of carp by preying on fry and eggs (Pierce pers comm; Geddes pers comm).

Carp densities (proportion of biomass of large fish 100 mm+) are currently less than 50% of 1989 levels due to a combination of enhanced freshwater native fish predator stocks and more effective/intensive adult carp harvest by commercial fishing.

Aquatic vegetation growth in the Mundoo Channel area and elsewhere has increased dramatically over this same period. Both these existing management components need to be continued and enhanced.

Dryland salinity

The problem of dryland salinity on the southern portion of Hindmarsh Island should be addressed. Related issues include raised watertables and local drainage. The possibility of benefits from lowering lake levels should be investigated.

CONCLUSIONS

KEY ISSUES

The scientific panel identified several important conclusions during this evaluation, particularly the following points:

- The River Murray does not end at the barrages and flow management must take into account the flow regimes and ecological needs of the remnant estuary, the Coorong, the mouth channel and the off-shore zone.
- The current operating system of the freshwater Lower Lakes is not sustainable, with increasing problems with water quality predicted due to accelerated sedimentation and nutrient accumulation, coupled with reduced through-flows.
- The remnant estuary, including the northern and southern lagoons, is only 11% of the natural area with less freshwater inflows than the natural system, allowing seawater to dominate conditions.
- The value of commercial fish in the remnant estuary area is equal to the value from the whole of the freshwater lakes area, which is nine times larger.
- Very significant improvements in ecological value of this region could be achieved through a package of recommended actions, with major social and economic benefits associated.
- The extent of ongoing lakeshore erosion caused by the combination of high water levels, wind and highly erodible soil formations is seen as a significant contribution to sediment and nutrient loads in the lakes, requiring active control measures.
- Current limited evidence indicates that the primary major sources of sediment and nutrient inputs to the lakes are from their own catchments, rather than from the River Murray.
- The current status of aquatic plant communities and habitat diversity in the Lower Lakes is reduced primarily through decreased throughflows and increased turbidities, and active management measures are required to increase biodiversity and extent of plant communities.

It is suggested that a more diverse native plant community and associated animal species, although requiring reduced turbidities, would decrease the overall risks of algal blooms in the Lower Lakes.

The scientific panel identified six key issues driving the degradation of the environmental values of the Lower Lakes and Coorong. These are:

- the reduced area of estuary
- changed water regimes of the lakes and river
- freshening of brackish and saline habitats
- reduced habitat for aquatic plants
- increased algal blooms
- dryland salinity.

The first two issues are the most significant in terms of the scale of their impact and because they are driving some of the other key issues.

Reduced estuarine area

Prior to the commencement of construction of the barrages in the 1930s the area of the lakes subject to tidal influence was approximately 97 km2. The area of effective estuary has now been reduced by approximately 93%. This major reduction of the estuary has had serious impacts on the ecosystem function.

The reduced estuarine area, in combination with the modified flow regime, has led to greatly reduced flushing of the mouth of the river. As a consequence there have been large amounts of sediment deposited inside the estuary opposite the river mouth and in nearby channels. This process will promote further sedimentation and increase the frequency and duration of mouth closures.

There have been serious impacts on aquatic and riparian vegetation due to the reduction in estuarine area. Prior to the construction of the barrages a wide-ranging salinity gradient existed from fresh to hypermarine over a large area. This supported a wide range of plants species with different tolerances to water and soil salinities. The barrages have now created a sharp disjunction between estuarine and freshwater systems and replaced most of the estuarine system with a freshwater system. Lack of freshwater inflows has produced hypersaline conditions in the Southern Lagoon. Consequently, the vegetation adapted to the transitional estuarine zone is greatly reduced.

The reduction in estuarine vegetation and the growth in area of freshwater wetlands, notably reedbeds, has reduced the habitat best suited to waders and increased the habitat for waterfowl.

Fish populations have declined due to the reduction in estuarine area, as many species are dependent on estuarine salinities to trigger reproduction and recruitment. Many species that migrate from the sea to the estuary have been affected by the increasing frequency and duration of mouth closures due to siltation, as well as the physical barrier of the barrages in themselves.

Changed water regimes of the lakes and river

The barrages are managed to maintain a relatively static water level (0.6–0.85 m AHD) whereas in the past this would have fluctuated greatly.

The river has been regulated so that average flow to the lower River Murray is 37% less than original flows and the median flow is reduced by 80%. The frequency of extended periods of no flow at the barrages has increased from 1 in 20 to 1 in 2. Minor to medium floods (up to 1 in 7 year event) have been eliminated. Much greater amounts of turbid Darling River now enter the lower River Murray. While the seasonality of peak flows is unchanged, the river no longer experiences low flows in summer but is held at an artificially high level.

Increasing periods of low or no flow have contributed greatly to the sedimentation occurring at the mouth of the river and nearby channels.

Increasing turbidity and longer periods of higher water levels may be responsible for the lack of submerged plant species. Rapid changes in water level as the barrages are opened or closed causes is drowning or desiccation of emergent species in the estuary and Coorong.

The more or less constant water and higher water level has reduced the area of seasonally exposed shoreline and associated shallows. This has may be responsible for the large drop in the numbers of all species of waders. Water levels being too high or too low at the wrong time, as well as rapid changes in water levels have limited the ability of the key aquatic plant *Ruppia tuberosa* to set seed and develop turions. These are both major food sources for waterbirds. Also the plant is a key habitat and food source for macroinvertebrates and fish which are important food sources for waterbirds.

Increased sedimentation, lower flows and the barrier of the barrages have reduced the opportunities to for fish passage between the sea, the estuary and the estuarine Northern Lagoon of the Coorong. Long periods of barrage closure, particularly through winter, have greatly reduced available habitat for native species to improve condition prior to spawning.

Increased algal blooms have been linked to reduced flow rates. Lower flows in winter and spring may exacerbate wind induced internal cycling of nutrients and increase residence time for cell growth and accumulation. Lower flows in summer and autumn may lead to reduced turbidity which increases light penetration and photosynthesis of algal cells.

Freshening of brackish and saline habitats

Many of these changes have been described under the previous two issues. A significant additional problem is the loss of saltmarsh habitats around the edge of the lakes. This is caused by the more or less constantly high water levels that results in significant wind-driven splash into these habitats. These habitats would have been dominant in the natural estuary but are very limited under regulated conditions. These are key habitats for migratory waders.

Reduced habitat for aquatic plants

This problem has largely been described under the first two issues. Another factor is disturbance of the habitat by European carp.

Increased algal blooms

This is a significant issue from a consumptive use viewpoint. Water in the lakes is used for stock, domestic and irrigation purposes. The key flow-related mechanisms that drive this problem include reduced throughflow, increased nutrient inputs and reduced aquatic plant communities. The rise of algal blooms is increased during periods of low flows and warm conditions, which allow temperature stratification in the water.

Dryland salinity

Dryland salinity is a significant problem in the district surrounding the lakes and Coorong, particularly to the east and south, where around 10 000 hectares is salinised. Another 37 000 hectares is at risk in the next 50 years (Anon 1997). This process is being driven by increased regional groundwater recharge since broadscale vegetation clearance.

Dryland salinity is leading to the loss of riparian and wetland native vegetation and given the areas identified as being at risk it has potential to degrade or destroy much of what remains.

It also contributes to increased lake salinity. It is a particular problem on the southern part of Hindmarsh Island, where clearing, grazing and rising water tables have created significant areas of scalded salt-affected land.

CURRENT STATUS AND FUTURE PROGNOSIS FOR THE LOWER LAKES AND COORONG

The panel concluded that without action the system would continue to degrade. It is predicted that problems related to sedimentation in the lakes, with accompanying nutrient accumulation, may create significant problems which would interfere with the continued operation of the lakes as a regional water supply. The primary sources of nutrients are with the lake sediments and from the regional catchment of the lakes, not from the river.

The 'do nothing' option is likely to result in further degradation of the system, particularly the region between the barrages and the river mouth, due to sedimentation and lack of freshwater flows. Given this fact, the short-term actions should be implemented as soon as possible. A long-term management plan should be formulated as a matter of urgency, based on the package of recommended actions.

It is imperative that no management actions should be undertaken without a comprehensive monitoring and review mechanism to allow effective adaptive management. This process should be established as part of operational management of the barrages, with a comprehensive monitoring baseline, regular monitoring of performance indicators, with regular reviews and an adaptive management feedback loop to allow fine-tuning of management actions based on effectiveness.

The dominant effect of wind-induced seiche movements on lake levels overrides the potential for small-scale manipulation of levels using the barrage structures. Any actions which have the potential to reduce wind and wave action deserve priority consideration, eg catchment revegetation.

RECOMMENDATIONS OF THE SCIENTIFIC PANEL

The panel formulated the following recommendations over three time scales:

Short-term

- establish coordinated monitoring programs as a basis for adaptive management
- articulate the current operating guidelines and triggers (ie actions taken to achieve the operating rule of 0.75 m AHD lake levels) in order to identify constraints and opportunities for changes in operating guidelines
- articulate detailed environmental operating principles and guidelines to meet identified ecological needs
- identify short-term changes in operation of the existing structures within the current range of lake levels to be implemented immediately
- identify short-term environmental flows needs, eg for fish passage, in terms of volume, location, gate openings and timing
- develop specific arrangements for maximising the ecological benefits of the non-consumptive proportion of entitlement flows to South Australia
- evaluate the proposal to construct levees across low-lying island spillways and modify to allow interface between saltwater and freshwater systems, protecting the essential ecological transfer processes occurring at this interface
- automate 22% of gates across the five barrages as soon as possible (see Table 3.3 for details)
- investigate operating automated gates at a greater range of lake levels (ie higher than 0.60–0.85 m EL)
- evaluate impacts of proposed changes and trade-off environmental, economic and social benefits against environmental, economic and social costs, using the Tong model of the estuary and Coorong lagoons to assess potential impacts and benefits of various management options
- determine what different monthly and/or daily flows in the pattern of delivery of entitlement flows would be of environmental benefit through providing season flows at the barrages
- negotiate a different pattern of delivery of flows by submission from the South Australian Commissioners to the Murray–Darling Basin Commission
- investigate opportunities to divert saline drainage water from the Angas–Bremer basin to sustain saltmarsh communities on the western shores of Lake Alexandrina
- commence investigations on the long-term options to ensure objective assessment based on adequate information

Medium-term

- review effectiveness of changed operating guidelines and adapt management measures as required, update monitoring baseline

- enlarge Mundoo Barrage to allow greater through-flow and operate preferentially to limit sedimentation in the mouth zone
- identify environmental needs for operation of the lakes over a wider range of levels
- evaluate costs and benefits of altered operating regimes, and determine preferred operating guidelines and performance indicators
- trial altered operating regime with wider range of lake levels
- automate more gates as indicated by adaptive management monitoring program
- investigate opportunities for water savings upstream for transfer to the Lower Lakes and Coorong environment to meet identified environmental needs
- review and refine long-term options

Long-term

- review effectiveness of changed operating guidelines and adapt management measures as required, update monitoring baseline
- evaluate options for relocation and revised operation of the barrages and implement preferred option
- identify environmental criteria for maximising and maintaining estuarine area under revised operation of barrages
- negotiate agreements for supply of fresh water to maintain estuarine environment

General recommendations

- maintain a transition zone in the estuary, as a buffer to the abrupt change from marine to fresh conditions at the structures
- in addition to the recommended changes to flow management, a range of complementary actions are also recommended, including revegetation and regeneration of the riparian buffer zone and shore protection in areas subject to shoreline erosion
- recommendations on changes to flow management need to be integrated with all other planning and catchment activities in the region, including the Ramsar planning process, the development of the River Murray Catchment Board, Natural Heritage Trust projects and the Murray–Darling Basin Decision Support System for river management.

IMPLEMENTATION

A draft work program identifying responsibility for recommended actions has been proposed in conjunction with this assessment. This program will be referred to the Interstate Working Group on River Murray Flows to coordinate implementation. In this assessment a framework of guidelines and operating criteria has been established to set the direction for future management of the lakes and Coorong, as summarised below.

GUIDELINES

The following guidelines are intended to provide the framework for development of detailed operating strategies:

Barrage operation

- allow flexibility in the operation (timing, frequency or duration) of gate opening and investigate opportunities to allow adjustment of water levels outside the current operating range of 0.60–0.85 m EL
- open gates progressively, starting a little earlier than currently happens, keeping some of the gates open for a longer period into summer
- gates could be closed progressively, perhaps starting earlier than is currently the case but extending the period over which the gates are closed
- provide rapid responses to fluctuating conditions
- open the gates at Mundoo strategically during windy weather, when sediment has been resuspended, and during a falling tide to maximise the probability that this turbid water will be flushed straight out to sea with minimal impact on the marine environment
- as Mundoo Channel has the steepest gradient to the sea, Mundoo Barrage should be opened first and more frequently to maximise flow velocities. Options to increase flow volumes and scouring effects should be investigated as a matter of priority.
- release water strategically for parts of the day when tides are lowest and winds are favourable

Coorong water levels

- close the Tauwitchere Barrage last to prolong water level recessions in the Coorong
- allow water levels to be dropped more gradually downstream of the barrages during late summer or autumn

- strategic release of high flows over the Tauwitchere Barrage (while the others are not opened) to buffer level changes
- strategic opening and closing sequences to remove sand accumulating in the Coorong estuary channels between the mouth and Tauwitchere

Flushing of lakes

- flushing to improve habitat quality should take place during summer when low tides predominate or during periods of low tide and calm seas
- direct turbid water over the barrages and out to sea with minimum interaction with the Coorong (note that this would have minimum impact in the marine zone, where turbid river water quickly disperses and mixes)

Enlarge estuary

- allocate more water for environmental use downstream of the barrages
- extend the period of flow over the barrages until later in the year
- maximise the transfer of freshwater from the lakes to the Coorong particularly during times of seasonal low flow from January to May

Fish passage

- promote freshwater flushing through the Murray Mouth, maintaining access for fish
- maintain open passage particularly in period of likely high fish migration in and out of the Murray Mouth (October to December)
- provide flows for fish passage and attractant flows at the barrages based on tidal and lunar cycles to entice estuarine species to naturally migrate into and out of the Lower Lakes habitat, with particular emphasis on winter low flow periods
- retain at least two open gates at Tauwitchere and Goolwa sites over winter to enhance native Coorong fishes over the full limiting winter period
- smooth and extend the spring flood recession outflow to the Coorong to mimic natural conditions, particularly over the period September to January

Lake levels

- operate lakes at lower levels to protect saltmarsh from freshwater splash during storms and wind set-ups
- operate lakes at lower levels to expose more mudflat habitat for wader during summer
- drop lake levels at appropriate times enable farmers to undertake lakeshore erosion control measures

Vegetation

- ensure that there is an adequate re-vegetation of the lakes shore and restriction of grazing and cultivation of the riparian zone. This may include revegetation with species such as *Typha* and *Phragmites* as a first step, but could also include *Cyperus gymnocaulus* and other bank stabilising species (eg *Eleocharis acuta*)
- protect and maintain aquatic vegetation through management of water levels under the following guidelines:
  - the rate of fall should not exceed ca 2 cm per day for no longer than 30 days
  - seedlings should not be top flooded for more than two weeks
  - average water column irradiances given for *Vallisneria americana* should be used as a guideline for the duration and depth of flooding (see operating criteria below)
  - at least 10% of emergent leaf area should be maintained at the maximum operating height

Sedimentation

- ensure that the catchment is adequately vegetated to reduce the rate of wind-borne soil particles entering the lakes

Erosion control

- implement shoreline protection including erosion control works.

OPERATING CRITERIA

The following preliminary draft criteria have been formulated as an indication of the types of operating criteria required:

1 aim to increase illuminance to allow colonisation of bottom sediments by aquatic plants

Criterion:

- operate lake levels according to the guidelines in Ganf (ibid), eg 90 NTU allows growth to a depth of 110 cm

Action required:

- assess current situation of turbidity vs plant habitat, need bathymetry, turbidity/illuminance, contour model of lakes

2 aim to prevent desiccation of aquatic plants

Criterion:

- control rates of fall in lake level, using as guidelines desired rate of fall of not more than 2 cm/day, with a maximum total of 60 cm change over spring to summer seasons

Action required:

- assess current rates of fall, opportunities to modify, assess effect of leaving gates open longer, closing Tauwitchere last to buffer rate of fall in Coorong

3 aim to maintain flow path through the mouth zone

Criterion:

- provide 20 000 ML/d for 30 days through mouth from all barrages to maximise scouring effect when sediment is accumulating inside the Murray Mouth, eg during flows >15 000 ML/d, open Mundoo first

Action required:

- develop guidelines to maximise the effect of low tides and high turbidities in the lakes for maximum flushing of sediments and nutrients
- assess potential opportunities, frequency, set up performance indicators for monitoring

4 aim to provide fish passage

Criterion:

- during periods of extended barrage closure, especially during summer, autumn and winter seasons, open a limited number of gates

Action required:

- open one gate per barrage for two hours prior to opening automated gates
- operate one gate in Tauwitchere and Goolwa barrages continuously over winter in natural flow pattern
- operate all automated gates for 30 minutes at the top of one tidal cycle from mid-May to November

5 aim to avoid drowning of aquatic plants

Criterion:

- limit maximum water levels to not more than 90% of plant height of deepest stands of emergent macrophytes (eg *Typha*, *Phragmites*)

Action required:

- avoid excess flooding of fringe vegetation
- identify indicator stands, eg near Goolwa Barrage, to guide operators, involve community in monitoring

6 aim for increased tidal prism to maintain mouth channel, fish passage and extended estuarine habitat, reduce turbidity and sedimentation in lakes

Criteria:

- at entitlement flows with closed barrages, open single gates for fish passage for very short periods in conjunction with tides
- at flows 10-20 000 ML/d, open limited gates to freshen and extend estuary
- at flows 20-30 000 ML/d, open barrages for freshening of estuary and flushing of sediments and nutrients from lakes

Action required:

- change operations and monitor effects

FURTHER INVESTIGATIONS

The scientific panel identified several areas where more information is required to determine what management actions would be appropriate, as outlined below.

Sedimentation

A detailed study is required of the size of the flows that can be generated, the optimum size of opening in the Mundoo Barrage and the optimum operating strategy to maximise scouring effects at the Murray Mouth. The recommended automation of the barrage (in association with other benefits such as fish migration) will facilitate short-term responses that are essential in operating this barrage.

The danger of flooding downstream of the barrage and the impacts on upstream irrigators in Mundoo Channel would need to be investigated. This option is essential for maintenance of an estuarine environment and flow through the Murray Mouth in the medium to long term. Without action, the frequency of mouth closures will increase, with associated losses to fishing, recreation and tourism. The cost of re-opening the mouth to prevent serious flooding is also significant (Bourman ibid).

Research is also needed on the sources, pathways and fates of sediments moving from the Lower Lakes to the Coorong and estuary.

Bird ecology

Some data on the extent of disturbance and the consequences to the birds is urgently needed as a basis for an appropriate management program for human activity in the region. This is currently being researched by Dr D Paton, The University of Adelaide, and the results will be addressed by the Coorong and Lower Lakes Ramsar Management Plan.

A comprehensive monitoring program is needed to count the numbers of waterbirds and waders at selected sites around the shoreline. Initial counts need to establish a baseline from which management actions can be subsequently assessed. The major concern at present is the decline in waders near the mouth region. Research should focus on wader foraging success and food supply, and possible factors including human recreation that may lead to disturbing foraging birds.

Research is also needed to establish the cues which cause *Ruppia tuberosa* to switch from seed to turion production.

Fish and invertebrates

Further research is needed to determine requirements for effective flow management for fish passage. Research is needed on the following:

- spawning and larval/juvenile recruitment of fish species in the Coorong
- detailed information on the ecology of the system and biology of fish species before implementation of long-term management recommendations
- optimal environmental flow regime for fish movements through the Murray Mouth
- experiments on fish passage via locks and barrage gates, which is currently being undertaken by Bryan Pierce of SARDI
- requirements of fish passage as they relate to lunar cycles, tidal cycles and attractant flows for finer operation of automated barrage gates.

Hydrological management

The extent of leakage at the barrage structures should be quantified, to determine whether this can be controlled or redirected for ecological benefits.

Phytoplankton

Further research is needed to increase our understanding of the causes and consequences of cyanobacterial blooms in the Lower Lakes. Information is required on:

- the sources of turbidity and nutrients in river inflows (Murray vs Darling) to the Lower Lakes and their relative contribution to the development of blooms. The significance of turbidity and nutrients from resuspended lake sediments and from eroding lakeshores also requires further investigation
- the effect of higher summer turbidities in the River Murray (from River Darling releases) on the suppression of benthic algal growth in the Lower Lakes (refer 'Upstream scientific panel', Part 1). Information is required to quantify the effects of reduced light availability on biodiversity of benthic communities and possible implications for the food chain
- the relationship between higher aquatic plants and cyanobacterial growth and the underlying significance of turbidity

- the relationship between salinity levels and the growth of *Nodularia spumigena* and *Anabaena circinalis*, including the germination of akinetes (resting cells) in cultured strains isolated from the Lower Lakes
- the fate of cyanobacterial toxins in the environment and the consequences of bio-accumulation of toxins in the food chain.

SALINITY

- The impact of the proposed levee banks across the low-lying spillways on the barrier islands, and the impact of drains on the fresh water side of the islands, on the saltwater marsh should be investigated. A more environmentally beneficial design for controlling marine invasions while allowing the salt water/fresh water interface to occur is required.
- The degree of saline groundwater accessions to Lake Albert during empty-fill operations requires evaluation, to determine what the impacts would be of operating the lake over a wider range of levels under a revised operating regime.

LINKS TO OTHER ACTIVITIES

The key links to be made to other activities for implementation of these recommendations include:

- Ramsar planning process for Lower Lakes and Coorong, including Community Reference Group
- management of national parks and reserves in the study area
- Local Action Planning groups:
  - Bremer-Barker Catchment Group
  - Coorong and Districts Soil Conservation Board
  - Goolwa to Wellington
- River Murray Catchment Board (in process of nomination) under the Water Resources Act 1997.
  - catchment planning process (monitoring, investigations programs)
  - water allocation planning process (allocate waters).

A particularly sensitive issue is the need to observe the obligations for wise use and sustainable management of the Ramsar site. Any significant changes (eg relocation of barrages) to the recognised ecological character of the site must be referred to the Ramsar Bureau via the Australian delegated authority (Environment Australia) and the Scientific Technical Review Panel for approval.

Funding applications for implementation are likely to be addressed jointly to the Natural Heritage Trust, Murray–Darling 2001 and the Catchment Management Board over the next four years. National Heritage applications will require support from the Regional Assessment Panel and the State Assessment Panel.

The issue of inflows from the South East into the Southern Lagoon of the Coorong is closely linked to management of the estuary. Current recommendations limit the volume of drainage water allowed to 40 000 ML/year, to ensure that impacts on the level and salinity of southern lagoons are minimal.

IMPLICATIONS FOR MANAGEMENT AGENCIES

The role for coordination of South Australian issues lies within the brief for the River Murray Catchment Board. SA Water would continue to manage the structures on behalf of the MDBC. Basin-wide issues will be coordinated by the MDBC, at least initially through its Interstate Working Group on River Murray Flows.

The key links to agencies include:

- SA Water Murray Mallee region, including barrage superintendent
- Primary Industries SA Murray Bridge region, particularly for management of the Lower Murray irrigated dairy swamps
- SARDI for research and monitoring of fish species
- MDBC for coordinated decision-support systems
- Australian Water Quality Laboratory for water quality monitoring
- DENR regional officers for monitoring of land and wildlife management issues.

IMPLICATIONS FOR UPSTREAM WATER MANAGEMENT

This report highlights the major impacts of upstream activities on the health and sustainability of the Lower Lakes and Coorong ecosystems. The recommendations have implications for upstream management in the following areas:

Impacts of upstream management on Lower Lakes and estuary

- need to reduce upstream diversions to allow more water to flow to the lakes, through the barrages, into the Coorong and out through the Murray Mouth

- need to change flow delivery patterns and volumes to provide flushing flows to remove nutrients and sediments from the lakes in a manner which protects the Coorong from contamination
- need to reduce the dominance of turbid Darling flows, to allow clearer Murray water to reach the lower reaches, especially in the peak breeding times of late spring and early summer
- need to recognise the value of small flows maintained at the barrages through key periods of fish migration
- need to recognise the value of maintaining an open channel at the Murray Mouth

Impacts from barrages on upstream levels

- need to recognise the extensive impact of level changes at the barrages on fish, aquatic biota, irrigators and rural communities, with the critical zone extending as far as Mannum and more limited effects up to Blanchetown.

CONSULTATION

The recommendations of this report have far-reaching consequences for many interest groups. However, the issues raised are being addressed in different ways concurrently by several groups. Consultation with the wider community and interest groups should be coordinated and integrated for maximum effective input and best use of support resources.

It is therefore recommended that consultation on these proposals be linked in the short term to the Ramsar planning process. This has been made possible by making draft information available from the Scientific Panel report for incorporation into the Ramsar discussion paper on Flow Management. The process of community consultation which is already underway can thus provide timely initial feedback for implementation and adoption of the proposed work program.

It is noted that the Catchment Management Board will be required to carry out extensive consultation processes as part of the development of the required water allocation plan and catchment management plan. Therefore, it is recommended that responsibility for coordinated implementation of the work program be assigned to the Catchment Management Board.

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APPENDICES

I PROCESS FOR EVALUATING ENVIRONMENTAL FLOW REQUIREMENTS FOR THE RIVER MURRAY BARRAGES

Anne Jensen, DENR

FIGURE I.1 PROCESS OF DEVELOPMENT OF EVALUATION METHODOLOGY

WORKSHOP SESSION 1

(panel and steering committee)

brief

identify key environmental flow requirements in relation to management of flow through the barrages, as it relates to maintaining the ecosystem of the Lower Lakes, the Coorong estuary and Coorong lagoons

background information (see Appendices II-VI)

- upstream methodology
- Ramsar planning process
- current operating strategies
- flow modelling of estuary and Coorong
- sediment transport
- fish passage proposal
- land management issues
- suggested list of issues for consideration (see brief)

discussion of methodology (Part 1)

- scope
- environmental objective
- scales
- level of detail
- responsibilities for write-up
- recording sheet
- links with Ramsar
- links with upstream panel

preliminary list of issues agreed by panel

- barriers to flow
- higher water levels
- major water extractions
- rate of fall in water level
- nutrient accumulation and transport
- cyanobacteria
- dryland salinity

FIGURE I.1 PROCESS OF DEVELOPMENT OF EVALUATION METHODOLOGY

(continued from previous page)

FIELD TRIP

(panel and support team)

sites visited/issues considered
- Tolderol
- community concerns
- Goolwa Barrage
- Murray Mouth
- Mundoo Barrage
- Boundary Creek Barrage
- low-lying road fords
- Ewe Island Barrage
- Tauwitchere Barrage
- professional fisher's concerns
- Southern Lagoon
- Hells Gate
- Northern Lagoon
- lakeshore erosion

evaluation of methodology
- testing and revision of recording sheets

WORKSHOP SESSION 2

(panel and steering committee)

discussion of field trip observations

review of recording sheet (see Figures I.1, I.2)

changed methodology (see Figure I.1)
- problem v cause v region
- opportunities to change barrage operations (major/minor, short/medium/long term)
- environmental needs v region

report outline

FIGURE I.1PROCESS OF DEVELOPMENT OF EVALUATION METHODOLOGY
(continued from previous page)

WORKSHOP SESSION 3

(panel and steering committee)

update of progress with steering committee

presentation by panel members on current status, key issues, opportunities and interim recommendations for each discipline

- fish & invertebrates
- hydrology
- geomorphology
- riparian & aquatic vegetation
- bird ecology
- algae

discussion of findings and interim recommendations

(panel and steering committee)

evaluation of environmental needs vs options vs regions

development of operational guidelines

development of preferred options

WRITE-UP PHASE

(panel and support team)

agreed outline

panel contribute chapters by discipline (current status, key issues, opportunities and recommendations)

support team coordinate editing and infill supporting information

draft circulated to panel and steering committee

final report submitted to Water Audit Working Group of Murray–Darling Basin Commission

FIGURE I.1 PROCESS OF DEVELOPMENT OF EVALUATION METHODOLOGY
(continued from previous page)

DEVELOPMENT OF RECORDING SHEET

- amended recording sheet based on upstream panel method provided for consideration by panel (Figure I.2)
- panel agrees to develop new recording sheets based on five landform-based regions by seven key issues, using a recording sheet based on evaluating the impacts and benefits of minor and major management opportunities over the short, medium and long term (Figure I.3)
- field testing of recording sheet leads to minor modifications, moving the minor/major dichotomy under the timescale categories, and inserting additional room at the top of the sheet to describe the issue, the problem and the cause of the problem (Figure I.4)
- panel assesses task of filling out up to 35 recording sheets to cover the issue v region matrix (minimum 19 (√), maximum 26 (√ + **?**) sheets required) (Figure I.5)
- panel tests recording sheet (for shore erosion in the eroding lakeshore region) (Figure I.6) and concluded that the task would be very time-consuming
- panel lists key problems and causes and cross-checks by five regions (Figure I.7) and concluded that management opportunities could be divided into two regions instead of five (ie upstream and downstream of the barrages)
- panel cross-checks environmental needs by opportunities (see Table 3.5) to assess the full benefits of the management options
- panel cross-checks environmental needs by region and adds codes for opportunities (see Table 3.5)
- panel develops operational guidelines to address key issues (see Part 3)

FIGURE I.2 AMENDED BARRAGES RECORDING SHEET, BASED ON UPSTREAM METHODOLOGY

Reach name or number: . . . . .Recorder: . . . . .Date: . . . .

1. CURRENT STATUS – SUMMARY	
GEOMORPHIC PROCESSES	
RIPARIAN VEGETATION	
FLOODPLAIN	
ALGAE	
MACROPHYTES	
INVERTEBRATES	
FISH	
OTHER	

FIGURE I.3 AMENDED BARRAGES RECORDING SHEET (STAGE 1)

Region: . . . . Problem: . . . . Recorder: . . . . Date: . . . .

SHORT			
MEDIUM			
LONG			

FIGURE I.4 AMENDED BARRAGES RECORDING SHEET (STAGE 2)

Region: .... Recorder: .... Date: ....

Issue: .... Problem: ....

Cause: .... Description: ....

	OPPORTUNITIES	BENEFITS	IMPACTS
Short Term Minor			
Short Term Major			
Medium Term Minor			
Medium Term Major			
Long Term Minor			
Long Term Major			

FIGURE I.5 ASSESSMENT OF RECORDING SHEETS NEEDED TO COVER THE ISSUE VERSUS REGION MATRIX

ISSUE/REGION	LAKES – ERODING SHORELINE	LAKES – PROGRADING SHORELINE	ESTUARY	NORTHERN LAGOON	SOUTHERN LAGOON
Reduced estuary			√	√	
Freshening of brackish & saline habitat	√	√			
Changed water regime (lower volumes, changed seasonality)	√	√	√	√	√
Reduced habitat for aquatic plants	?	?	√	√	√
Increasing nutrients levels and sedimentation	√	√	√	?	?
Increased frequency of algal bloom	√	√	?	?	?
Dryland salinity	√	√			

√ = data sheet required for this region

? = data sheet may be required for this region

blank = no data sheet required

FIGURE I.6 RECORDING SHEET TEST (FOR THE ISSUE OF SHORE EROSION IN THE ERODING LAKESHORES REGION)

	OPPORTUNITIES	BENEFITS	IMPACTS	COMMENTS
Short - term (1 – 3 years)				
minor major	– shore protection – establish riparian vegetation – protect all shores immediately – major protective plantings – operate lakes at lower range of levels	– protect shores, stop erosion – retain grazing land – reduced nutrients into lakes	– visual impact of tyres – lost productive land to revegetation – lower lake levels	– synergy with LAPs om floodplain management – liaise with EPA on tyres
Medium - term (3 – 10 years)				
minor major	– extended shore protection – riparian vegetation around all eroding shores – network of windbreaks in key areas eg Point Sturt (strategic revegetation)	– establish riparian zone – increased removal from lakes by plants – increased macro-invertebrate habitat (positive effect on food chain) – improved aesthetics (rip vegetation) – reduced wind – reduced evaporation – increased agricultural production	– less turbulence – more algal blooms	* investigate wind effects
Long - term (>10 years)				
minor	– tyre reefs and islands			– need investigation
major	– reduce water levels – remove barrages to Wellington	– limited if only 10-20 cm, needs to be >0.5 m to be effective	– impacts on other users if >20 cm	– not very effective unless there are major changes

FIGURE I.7 KEY PROBLEMS AND CAUSES CROSS-CHECKED AGAINST THE FIVE REGIONS

REGION						CAUSE
Problem	**Lake Erosion**	**Lake prograding**	**Erosion**	**North Lagoon**	**South Lagoon**	**Northern Lagoon**
Reduced biodiversity – reduced fish habitat (comm and rec fish)	+	+	+	+	?	– changed water regime(less flow water at mouth, less passage) – reduced area of suitable water salinities, carp
Physical processes – siltation (progradation of lake shore?)	+	+	+	+	–	– reduced river flows, barrier restriction, reduced volume of tidal exchange, reduced estuary, reduced velocity – carp
Modified bird habitat	+	+	+	+	+	– changes in food resources, rapid level changes, reduced saltmarsh & brackish habitat, increased reedbeds, changed water regimes, levels too static, higher levels, turbidity
Shore erosion	+	–	+	–	–	– higher levels, wind, soil types, mouth migration
Water quality – increased algal blooms – turbidity – salinity (reduced variability)	+ + +	+ + +	**–** **?** **+**	– + +	– + +	increased nutrients, changed flow rates, decreased salinity – increased fine river sediments, wind, shallowing (sand) – changed water balances, abrupt changes
Dryland salinity	+	+	–	–	–	– high lake level holding up rising ground water

FIGURE I.8 SUMMARY OF ISSUES COVERED IN THE AMENDED FIELD RECORDING SHEET

Current Status of:

Hydrology

current flow regime

Changes from natural state

Geomorphology

major gepmorphological influences

stability of syubstrate

changes from natural state

Riparian & Aquatic Vegetation

inventory

major habitat types

condition of habitat types

changes from natural state

Bird Ecology

inventory

major habitat types

condition of habitat types

changes from natural state

Fish & Invertebrates

inventory

major habitat types

condition of habitat types

changes from natural state

Algae Current Status

inventory

major habitat types

condition of habitat types

changes from natural state

Flow regime requirements for:

- geomorphology
- Riparian & Aquatic Vegetation
- Bird Ecology
- Fish & Invertebrates
- Algae

Hydrology in terms of:

- current flow regime
- changes from natural state

II ASSESSMENT PROCESS FOR ENVIRONMENTAL FLOW REQUIREMENTS FOR THE RIVER MURRAY AND LOWER DARLING

Jane Doolan, Manager Wetlands and Waterways Unit, DCNR, Victoria

OBJECTIVE:

To identify changes in river operations for the River Murray and Lower Darling that should result in general improvements in the environmental condition of these river reaches whilst considering the current needs of existing water users.

Issue:

- that the river cannot be returned to its pristine or pre-European settlement state.

Recommendation/aim:

- to at least maintain and, where possible, improve the natural habitats and functions of the river as it is today.

However, habitat/ecosystems resulting from anthropogenic changes do not have precedence over identifiable ecological benefits (habitat/function), derived from modifying flow towards natural patterns.

Three major principles were adopted for the assessment:

- the natural diversity of habitats and biota within the river channel, riparian zone and the floodplain should be maintained
- the natural linkages between the river and the floodplain should be maintained
- the natural metabolic functioning of aquatic ecosystems should be maintained.

Two guiding principles on variability were adopted:

- elements of natural seasonality should be retained as far as possible, in the interests of conserving a niche for natural rather than invasive exotic species and in maintaining some natural functions for the river
- consistent and constant flow and water level regimes should be avoided as much as possible, because this is the reverse of the natural regime of the River Murray.

The scientific panel assessment included the following steps for each reach:

- assess current values and conditions
- identify threatening processes (not just flow)
- determine management options with expected environmental benefits
- set priorities on options from environmental perspective
- consider feasibility
- set overall priorities.

For each reach the panel identified:

- the different habitat types and current ecological condition
- priority ecological impacts
- causal factors (flow-related and others)
- broad operating principles to redress these
- specific management actions required

TABLE II.1 COMPOSITION OF RIVER MURRAY ENVIRONMENTAL FLOWS SCIENTIFIC PANEL

Area of expertise	Expert appointed	Organisation
geomorphology	Martin Thoms	Senior Lecturer, University of Canberra
river operations	Andy Close	MDBC
floodplain ecology	Terry Hillman	Murray–Darling Freshwater Research Centre
water quality and algae	Gary Jones	Principal Scientist, CSIRO Water Resources
macroinvertebrates	Phil Suter	Lecturer, Latrobe University, Albury/Wodonga campus
fish	John Koehn	Principal Scientist, Marine and Freshwater Resources Institute, Victoria
riparian vegetation and macrophytes	Jane Roberts	Senior Research Scientist, CSIRO Land and Water Resources

From the geomorphological perspective, the major tasks were to:

- identify major characteristics of flow regime to maintain restore ecological values
- assess impact of current operating regime, biodiversity and ecological processes
- identify changes in current management to improve ecological values
- set priorities on management actions according to predicted environmental benefits and assessment of ease of implementation.

Outcomes were classified in the following categories:

1. minor changes to water management with some environmental benefit specific operational options for meeting that management action
   - priorities for implementing operational options.
2. changes to water regimes with user impact but may be implementable
3. identify flow regime that meet environmental needs.

The draft report of the River Murray Environmental Flows Scientific Panel is still in preparation. A summary of the draft conclusion for the Wentworth to Wellington reach is given in the introduction of this report.

III ISSUES RAISED IN RAMSAR PLANNING PROCESS FOR THE LOWER LAKES AND COORONG

Bernice Cohen, Natural Resources Policy, DENR, South Australia

The close linkages between the briefs of the Barrages Environmental Flows Scientific Panel and the Ramsar planning process demand close coordination between the two activities. The following issues should be taken into account:

1 the need for a joint approach to issuing a paper on environmental flows from both MDBC and the Ramsar plan

Benefits include:

- avoiding duplication
- maximum exposure
- community acceptance
- consider the Ramsar plan as a vehicle for implementation, given its strong community focus and the requirements for Cabinet approval.

2 the need to promote a focus on the lakes, Coorong and estuary, so that this area is not seen to be a passive recipient of the results of decisions made upstream

The management issues to be taken into account include:

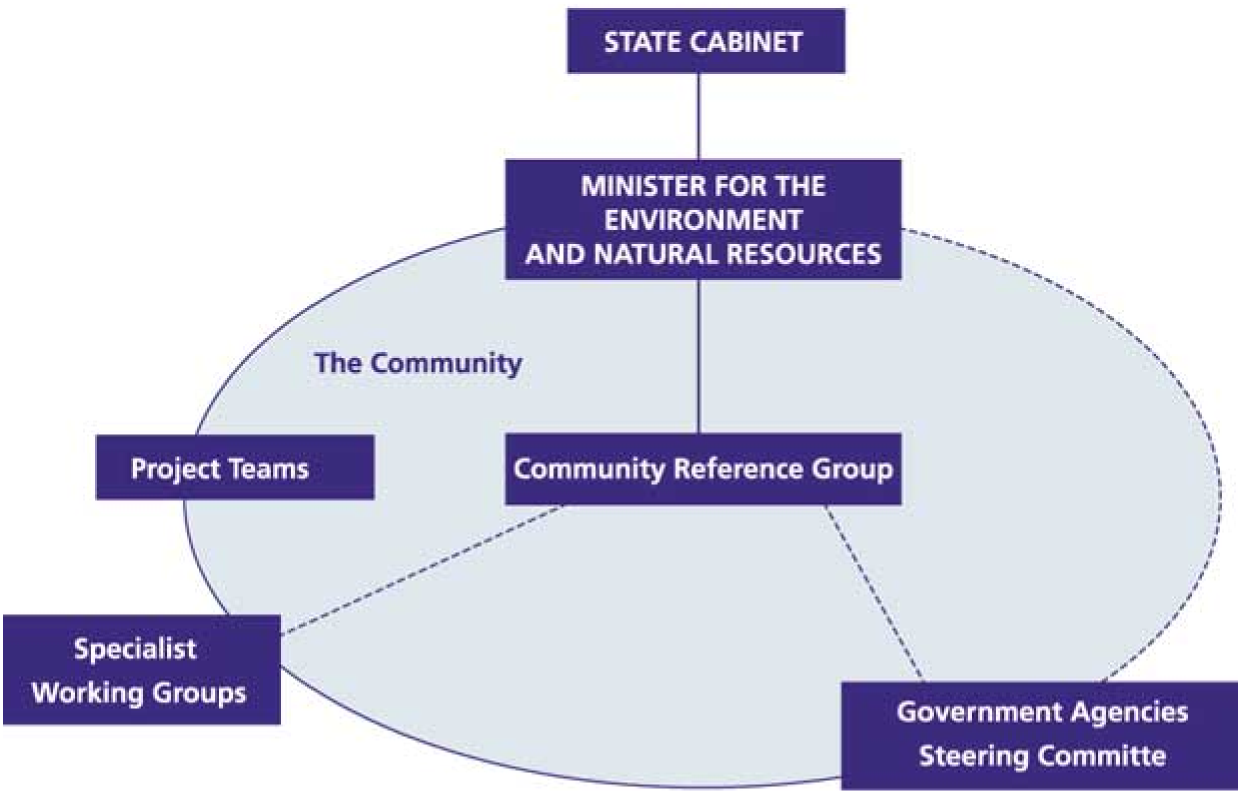
- interactions of flow management with other possible changes to the area (eg use; drainage scheme; climatic change)
- consideration of interactions with other users of the area
- identification of the constraints placed on management of the lower end of the Murray Darling system from decisions made upstream, and if necessary to influence these.

The following Ramsar discussion papers are in the process of production and circulation:

- waterbirds and wetland habitat conservation
- water quality in the Lower Lakes
- water management
- recreation, tourism and urban development
- Coorong and estuary issues
- Aboriginal issues.

The process for development of the Ramsar plan with extensive community involvement is shown in Figure III.1.

FIGURE III.1 RAMSAR PLANNING PROCESS



IV CONSTRAINTS AND CURRENT OPERATION STRATEGIES FOR THE BARRAGES AND LOWER LAKES

John Parsons, Regional Manager, Murray Mallee, SA Water

MANAGEMENT OF LOWER LAKES

The following historical points are relevant:

- the concept of barrages has been strongly supported by landowners along the lower reaches of the river and lakes since early days of settlement
- barrages were considered for Wellington to keep lower river reaches fresh, or at the Murray Mouth, keeping lakes Alexandrina and Albert fresh
- barrages would stabilise river levels, protect land from flooding and allow irrigation by gravitation rather than pumping
- in 1931 the River Murray Commission recommended that five barrages be constructed. Work commenced in 1935 and the barrages were completed in 1940.

Operational management

- the barrages and the Lower Lakes are managed by SA Water on behalf of the Murray–Darling Basin Commission, which sets the management policy for the Murray–Darling Basin catchment area
- operation and management of the Lower Lakes is by the SA Water regional office in Murray Bridge.

Background

The following points are relevant to management of the barrages:

- approximately 270 km of river miles are influenced by barrages
- South Australia is heavily dependent on the River Murray for water (up to 90% in a dry year)
- Eyre Peninsula, Yorke Peninsula, Barossa, Onkaparinga are all reliant upon the lower reach, from Morgan downstream
- most pumping occurs in summer (when less water is in reservoirs).
- it is not possible to change the timing of pumping from the Murray to top up reservoirs
- 3000 ML/day is the summer entitlement flow in the River Murray (Table IV.1)

Barrage structures

- earthen embankments and concrete structures (incorporate sluice structures)
- Tauwitchere Barrage is the easiest to operate
- barrage operation is fairly broad on a day to day basis, only quick decisions need to be made in a storm event. Gates are opened 10-30 at a time.
- there are areas of hydraulic constraint between Tauwitchere and Goolwa, making it very hard to shift water in this area

Lake operation

- lake operation is dynamic to account for the wide variety in run-off volumes and patterns from the Murray–Darling catchment, and must allow maximum water in lakes and minimise high tide, can lose reasonable amount of water during process (up to 24 hrs)
- 2 m depth average of lakes
- north-eastern shores of lakes are subject to erosion at high water levels (0.85 m EL)
- high salinities occur in Lake Albert, to overcome this Lake Alexandrina's level is lowered to 0.65 m EL so that water flows out of Lake Albert and refills when Lake Alexandrina is higher. Problems and timing occur in this system at times of major tidal flows - also lowering Lake Albert for long periods may allow water inflow via groundwater (becoming increasingly saline)
- time periods are flexible between known flooding events - there is several weeks warning in advance for flood events in Victoria, up to 6-8 weeks for floods of 100 000 ML/day. As the flow gets closer there is more fine-tuning. Gate opening occurs by judgement depending on how drawn down the lakes are; closing of gates is generally gradual, but it can occur quickly.

Three main strategic considerations for management include:

- operating procedures
- operating constraints
- water quality (salinity).

Operating constraints

- water levels must be maintained above a minimum level of about EL 0.6 m for irrigation activities around the lakes and reclaimed swamps up to Mannum. Levels down to EL 0.55 m can only be tolerated by irrigators for short periods of time (days)
- lake levels above EL 0.85 m cause fresh water to be spilled over the low level island causeways, which together with the barrages acts to exclude sea water, and cause inundation of shallow areas adjacent to the lakes (eg Waltowa Swamp - adjacent to Lake Albert)

- land owners consider that high water levels aggravate foreshore erosion problems – thus for the purposes of irrigation, recreation, water supply and bank stability, operating rules aim to maintain water levels within a narrow band of EL 0.6 m to EL 0.85 m, a range of 0.25 m.

Salinity

Lake Albert salinity (measured at Meningie) ranges from 1300 to 2000 EC, but can range from 1800 EC to 3000 EC, following extended periods of low river flow (note salinity of sea water is 50,000 EC). Productivity of irrigated crops and pastures is significantly reduced by salinities above 1500 EC.

Lake Alexandrina (measured at Milang) ranges from 400 EC to 1200 EC – generally reflecting salinity levels of the River Murray.

Groundwater surrounding the lakes has naturally high concentrations of salt in the range of 10 000 to 20 000 EC. A slight natural gradient of this saline groundwater towards the lakes causes seepage and increasing salinity. Reductions in water levels below EL 0.65 m can greatly increase saline seepage, therefore raising/lowering cycles aimed at improving water quality are generally limited to the range EL 0.65 m to EL 0.85 m.

GENERAL OPERATING PROCEDURES

- The main operating target for the Lower Lakes is to maintain an average water level of EL 0.75 m, or a height of 0.75 m above mean sea level.
- Sufficient barrage gates are opened or closed to maintain this level. As River Murray flow increases, more gates are opened to maintain EL 0.75 m. Sometimes high tides and strong winds, often in combination, tend to reverse flow through the barrages, with the result that a slug of sea water could enter Lake Alexandrina. When these conditions are forecast, barrage attendants close gates until conditions abate. Ease of operation, wind and tide conditions influence which barrages are opened and closed.
- When River Murray flows are limited to ‘entitlement’ flows over summer, evaporation from the lakes exceeds inflow and lake level drops, typically by 0.25 m. Therefore, the lakes are surcharged to EL 0.85 m at the beginning of summer, in preparation for evaporation dropping the level to a minimum of about EL 0.6 m in autumn. The barrages remain closed during this period.

In years of above entitlement flow, with sustained flow at Lock 1 of more than 15 000 ML/d, opportunistic cycles of raising and lowering lake water levels are employed. This allows the more saline water in Lake Albert to be drawn out to sea (via Lake Alexandrina) during the lowering phase, and to be replaced with fresher, lower salinity river water, with subsequent mixing resulting in lower lake salinity.

Management issues

The following factors should be taken into account:

- November 1991 the Fish Management Plan for the Murray–Darling Basin was adopted
- professional fishers are given advance notice of the barrage opening and can take the freshwater fish that are flushed out
- ad hoc management changes have been undertaken on a minor scale in consultation with professional fishers
- in 1993–94 the commission approved funding to develop options for the management of the Lower Lakes and barrages to enhance environmental values which particularly related to fish management, and competing demands of water supply for recreation, fisheries and the environmental requirements of the area.

A trial in lake operation in 1992–93 was conducted as follows:

- one raising/lowering cycle to improve water quality, with one more cycle at high river
- 5000 GL of water was passed into the Lower Lakes during the high river
- 400 barrage gates were opened at the peak of the flow
- at the end of the period of high flow, salinity in the lakes was expected to be 350 EC and 1300 EC in the Lakes Alexandrina and Albert respectively. Salinity was in fact 800 EC and 1700 EC.

TABLE IV.1 FLOW TO SOUTH AUSTRALIA

		% OF YEARS WHEN FLOW EXCEEDED			
DAILY FLOW* (ML/D)	MONTHLY FLOW* (GL/MONTH)	NATURAL	CURRENT	CURRENT & OPTION 1	CURRENT & OPTION 2
3000	91.5	100	100	100	100
5000	152.5	100	100	100	100
10000	305	100	96	100	100
15000	458	100	73	99	100
20000	610	99	63	74	98
25000	763	97	54	66	100
30000	915	95	49	56	74
35000	4220	89	39	46	56
40000	1373	83	33	41	50
45000	1525	75	29	34	45
50000	1678	64	25	30	41
60000	1830	56	20	27	34
65000	4938	51	15	22	30
70000	2135	46	13	18	26
75000	2288	43	13	14	20
80000	2440	39	11	13	16
85000	2593	32	10	11	14
90000	2745	32	10	11	13
95000	2898	31	9	10	11
100000	3050	26	8	10	11
110000	3355	22	5	7	9
120000	3660	18	5	5	7
130000	3965	15	4	5	5
140000	4270	10	4	4	4
150000	4575	7	4	4	4
200000	6100	2	1	1	2
250000	7625	1	1	1	1
300000	9750	0	0	0	0

* Based on 96 years of flow data (1891-1987)

1 Current & Option = adding 6 500 ML/d to Peak Flow from Lake Victoria

2 Current & Option = adding 16 000 ML/d to Peak Flow from Lake Victoria.

TABLE IV.2 PARTICULARS OF BARRAGES (SOURCE: SA WATER)

	GOOLWA CHANNEL BARRAGE	MUNDOO BARRAGE	BOUNDARY CREEK BARRAGE	EWE ISLAND BARRAGE	TAUWITCHERE BARRAGE
Total length of Barrage	632 m	792 m	244 m	2271 m	3658 m
Number of Openings	128	26	6	111	322
Length of each opening	3.58 m	3.58 m	3.58 m	3.86 m	3.86 m
Type of Opening	Stop Logs	Stop Logs	Stop Logs	Radial Gates	Radial Gates
Size of Lock	30.48x6.10 m		–	–	13.72x3.81 m
Navigable Pass	20.65 m	–	–	–	–
Timber Piles	4 770 No.	–	–	–	–
Steel Piping	1 050 c. m	–	–	–	–
Concrete	13 550 c. m	2 254 c. m	343 c. m	3 223 c. m	9 752 c. m
Steel Reinforcement	770 tons	106 tons	23 tons	210 tons	567 tons
Stone Protection	20 443 c. m	7 199 c. m	8 122 c. m	35 205 c. m	
Jarrah	511 c. m (216 581 sup. ft.)	48 c. m (20 508 sup, ft.)	107 c. m (45 485 sup. ft.)	225 c. m (95 484 sup.ft.)	658 c. m (278 772 sup.ft.)
Excavation	49 925 c. m	2 163 c. m	467 c. m	4 010 c. m	14 620 c. m
Earth Embankments	–	13 340 c. m	3 917 c. m	36 510 c. m	51 684 c. m
Cost	$750 000	$131 150	$21 250	$174 960	$418 700

V CONSTRAINTS AND OPERATING STRATEGIES FOR THE RIVER MURRAY SYSTEM

Andy Close, Murray–Darling Basin Commission

The following factors are relevant to the discussion:

- allocations made in the past were high to encourage use of water and nor all water allocated was used
- with recent increases in the value of water and pressure to increase production, the rate of use of these allocations has escalated
- this trend of increasing diversions led to the cap applied by the MDBC, to halt further diversions at the level of 93–94 diversions while the detail of usage is compared to this designated level
- current flows are directly affected by the rate and pattern of diversions
- changes to flow regimes will have a direct affect on water users
- approximately 30-40% of mean natural flows still occur, but this figure includes large flood events. Only approximately 20% of median natural flows still occur
- only management of lake levels at the barrages (± 0.1 m) can be overtaken by major wind-generated fluctuations (eg 0.5 m in 24 hours)
- the large evaporative loss from the large surface area of the lakes masks the effect of evapotranspiration by plants
- the greatest potential for additional flows at the barrages is from reducing upstream demand.

Hydrographs and diagrams of changes to flow patterns have been included in the hydrology section.

VI IMPACTS OF THE BARRAGES ON SEDIMENTATION INTERACTIONS BETWEEN THE LOWER LAKES AND THE COORONG

Prudence Tucker

Prudence Tucker presented results from her Honours thesis (Tucker 1996).

KEY RESEARCH FINDINGS (SUMMARY)

- when the barrages at the Murray Mouth are open, sediments from Lake Alexandrina are transported into the Coorong Northern Lagoon (Figure VI.1)
- the barrages induce the selective transport of fine sediments into the Northern Lagoon (Figure VI.2)
- these suspended sediments have a unique particle size distribution such that their redistribution can be traced throughout the system (Figure VI.3)
- the selective transport of sediments into the lagoon is paralleled by the preferential transport (Figure VI.4)
- suspended Lake Alexandrina sediments are being deposited in the system, thus the effects are accumulative, influencing the condition of the Coorong for an unknown period of time.
- in line with the selective transport of fine sediments into the lagoon system there is a process of preferential nutrient transport into the system, with 90 000 times the concentration of phosphorus associated with the Lake Alexandrina suspended sediments as opposed to phosphorus in solution
- combined with flow data obtained from the River Murray Flow model, for 21 July 1996 there was an estimated 239 kg of phosphorus being transported into the Coorong Lagoon.

POTENTIAL IMPACT OF BARRAGE OPERATION ON THE COORONG NORTHERN LAGOON

- the release of freshwater into the Coorong occurs most frequently during the winter months. It is during this period that nutrient and sediment loads in the river system are highest, eventually impacting on the Lower Lakes
- low river water quality compounds the low chemical quality evident in Lake Alexandrina towards the end of summer
- high wind speeds and winter water levels in the lake promote shoreline erosion and sediment resuspension processes within the system
- turbulent conditions prevail during winter, leading to a further decline in the chemical condition of Lake Alexandrina with the release of nutrients from the pore waters of the sediments
- the selective process of fine sediment transport between Lake Alexandrina and the Coorong is associated with the transport of high concentrations of total phosphorus
- the barrages effectively act as a point source of contaminants to the lagoon
- short-term benefits of suspended sediments in the system include lower light penetration for the protection of microfauna and juvenile fish from predators at higher trophic levels. However, it may be affecting the intricate ecological balance within the system
- the physical impacts of suspended sediments may result in changes to the food chains of the system by inhibiting the growth of aquatic plants and benthic flora and fauna in a blanketing/smothering process
- the expansion of the calcareous benthic faunal Bryozoa populations (tenfold since 1988) indicates that the ecological balance in the Coorong Lagoon is being affected, possibly by the influx of nutrients associated with the suspended sediments
- the calcareous fauna not only provide evidence for changes taking place in the ecosystem but have become potential sites of sediment deposition
- whilst widespread algal outbreaks are not frequent in the Northern Lagoon, nutrients are present. However, the dynamic nature of the system promotes dispersal of any manifestation
- the fact that evidence of deterioration in the water quality is not immediately obvious leads to delays in management response. Without management the problem is compounded as fine sediments continue to accumulate.

MANAGEMENT TO MINIMISE IMPACTS OF THE BARRAGES ON THE ECOLOGY OF THE COORONG NORTHERN LAGOON

The problem must be addressed at both regional and local levels.

Short-term objective

- change operation of the barrages to reduce the immediate impact of the suspended sediments and associated nutrients on the Coorong ecosystem, to promote a flow mimicking natural conditions.

This approach may involve

- opening the barrage during falling tidal conditions in winter

- releasing some water from Lake Alexandrina during the summer months when sediment and nutrient loads are low

Medium-term objective

- to establish predictive models for identifying suspended sediment transport and redistribution patterns and to monitor the transport of suspended sediments into the Northern Lagoon of the Coorong

- this research could then be used as a basis for the implementation of changes to barrage operation

Long-term objective

- local and regional catchment management to reduce the external sediment and nutrient loading to Lake Alexandrina
- additional research on dynamic processes is required to design an ecosystem approach, which is strongly recommended for management of estuarine systems (Imperial and Hennessey 1996).

TABLE VI.1 DATA HIGHLIGHTING THE CHANGING CONDITION OF THE SURFACE WATERS OF THE PELICAN POINT CHANNEL

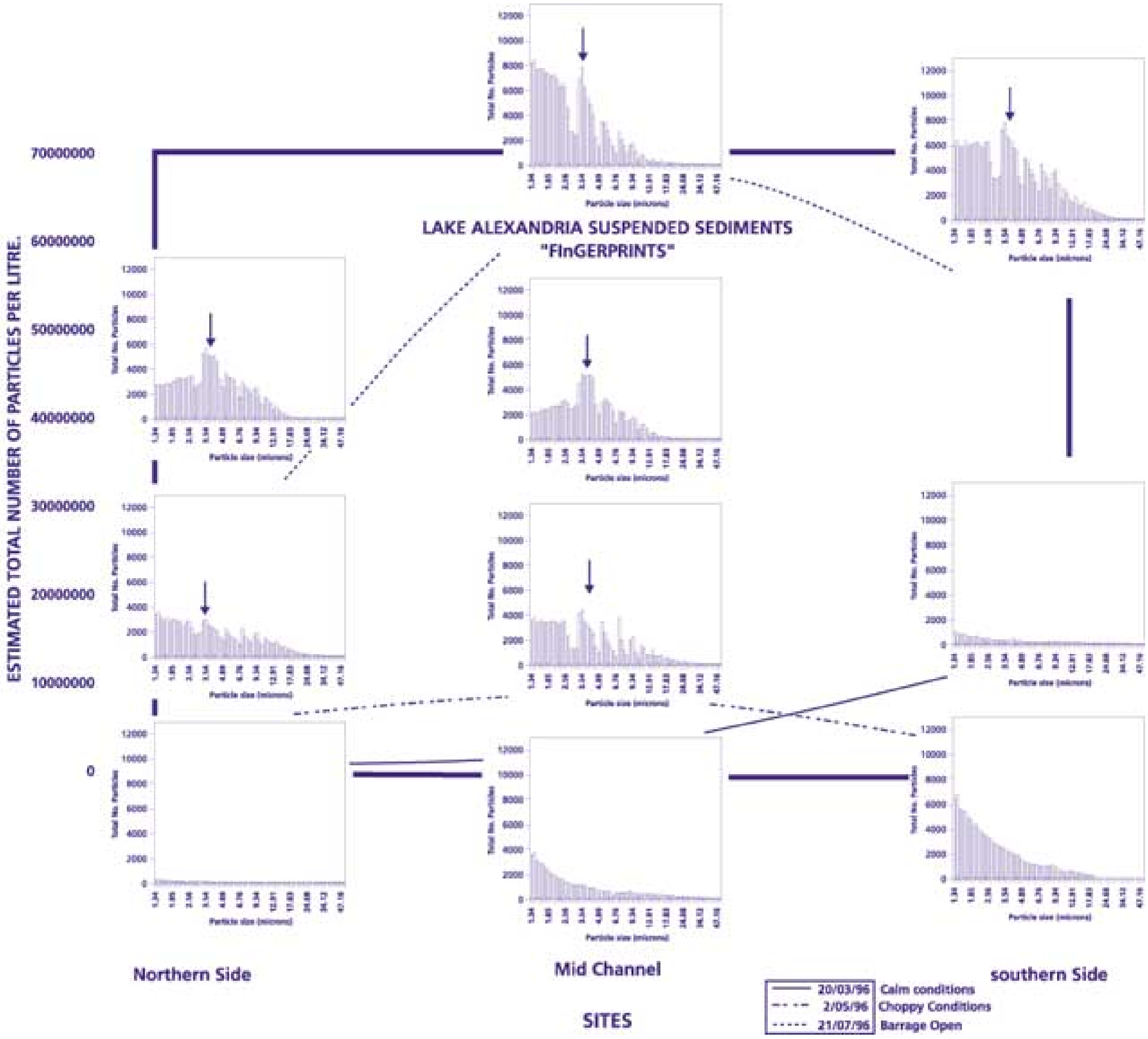


TABLE VI.2 PERCENTAGE OF SILT-CLAY RELATIVE TO SAND, LAKE ALEXANDRINA SUBSTRATE

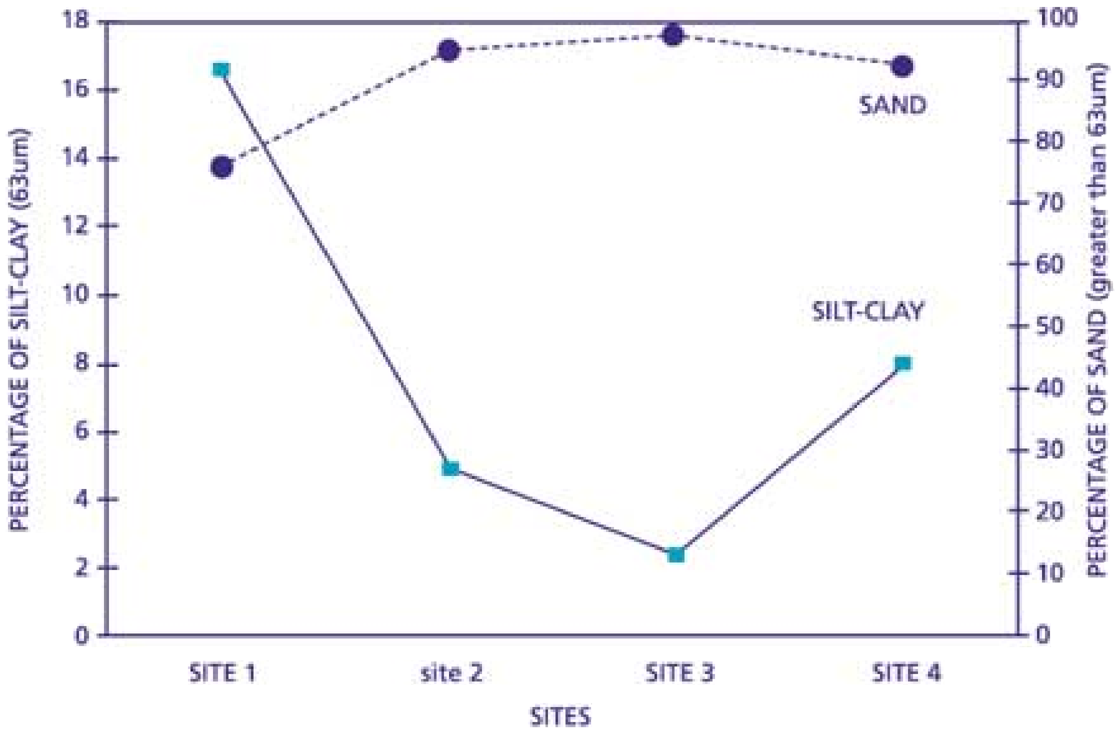


TABLE VI.3 PARTICLE SIZE DISTRIBUTION OF FINE DEPOSITED SEDIMENT

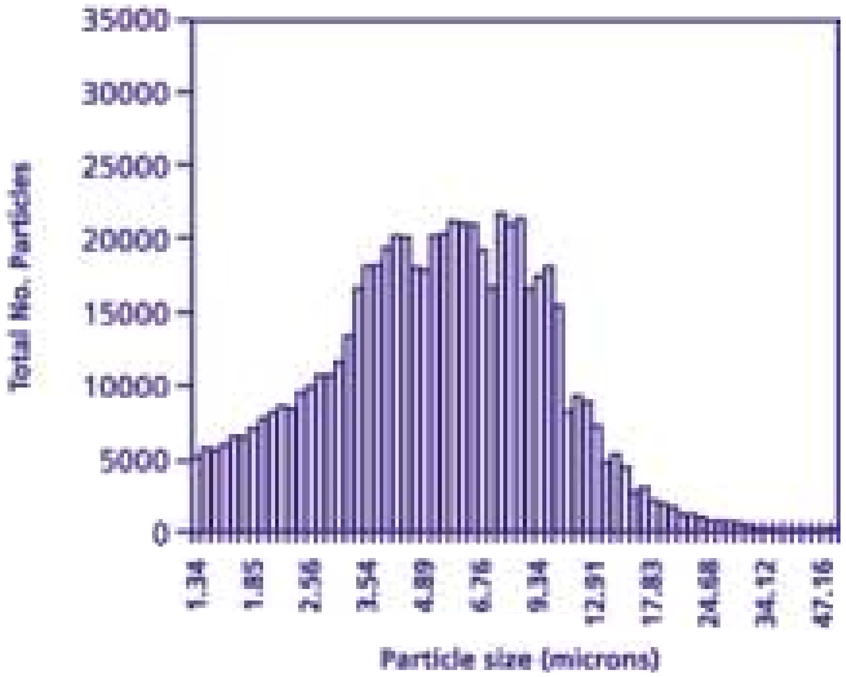


TABLE VI.4 SOUTH-EASTERLY EXTENT OF DEPOSITED LAKE ALEXANDRINA SUSPENDED SEDIMENTS, EXTRAPOLATED FROM PRESENCE OF 'FINGERPRINT'

VII ISSUES IN FISH MANAGEMENT AND PROPOSALS FOR CHANGED MANAGEMENT OF THE BARRAGES

Anne Jensen, Manager Wetland Program, DENR, South Australia

The following summary has been prepared from material supplied by Bryan Pierce of SARDI.

The barrages fish passage proposal put forward by SARDI seeks to increase the movement of fish between the reduced estuary and the freshwater lakes, in the zone of the former large natural estuary. The proposal has two recommendations:

- to automate barrage gates to allow opening at key times for fish migration and flow management, and closure at the majority of non-use times
- to revise lock activity at fish migratory times across season.

SARDI research findings

The research findings listed below demonstrate the potential for fish movement through automated gates on the barrages:

- trials over 12 months have demonstrated mechanisms to entice mulloway, black bream, greenback flounder and mullet to migrate into Lake Alexandrina in very large numbers
- mulloway move into the Coorong annually, using it as grow-out habitat, with numbers proportional to amount of useful habitat
- black bream and greenback flounder reproduce most successfully in response to natural flooding flows, and automation can be used to mimic these conditions
- estuarine species are highly mobile, following the brackish water zone, so automation would maximise opportunities to move with this zone
- most estuarine species move at night and at the top of the tidal cycle
- attractant flows as minimal as 1200-1500 litres will bring estuarine species into position below radial gates
- opening of key gates for 20-30 minutes at the top of the tidal cycle will provide sufficient time and conditions for fish passage
- location of the opening at the bottom of the gates suits most estuarine species which avoid the surface
- minimal head differences between fresh and marine maintains low enough flow velocities for fish passage
- some head difference is required to keep marine waters from invading
- mulloway have been tracked living and growing in freshwater for at least three weeks
- black bream have been recorded living and growing in freshwater for one year
- mulloway and black bream prey on european carp.

Note: Fish are known to return to the estuary when the gates are opened, by looping back through the barrage. Work by Hall in the 1980s demonstrated the enhancement of breeding by mulloway with increased freshwater input. Fish condition has been demonstrated to improve when provided with extra habitat by the lakes – at present those staying in the Coorong are in poorer condition than those which get into the lakes.

TABLE VII.1 ESTIMATED COSTS OF AUTOMATED BARRAGE GATES

BARRAGE	GATES TO BE AUTOMATED	TYPE*	COST
Goolwa	20 (128)	B	$240 000
Mundoo	15 (26)	B	$180 000
Boundary Creek	5 (6)	B	$60 000
Ewe Island	30 (111)	A	$135 000
Tauwitchere	60 (322)	A	$270 000
total	130 (593)		$885 000

* cost estimates:
type A gate: automate existing radial gates @ $4500
type B gate: replace logs with radial gates, then automate @ $12 000 each.

Estimate of value of lower River Murray fishery

The following estimated values were reported from a contingent valuation by Baker and Pierce (1997):

recreational sector	\$9.6 m
non-consumptive sector*	\$45.2 m
commercial sector	\$1.1 m
Total	**\$55.9 m**

* environmental concerns/preservation value

Present value of estimated net benefits (1996–97 prices)

commercial fishing benefits only	\$115.9 m
all benefits	\$186.1 m
benefit: cost ratio	74.38

Other issues

The following issues must also be taken into account in determining the operation of automated gates:

- saltwater management, quantify saltwater intrusion and options to minimise impacts, eg deepwater drainage and benthic dams
- optimise flow management to benefit recruitment of estuarine species
- monitoring, including radio tracking to determine behavioural needs
- quantify economic benefits to every sector
- examine needs of non-commercial species, eg congolli and common galaxias.

VIII INTERACTIONS WITH COORONG RESERVE MANAGEMENT ISSUES

Phil Hollow, Coorong District Ranger, DENR

The following issues were highlighted for consideration:

- fox control in the Coorong National Park becomes harder when water levels are low, there is movement between the Peninsula and the area of land between Lake Albert and Lake Alexandrina
- the movement of the Murray Mouth is important in ownership, it has moved significantly in the past 8–10 years, and therefore boundaries change
- tourist impacts are high which also depend on the water level, especially in the Southern Lagoon.

IX ON SITE TALK TO EXPERT PANEL

Gary Hera-Singh, DENR, South Australia

Transcript

You have had a bit of a look around today. Let's have a closer look at some of the areas/issues that have been created over time by the construction of the barrages, and eventually decide if we want to make these problems worse or seek ways to lessen the impact and actually give nature back an environment that will suit our native aquatic and avifauna.

This once magnificent estuary has been reduced by roughly 90%. I would like to suggest our birds and fish have been roughly diminished by about the same amount. Most of the time this area is left with two distinct water environments ie fresh and saltwater. There is another important water regime ie brackish that either does not exist for long periods or continues at about 10% of its original area. This brackish area has increased in recent years with the cooperation from SA Water operations personnel by simple barrage operations to maximise the area of brackish water eg Goolwa to Tauwitchere. The fishing industry initiative has been to maximise the use of water in the estuary region before it leaves to enter the sea.

Clearly, right around the world estuary systems are the most productive area for aquatic fauna and support very high densities of birds.

The Fish Passage Proposal put forward by the fishing industry and SARDI addresses the massive decline in native fish stocks of this region. The benefits are far more widespread. The automation of some gates on all barrage structures will allow for:

a) Improved usage of seldom used or redundant Mundoo and Boundary Creek barrages;

b) Increase the food chain in the estuary region for birds and fish by allowing small fish and nutrients through to the tidal flats of the Coorong;

c) The hydraulically driven, computer operated system can assist and be very useful to SA Water / MDBC, as an extra management tool to alleviate salt water intrusions that are natural and sometimes accidental;

d) Transparency of the barrage structure for fish, particularly during lunar phases.

The Fish Passage Proposal is a joint fishing industry and SARDI idea. The details and fine scale needed to make this a successful world first fish passage will not be released until the fishing industry is locked into a joint management group program and operate the automated gates to the benefit of the community.

We can talk more generally about the proposal later. There are a couple of issues I want to bring to the surface before I go:

1 The proposed levee bank across the islands from Boundary Creek to Tauwitchere Island

If a levee is built this will be another ecological disaster. Levee banks right up to Lock 1 assist anything and everything that is not native. Carp habitats instantly come to mind. Much of our river and lake fauna are dynamic and opportunistic.

A policy of no levee bank will maintain the biodiversity that is sadly lacking in this region. The barrages have provided this as a clear cut fresh – salt water regime. Another levee is no different.

A levee bank will turn the islands into a massive reed bed [similar to those at Pelican Point-very extensive]– causing further degradation natural habitat. The area from Pelican Point to the Murray Mouth provides habitat for about 52 bird species in spring and summer.

The creeks that flow over these islands with strong northerly winds allow freshwater to wash over the islands creating a minor thoroughfare for small fish (congolli and galaxias) and turtles to cross the islands.

These creeks also provide important nutrient sources for various aquatic invertebrates in the Coorong region (again tucker for birds and fish).

Importantly look at the islands that are surrounded by freshwater. Yep- they are engulfed in freshwater reeds, these islands will end in the same way. Further denying waders and waterfowl of areas that are continually in decline.

2 Lake levels

The maintenance of high lake levels ie 74 cm AHD and higher have caused ecological disaster year after year. In the spring of '92 & '93 hundreds of addled swan eggs were washed off their nests because of extremely high lake levels coupled with moderate to high River Murray flows.

Maintenance of high lake levels is having a huge impact, continually recharging the local aquifers. There will eventually be massive land salinisation problems around the lakes because of the rising water table bringing salt closer to the surface.

Apart from the Langhorne Creek area. Another 20-30 years then what, a saline Lake Albert (no algal blooms) then Alexandrina.

There should be far greater flexibility in lake levels. Summer time levels could be half of what they are now. Then produce the naturally high levels of winter.