WATER FOR A HEALTHY COUNTRY

National Research Flagship

COORONG, LOWER LAKES AND MURRAY MOUTH
Knowledge gaps and knowledge needs for delivering better ecological outcomes

Sébastien Lamontagne, Kerryn McEwan, Ian Webster, Phillip Ford,
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For further information contact:

Ph: 02 6246 4565

Fax: 02 6246 4564

Email: leane.regan@csiro.au

www.csiro.au

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Foreword

The Coorong, Lower Lakes and Murray Mouth Region is a unique area of the Murray basin, with internationally recognised ecosystems, important indigenous heritage, commercial and recreational fishing, water sports and a growing tourism sector. However, some of the renowned characteristics of this area have already changed as a result of irrigation development in the Murray Basin and the installation of weirs at the mouth of the river.

The Coorong area is a microcosm of the increasing social, economic and environmental demands being placed on the River Murray. The increasing profile of such issues nationally has led to the formation of a national research Flagship, Water for a Healthy Country, which focuses on water, its use and its values.

While it is extremely unlikely that the Coorong and environment will be returned to its original state, there are some warning signs that management will need to change if we are to conserve some of the key ecological, economic and social values. In particular, prolonged mouth closure will affect water level, salinity and oxygen levels in the Coorong. In turn, these will impact on the fish and bird populations, tourism, and indigenous values. While regional management such as barrage operation will be important, further improvements will only be achievable through greater upstream flows and hence changes in the current use of the water. Supplying information and tools to help support decisions that underlie the competing demands on the water and the combination of regional and basin-wide management required to address them is the basis of the River Murray node of Water for a Healthy Country.

Sarah Ryan

Coordinator, River Murray Region
CSIRO Water for a Healthy Country

This report describes some of the outcomes of the first stage of the Coorong, Lower Lakes and Murray Mouth Project in the River Murray Theme of Water for a Healthy Country. Activities during this first stage included:

- a review of the water balance, hydrodynamics and biogeochemistry of this area;
- listing of other current research activities; and
- data collation and determination of knowledge gaps.

An important driver for this report is the Living Murray and SA Environmental Flow Strategies, and the Coorong, Lake Alexandrina and Lake Albert Ramsar Management Plan, which will need an understanding of the water requirements for icon areas such as the Coorong. While an understanding of the biophysical system is crucial for this, it is recognised that the reviews have not been able to cover all facets of the knowledge required, including more detailed ecological and socioeconomic aspects. At the time of the report, a Knowledge Partnership between the community, CSIRO and other research providers was being discussed as a framework for addressing knowledge gaps for the Living Murray, including those missed by the current reviews.

This report will provide input to future collaborative work programs involving the best expertise in the universities, state and commonwealth agencies. Only by using the best expertise available and having a well-considered research program will the management of such complex systems truly address all of the competing values.

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Abbreviations

AHD	Australian height datum
CFMI	Computational Fluid Mechanics International
CLLAMM	Coorong, Lower Lakes and Murray Mouth
DEH	Department for Environment and Heritage
dS	deciseimens
DWLBC	Department of Water, Land and Biodiversity Conservation
EC	electrical conductivity
EMLR	Eastern Mt Lofty Ranges
EPA	Environment Protection Authority
LOICZ	Land-Ocean Interactions in the Coastal Zone
MDBC	Murray-Darling Basin Commission
MOI	mouth opening index
RMCWMB	River Murray Catchment Water Management Board
SARDI	South Australian Research and Development Institute
INRM	Integrated Natural Resource Management
USE	Upper South East
USED	Upper South East Drainage
USEDSFMP	Upper South East Dryland Salinity and Flood Management Plan

1. Aim of this report

The aim of this report is to summarise the authors' knowledge of the biophysical processes and the current management goals for the Coorong, Lower Lakes and Murray Mouth (CLLAMM) area of the River Murray. This was the first step in the development of a research program for CSIRO's Water for a Healthy Country flagship – River Murray Theme, which has the CLLAMM as a key component of the overall system. In addition to reviewing the existing literature, a strong emphasis was given to interactions with the numerous stakeholders, managers and other research providers working in the area. This was done to ensure that the information would be up-to-date and that our future research efforts would address existing needs in collaboration with other research providers. An attempt was made to frame the existing knowledge into a 'system' model, where the management goals were related to the physical driving mechanisms in the system (e.g. river flow) and the levers available to manage them (e.g. barrage releases). In more detail, this report covers:

- the environmental challenges and actions governments and communities already have in place to address them;
- the physical and practical constraints facing managers in influencing water flows in the region;
- an overview of the existing scientific knowledge about how the ecosystems of the region work;
- a summary of the knowledge gaps that if filled would best meet the needs of water managers; and
- the design of a technically sound research project addressing those knowledge needs.

In particular we want to promote discussion and test our conclusions with:

- technical agencies with responsibilities for managing and monitoring the region and environmental flows in the River Murray;
- communities with strong interests in natural resource management issues within the Lower Lakes and Coorong, and the River Murray generally;
- scientists working in the area; and
- Water for a Healthy Country Flagship partners.

We will be arranging opportunities to discuss this report with these people. Others are welcome to send comments via the webpage at <http://www.cmis.csiro.au/healthycountry/>.

2. Challenges for the CLLAMM

GEOGRAPHY

After its long journey across south-eastern Australia, the River Murray culminates in a series of lakes and lagoons before entering the sea. Initially it runs into Lake Alexandrina and Lake Albert (the Lower Lakes). Water from Lake Alexandrina then drains through five channels leading either to the Murray Mouth and Southern Ocean, or into the Coorong, a 2–3 km wide lagoon system that parallels the coastline to the east for approximately 100 km. The Coorong is divided into two lagoons, the Northern and Southern Lagoons (see Figure 1).

The Coorong lagoons and Lower Lakes support a variety of wetlands with hypersaline, estuarine and freshwater habitats, and a high biodiversity. The area is of national and international conservation status, especially as a habitat for birds. It is listed as a Ramsar Wetland and is protected as a national park. It also supports a commercial fishing industry, provides stock and domestic water, is a popular recreational area and is culturally significant for the Ngarrindjeri peoples.

In the 1930s, barrages were constructed across each of the five channels that connect Lake Alexandrina with the Coorong and ocean. The barrages prevent seawater from entering the Lower Lakes and Murray and maintain higher water levels in the naturally shallow lakes. The barrages:

- reduce salinity levels in the lower Murray;
- stabilise river levels in the Lower Lakes to provide water for irrigation as well as for pumping to regional communities; and
- concentrate flows to the ocean over a small area so that a channel for navigation is scoured during low flows.

A CHANGING ENVIRONMENT

The amount of water flowing through the Murray Mouth has decreased dramatically since the Murray–Darling Basin's rivers were regulated and the barrages built. Increases in river water use over the last 70 to 80 years, principally due to irrigation diversions and the construction of off-stream storages in the upper parts of the catchment, have reduced the volume and timing of water flowing down the river and has reduced the frequency, duration and timing of flooding. In addition, land use change and rising groundwater levels due to drainage from irrigation areas have resulted in increased inflows of saline groundwater to the river and changes in water quality. These changes have impacted on the Coorong, Lower Lakes and Murray Mouth environment. Recent studies in the CLLAMM area show that reduced flows due to upstream abstraction and the alteration of the natural flow regime by the presence of weirs and barrages has reduced flows to such an extent that, in a typical year, flow to the sea through the Murray Mouth is only 27% of the natural median flow. This has caused marine sand to build up inside the Murray Mouth so that it is now at a much greater risk of:

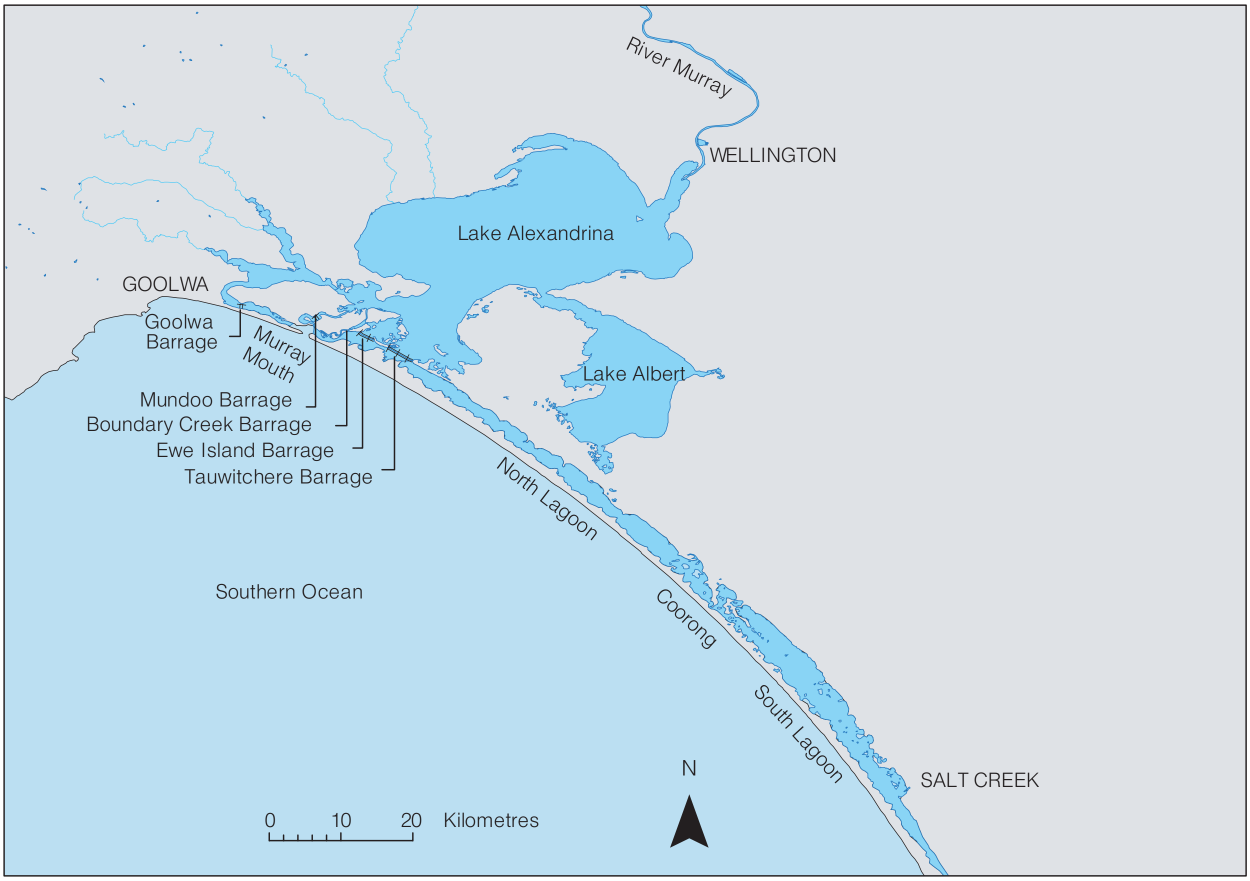
- completely closing—this has occurred only twice in recorded history, in 1981 and 2003;
- changes in the flow regime resulting in the loss of spawning cues for some native fish;
- restriction of fish migration—closure of the river mouth has impaired fish migration between the ocean and the estuary;
- erosion of the shores of the lakes due to relatively constant and unnaturally high water levels that may be contributing to excessive sediment and nutrients entering the Lower Lakes;

- abrupt changes in water levels that degrade the habitat for migratory birds which are protected under international agreements; and
- increased nutrients and the change to a freshwater habitat in the Lower Lakes to favour blooms of toxic blue-green algal species.

Overall this has resulted in:

- a substantial decline in the catch rates and economic value of the commercial fisheries;
- a reduction in the diversity of aquatic plant life through changes in salinity levels, low flows, static water levels and high turbidity as well as floodplain grazing;
- increased risk of towns and agricultural land around the Lower Lakes becoming inundated during floods if the Murray Mouth closes completely;
- the risk that water in the Coorong will become more saline if there is less river flow to freshen it;
- serious degadation of valuable habitat for native fish and waterbirds; and
- further compromising of the fishing industry, local tourism and recreation.

Figure 1. Location of the of the Murray Mouth, Coorong, Lower Lakes and Barrages.



GOVERNMENT AND COMMUNITY RESPONSES

A number of government agencies and organisations have environmental responsibilities in the region and no single policy deals with all aspects of environmental flows and riverine management. All have responded in recent years with a range of policies and programs addressing ecological needs of the region. Table 1 gives a summary of the organisations, the key policies and programs and the management decisions they lead. Detail of the more relevant policies follows.

Table 1. Operational process for management of the CLLAMM.

Operational responsibilities	Coordinating bodies	Relevant policies	Policy responsibilities
Barrage operating rules			
SA Water (on behalf of MDBC)	Lower River Murray Coordinating Committee	Living Murray (1) Draft SA Environmental Flows Strategy (2)	MDBC DWLBC
	Coorong and Lower Lakes Ramsar Taskforce	Coorong and Lakes Alexandrina and Albert Ramsar Management Plan (3) Water Allocation Plan for the River Murray (4)	DEH RMCWMB
USE drainage disposal rules			
USE Drainage Board	USE Steering Committee	USE Dryland Salinity and Flood Management Plan (5) Coorong and Lakes Alexandrina and Albert Ramsar Management Plan (3)	DWLBC DEH
Lakes and Coorong fish and fisheries			
PIRSA	–	National Parks Management Plan MDBC Native Fish strategy (1) Management Plan for the South Australian Lakes and Coorong Fishery (6)	DEH MDBC SARDI
Dredging			
SA Water (on behalf of MDBC)	Lower River Murray Coordinating Committee	Coorong and Lake Alexandrina and Lake Albert Ramsar Management Plan (3)	DEH
Wetland/ littoral zone			
RMCWMB	INRM committee	Coorong and Lakes Alexandrina and Albert Ramsar Plan (3) INRM Plan (7)	DEH RMCWMB
Water allocation			
RMCWMB	–	Eastern Mt. Lofty Ranges Water Allocation Plan (8)	RMCWMB
Land use impacts on water quality			
–	–	(9)	EPA & councils

1. The Living Murray

The Living Murray is a joint program between the Commonwealth and state governments designed to create a healthy working river. Large irrigation and other diversions have caused environmental degradation of waterways by the need to extract water from the river during summer and autumn. These extractions have reversed natural seasonal flow patterns. The program will identify an acceptable balance between the often competing values and uses of the river. It will include recovering water for environmental flows while maintaining production uses of river water.

This will be achieved through both structural measures (modifying dams, weirs and locks) and non-structural measures such as expanded water trading to promote more efficient use of existing water licences.

Under the Living Murray Initiative, the Murray-Darling Basin Ministerial Council committed to the First Step decision in November 2003 (MDBC 2003). The decision included $500 million to acquire an average of 500 GL in increased annual environmental flows over five years. The First Step decision addresses the declining health of the River Murray system and recognises that the health of the River Murray is important to maintain biodiversity and the health and economic success of the communities it supports. This water will be used in a managed way to achieve outcomes at six priority sites on the river: the river channel itself, the Chowilla Floodplain (SA/VIC border), the Hattah Lakes (VIC), Gunbower–Koondrook–Pericoota (VIC/NSW border), Barmah–Millewa (VIC/NSW border) and the Murray Mouth–Coorong and Lower Lakes.

Several Living Murray projects are underway in the Coorong, Lower Lakes and Murray Mouth area including:

- development of a management plan for the Coorong and Lower Lakes Ramsar wetlands;
- improvement in the operating procedures of the barrages, including exploring ways to allow fish to cross barrages and in designing fishways;
- testing fish ladders on the Tauwitchere barrages as part of the Native Fish Strategy for the Murray-Darling Basin 2003-2013 (MDBC 2004); the goal is to increase native fish populations to 60% of their estimated pre-European settlement levels over a 50-year period;
- investigations into sand movement inside the Murray Mouth examining how water flows can be better managed to improve the environment;
- water quality monitoring, lake shore revegetation, carp control and regional revegetation activities; and
- dredging of the Murray Mouth to prevent its closure.

2. South Australian Environmental Flow Strategy

The SA Environmental Flow Strategy, currently being prepared by the Department of Land, Water and Biodiversity Conservation, will set guiding principles for environmental flows. An interim operating strategy for CLLAMM would need to be developed to guide decisions (e.g. water releases at the barrages and upstream) for ecological purposes.

3. Coorong, and Lake Alexandrina and Lake Albert Ramsar Management Plan

The Coorong and Lower Lakes were declared a Wetland of International Importance in 1985 under the Ramsar Convention. The *Coorong, and Lake Alexandrina and Lake Albert Ramsar Management Plan* (SA DEH 2000) fulfills Australia's obligations under the Ramsar Convention to produce a plan for the management of the area. The initial plan does not address specific ecological outcomes with respect to flow and water quality requirements. A new plan for the area, which is required to be much more quantitative about its goals, management actions and outcomes, will be developed over the coming two years.

4. River Murray Water Allocation Plan

The Water Allocation Plan for the River Murray (RMCWMB 2002) provides for part of South Australia's entitlement flow to be taken from the Murray River to meet the needs of ecosystems. Water quality and timing needed by these ecosystems are:

- a minimum of 7025 GL coming into South Australia with low turbidity in late summer or early autumn in at least six out of every ten years;
- range and magnitude of flood flow to be sufficient to flush sand and keep open the Murray Mouth and to improve ecological health (minimum 600 GL/yr delivered over a consecutive 30-day period at 20 000 ML/d) to occur in late spring-early summer and should apply in six out of ten years;
- transfer of fresh water from the Lower Lakes to the Coorong to be maximised during periods of seasonal high flow from September to December and sudden fluctuations in salinity and water levels to be avoided;
- sufficient flows in the Lower Lakes to ensure that fish passage is not hindered, sediment is transported out of the Murray Mouth and fresh water enters the estuary (entitlement flows of at least 1850 GL/yr and median flows of 4850 GL/yr; median flow target is 7025 GL).

5. Upper South East (USE) Drainage Outfall

The Upper South East Dryland Salinity and Flood Management Plan (USEDSFMP) is an integrated approach to combating the rising water tables in the USE region of South Australia (Figure 2), while taking into account environmental, social and economic concerns of the area. The USE has 434 farmed enterprises, including large-scale sheep and beef cattle properties, cereal crop and pasture seed production. It is one of the largest areas in Australia with dryland salinity problems with approximately 438 279 ha at risk and the loss of productive land amounts to between $9 and $15 million every year. Also at risk are internationally significant wetlands and remnant vegetation in the region.

The plan has a number of components including construction of approximately 450 km of drains as part of a coordinated drainage scheme for the area to redirect excess surface water and groundwater. The drainage scheme has two outlets, including one that directly discharges into the southern lagoon of the Coorong at Salt Creek. The quality and quantity of the drainage discharge is being regularly monitored at the outlets to determine the impact of the drainage flow on the receiving waters. It is not clear what the impact of the releases will be on the Coorong, but they may be used to manage the salinity of the Southern Lagoon.

6. Management Plan for the South Australian Lakes and Coorong Fishery

The Coorong and Lower Lakes Fish Management plan, a state initiative being prepared by the South Australian Research and Development Institute (SARDI), will be completed around mid-2004. Focus of the plan is on management of fish stocks and it will address species requirements with regard to water flow rates, Murray Mouth status and the capacity for fish passage to optimise fish stocks.

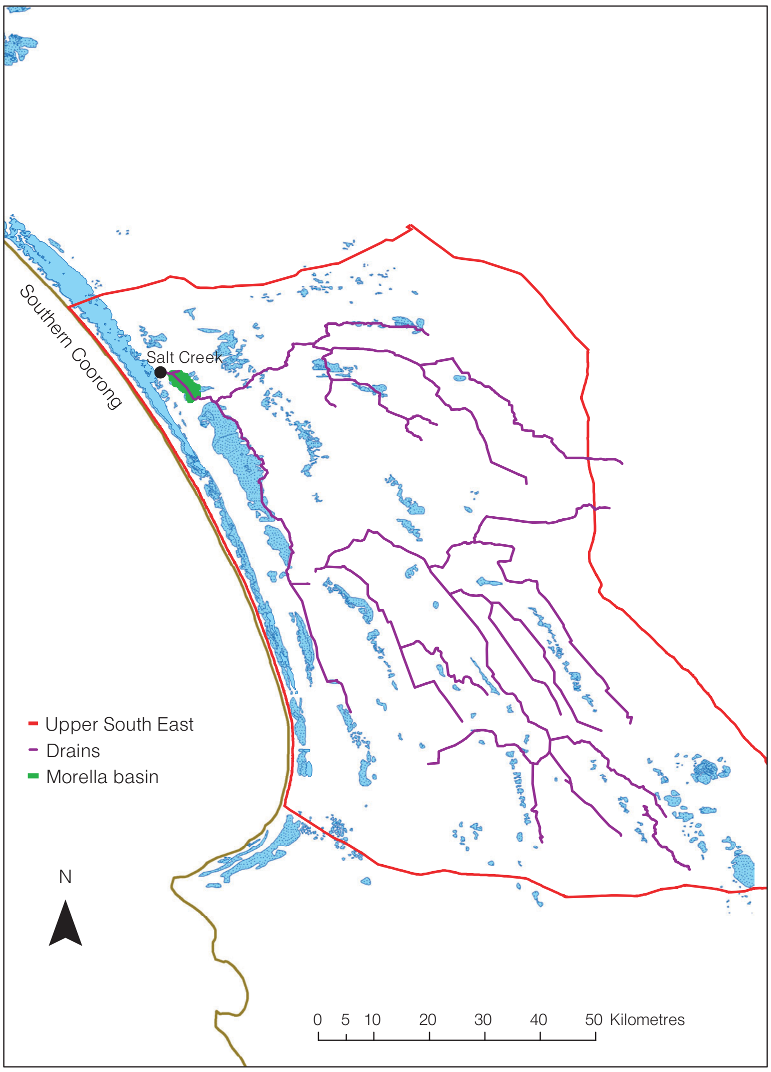
7. Integrated Natural Resource Management (INRM) Plan for the South Australian Murray-Darling Basin

The objective of the INRM plan is to integrate the strategies and actions defined through other planning processes so that natural resource outcomes are achieved in the most efficient way. The plan includes a strategy to improve the management of the CLLAMM and specifically addresses the provision of more water to achieve more natural flows to maintain, or improve, the ecology of the river and wetland environments and reduce likelihood of the Murray mouth closing. However, the plan has no control over the inflows from upstream states and from drainage from the South East. The plan acknowledges that water quality is an issue that requires more work in the area, including the CLLAMM.

8. Eastern Mount Lofty Ranges Water Allocation Plan

The catchments of the Eastern Mt Lofty Ranges (EMLR) are part of the Murray–Darling Basin system in South Australia, with several of the streams emptying directly into the Lower Lakes and the lower reaches of the River Murray. In recent years, increasing development has put pressure on EMLR water resources. The State Government, working in partnership with the River Murray Catchment Water Management Board, has moved to hold water use at current levels while it undertakes a detailed assessment of the EMLR water resource, current use and future trends. This is part of a long-term management proposal to develop a Water Allocation Plan for the resource under the provisions of the SA *Water Resources Act 1997*.

Figure 2. Location of the USE region, drainage scheme and discharge to Coorong at Salt Creek.



9. Other regulatory considerations

The CLLAMM area is located across two district councils, Coorong and Alexandrina. The council boundaries dissect Lake Alexandrina down the middle and meet at the Murray Mouth in an 'ambulatory boundary'. The councils are experiencing increased development pressure from demand for waterside residential properties and increased demand for recreational opportunities, particularly for Hindmarsh Island since the completion of the bridge connecting it to the mainland. As the island is included in the CLAMM Ramsar area development pressures will require clear direction to ensure that the Ramsar values are protected.

SUMMARISED MANAGEMENT GOALS

There is more compatibility in the management goals for the Coorong and Murray Mouth than for the Lower Lakes component of the CLLAMM. This occurs because the Lower Lakes have a role as a water supply, for biodiversity and for recreation, while the key management goal in the Coorong and Murray Mouth is the maintenance of bird and fish biodiversity (including fisheries). The different management aspirations for the Lower Lakes are not always compatible. For example, stable elevated water levels are needed to maintain the lakes as water supplies for irrigation, but this has biodiversity disbenefits. In more detail, some of the key management goals for the Lower Lakes include:

- maintaining salinity in the lakes below 1500 EC (irrigation);
- lowering the incidence and magnitude of blue-green algal blooms (human consumption and recreation);
- improving habitat for wading birds and macrophytes (biodiversity);
- improving migratory fish access to the lakes from the Coorong or the ocean (biodiversity/fisheries);
- improving recruitment of native fish (biodiversity).

In the Coorong and Murray Mouth region, flood prevention (by keeping the *mouth open*) and the preservation of fish and bird biodiversity are the key management goals. These management aspirations, unlike those for the Lower Lakes, are usually compatible. For example, keeping the mouth open by dredging as a flood prevention measure could also have benefits for bird and fish biodiversity. Thus, a greater range of environmental flow scenarios could be developed for this section of the CLLAMM. In more detail, the management goals for the Coorong and Murray Mouth include:

- keeping the mouth open;
- improving the salinity regime of the Southern Lagoon;
- improving wading bird habitat; and
- improving fish movement, spawning and recruitment.

Some of the management options that are currently considered to achieve these goals include:

- increasing flows during summer to help maintain the mouth open;
- enhancing spring flows to flush the Coorong, help open the mouth and encourage fish movement;
- modifying barrage operation to include environmental considerations as well as irrigation and recreational requirements;
- installing fish passages at barrages;
- dredging the Murray Mouth; and
- releasing water from the Upper South East Drainage Scheme (see Figure 2).

These management options will be reviewed in more detail later within the context of the proposed system models.

3. A knowledge system for the CLLAMM area

Implementing the above policies requires a good understanding of the 'drivers' for ecosystem processes in the CLLAMM area and how these can be manipulated (when possible) to achieve different management goals. While they form a whole, the Lower Lakes and the Coorong/Murray Mouth will be reviewed separately here as they have distinct environments and management objectives.

LOWER LAKES

Water balance

The water balance for the Lower Lakes is not well understood because the complex physical nature of the system makes the measurements of the various inputs and outputs difficult. The head difference from Lock 1 in the River Murray to the river mouth (~275 km river) is a maximum of 2.5 m but is usually less than one metre resulting in a surface water gradient of <0.01 m/km. Hence, when not in flood, water in the river and the Lower Lakes flows quite slowly. Little long-term flow monitoring data is available. Flow records at Lock 1 are considered unreliable and there are no long-term records for any of the other components of the water balance (e.g. flow over the barrages, other surface water inflows or groundwater inflow).

Currently, information on water balance is mainly generated using the BIGMOD model from flow measured at the SA/VIC/NSW border. BIGMOD is a daily flow and salinity routing model used for daily flood operation between Dartmouth and Yarrawonga. It was also used independently to produce weekly flow and salinity forecasts for the mid river.

The lack of data for calibrating and running BIGMOD means that modelled data for flow at Lock 1 and evaporation rates are almost 500 ML/d too high. Net loss from evaporation and rainfall for the Lower Lakes is ~7% of flow at Lock 1 and ~8% of the flow over the barrages (1971–2000). However, flow at Lock 1 and consequently flow over the barrages has varied considerably over this period, including lengthy periods of up to a year when there has been no flow over the barrages at all. Flow over the barrages from mid 1973 to mid 1976 was five times that for 1977 to 1997 and approximately 15 times that for 1997 to 2000.

Some seasonal changes are also not covered. Modelling suggests that there is no flow over the barrages between January and March (inclusive) for approximately 75% of the time. While periods of no flow are much less frequent for other months, there have been several lengthy periods (up to two years) when no water flowed. The water balance for the SA section of the River Murray is poorly constrained and not well monitored.

Water authorities are aware of the limitations to flow monitoring in the Lower Murray and have investigated the possibility of measuring flow close to the entrance to Lake Alexandrina. However, because of the wide channel and low flow in this area, better estimates of flow are unlikely, even using advanced technology. Various techniques are under investigation to better estimate flow over and through the barrages, but, even with the improved monitoring, errors are still likely to be in excess of 10%. A possible way to reduce the errors associated with the water balance, may be to conduct environmental tracer mass-balances (i.e. Cl^-, stable isotopes of water, etc.) on the system downstream from Lock 1 (Barr et al. 2000). Whether or not such an approach will be worthwhile would depend on the spatial and temporal availability of samples, the mixing within the Lower Lakes, and the salinity and isotopic signatures of the different water balance components.

Key ecosystem processes

A number of physical and chemical drivers have been hypothesised to control the ecology of the Lower Lakes including:

- lake level;
- River Murray inflow rate;
- turbidity;
- wind-driven hydrodynamic processes; and
- salinity.

The current *water level* regime is more elevated and static than under natural conditions. The target lake level is 0.75 m AHD but will generally vary between 0.6 and 0.85 m AHD on an annual basis (Parsons 2002). The lake level is surcharged to 0.85 m AHD in early spring to allow for evaporation losses during summer. When the lake level exceeds 0.85 m AHD, freshwater spillage may occur over some of the low-lying islands forming part of the barrages. The lake level must be maintained above 0.6 m AHD (0.55 m AHD as an absolute minimum for a few days) to enable flood-irrigation in the Lower Murray Swamps (approximately 50 km upstream from Lake Alexandrina). The maintenance of an elevated lake level has also impacted on the geomorphology of the lakes, including:

- prograded shorelines in sheltered areas;
- accelerated shoreline erosion in exposed localities;
- accelerated rates of sedimentation in the lakes;
- change in the character of the sediments deposited.

These have important implications for the littoral plant and wildlife communities, infrastructure damage and possibly turbidity and nutrient levels in the lakes.

Lower *flow rates* from the River Murray combined with the stoppage of outflow at the barrages during summer has increased the average water residence time for the Lower Lakes, resulting in a greater efficiency to trap sediments and reduced export of sediment and freshwater to the Coorong and the ocean.

The shallow and exposed nature of the lakes is favourable to *wind-driven hydrodynamic processes* including an efficient mixing of the water column and the generation of waves, currents, wind set-ups and seiches. Efficient mixing prevents the establishment of permanent stratification in the lakes (Geddes 1984b) but temporary stratification may persist during exceptionally calm periods. *Thermal stratification* has an impact on light-limitation of phytoplankton growth and oxygen levels in bottom waters. A well-mixed water column in the Lower Lakes favours light over nutrient limitation of phytoplankton growth and relatively better oxygenated bottom sediments (conditions less conducive to blue-green algal blooms).

Strong waves and currents contribute to shoreline erosion, sediment resuspension and the complex patterns in the dispersal of algal blooms across the lakes. Water level variations of up to 0.5 m by wind set-ups or seiches appear common in the Lower Lakes (Close 2002). Lake-driven seiches may extend beyond the Lower Lakes and foster increased exchange between wetlands and the river channel below Lock 1 (Webster et al. 1997). Seiches may also be a significant factor to promote the exchange of water between Lake Albert and

Lake Alexandrina. While the significance of hydrodynamic processes to the ecology of the lakes is well recognised, how these processes will respond to future environmental flow manipulations is not known.

Turbidity is a key factor controlling the plankton and macrophyte communities in the Lower Lakes through its impact on the light and nutrient environment. Studies by Geddes (1984a, b; 1988) have demonstrated that the plankton community in Lake Alexandrina has distinct 'clear' and 'turbid' ecological phases. The turbid phase is characterised by high nutrient concentrations, the dominance of a large filamentous green algae (*Planctonema lauterbornei*) and relatively large zooplankters. These conditions tend to be found during periods of high river flows, especially when a large proportion of the flow is obtained from the more turbid Darling River. When river runoff is low and dominated by River Murray water, the lake can enter a clear phase. This phase is characterised by relatively lower nutrient concentrations, a predominance of potentially noxious blue-green algae and a lower abundance and diversity of the larger crustacean zooplankton. These conditions are most common in summer during drought periods.

While the impacts of turbidity on the lake environment are known in general, how turbidity will respond to environmental flow manipulations is unclear.

Salinity. The typical high biodiversity associated with gradients of salinity in estuarine environments has been lost from the Lower Lakes. Most of the fauna and flora currently present is characteristic of a freshwater environment. There are still significant variations in salinity in the Lower Lakes, especially during drought periods. Higher salinities during drought periods can be conducive to blooms of the potentially toxic blue-green algae *Nodularia spumigena*.

Salinity levels in Lake Alexandrina range between 400 and 1200 EC and tend to reflect the trends in the River Murray. The salinity in Lake Albert is higher, typically ranging between 1300 and 2000 EC but occasionally exceeding 3000 EC. High salinities in Lake Albert compromise its use for the irrigation of crops and pastures. When high salinity events have occurred in Lake Albert, the water level in Lake Alexandrina has been decreased to 0.65 m AHD to allow flushing. However, it is suspected that lowering the water level may induce the discharge of saline groundwater to Lake Albert (Parsons 2002). To understand how salinity in the lakes will respond to environmental flow manipulations will require an hydrodynamic model sufficiently detailed to predict the movement of water across the lakes.

Submerged and emergent aquatic plants play an important role in lake ecosystems by providing the basis for the littoral food web and by generating habitats for a variety of fish and birds. Impacts of river and lake regulation on macrophyte communities in the Lower lakes include:

- decrease in diversity—species adapted to a range in salinity conditions have been replaced by a less diverse freshwater community;
- change in distribution of emergent macrophytes—prior to river regulation they may have been restricted to floodplains and temporary wetlands beyond the lake edge rather than the zone with a persistent rise and fall in water level;
- decrease in the extent of the lake area suitable for submerged macrophytes due to increased turbidity;
- uprooting of submerged macrophytes by carp; and
- damage by grazing cattle.

Bird communities. The fringing wetlands and marshes associated with Lake Alexandrina and Lake Albert rank amongst the top 20 sites in Australia for several wader species. The lakes are also important habitats for waterfowl. The reduction in the variability in lake level may have advantaged waterfowl over waders under current conditions. More frequent exposure of mudflats has been suggested to improve habitat availability for wading birds.

Under current conditions, the *freshwater fish* community is advantaged over estuarine and marine migrants. In addition to relatively healthy populations of native freshwater fishes, significant populations of two exotics (European carp and redfin) are present. Goals for the management of fishes in the Lower Lakes include:

- improved access across the barrages for migrants;
- improved habitat for flood spawning species and wetland specialists; and
- lowering the abundance of exotics.

Current efforts to manage the fisheries include the establishment of fish ladders on the barrages, carp removal through a commercial fishery and a range of fishing regulations (e.g. gear restrictions, seasonal closures, bag/size limits) for the commercial and recreational fisheries.

System model for the Lower Lakes

Within the existing constraints of the system, there will be a push to improve on the ecological values of the CLLAMM through environmental flow manipulations. To maximise the environmental benefits of flow manipulations in the Lower Lakes, a system model could be used to predict how different flow management options will impact on ecological processes. Such a system model would relate ecosystem drivers (water level, turbidity, etc.) to key management goals and ecosystem indicators (Figure 3).

Some of the ecosystem drivers in the Lower Lakes can be manipulated to some extent (water level, water residence time, turbidity/nutrients and salinity) and at least one cannot (wind). Some of the drivers also have complex interactions. For example, manipulations in *lake level* will directly influence the habitat available to wading birds and macrophytes and will partially determine water residence time, salinity and turbidity.

The *water residence time* indirectly controls several water quality parameters. With longer residence times, turbidity and nutrient concentrations should decrease through greater settling of particles, while salinity level should increase due to greater evaporative losses. The longer water residence times prevalent under regulated conditions are thought to have fostered the eutrophication of the Lower Lakes through increased sediment retention.

Turbidity may be the key ecological driver through its impact on the light environment, carbon and nutrient availability. It may have numerous components, including organic detritus, inorganic particles (clays) and phytoplankton. Turbidity appears to be a function of the amount of flow from the river, the origin of the flow, salinity, sediment re-suspension, the density of algae and possibly lakeshore erosion. Turbidity can be closely associated with the *availability of nutrients* as both phosphorus and nitrogen have large exchange pools associated with particles.

Salinity is the key driver for irrigation and domestic water supplies, and indirectly controls algal bloom formation through its impact on turbidity and algal species. It may not be critical for fish migrants from the Coorong and the ocean as several key species can cope with freshwater conditions.

Wind plays a major role in the hydrodynmaics of the Lower Lakes and the habitat available for macrophytes through its potential to generate seiches and other currents. It will be significant in generating turbidity through lake erosion or sediment resuspension.

Levers

Barrage operations, the inflow rate from the Murray and the origin of the inflow (Darling versus Murray) are three levers that are at least theoretically available to manage the water regime of the Lower Lakes. Barrage operations can set the height in lake level, control the rate in water level fluctuation and partially determine the water residence time in the lakes. Barrage operations can also help mitigate high salinity events in Lake Albert by promoting increased exchanges with Lake Alexandrina. Combined with barrage operation, the inflow rate also controls both the lake level and the water residence time. During low flow periods, the inflow rate could be managed through greater or lesser releases from the major reservoirs (Dartmouth, Hume, Victoria and Menindee lakes). Finally, turbidity/nutrients could be partially controlled by managing the source of the inflow to the lakes (i.e. high turbidity Darling versus low turbidity Murray water). All these levers are limited in scope under current conditions. In the short term, some improvements in barrage infrastructure could offer more flexibility to manage water levels. However, in the longer term, further potential to manipulate the water regime of the lakes will only be achievable through a greater flexibility to manipulate the rate of inflow and the source of the inflow to the lakes.

COORONG AND MURRAY MOUTH

A key feature of the Coorong and Murray Mouth environment is the variability in water levels at daily to annual time scales. These determine many of the physical and chemical properties of the habitat for fish and birds. However, river regulation has significantly altered the natural regime of water level variability in the system, limiting the range of habitats.

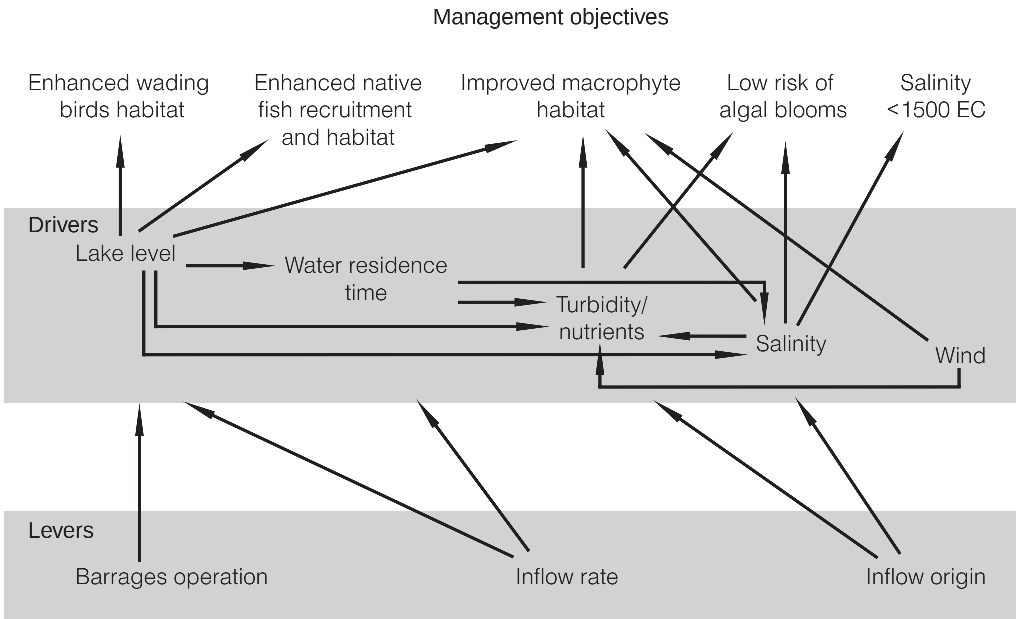
Water levels

Water levels within the Coorong and Murray Mouth region are determined by:

- winds along the axes of the Coorong lagoons that cause setup/setdowns at either end;
- flows through the barrages; and
- short-term (tides) and seasonal sea level changes.

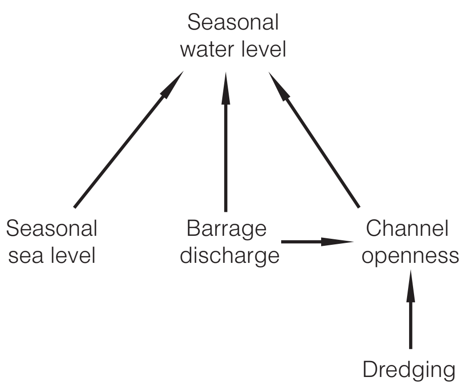
The amplitudes of these fluctuations and their timescales have important implications for ecological processes throughout the system.

Figure 3. Conceptual model of the links between key management goals, drivers of ecosystem processes and the levers available to manipulate the drivers in the Lower Lakes. For simplicity, only flow related issues and options are included here.



Seasonal changes in water levels in the Coorong range from 0.5 m at Goolwa, 0.7 m in the Northern Lagoon to 0.9 m in the Southern Lagoon with water levels generally lowest in February–April and highest in July–September. They appear to be caused by variation in sea level in Encounter Bay and variations in discharge through the barrages (Figure 4).

Figure 4. Principal factors determining water seasonal water level changes within the Coorong.



The generally higher seasonal variation in the Northern Lagoon may be due to the pattern of freshwater discharge through the barrages. Discharges through Tauwitchere Barrage tend to back up waters in the Northern Lagoon due to the constriction of Tauwitchere Channel. Release through Goolwa Barrage would also cause waters to back up within the Coorong–Mouth system, but to a lesser extent. Decreasing the degree of constriction of the connecting channels by dredging would reduce the impact of barrage discharge on water levels.

Seasonal water levels in the Southern Lagoon follow those in the Northern Lagoon for most of the year, but when water levels in the Coorong drop sufficiently, the channel connecting the two lagoons at the narrows can become dry so that water lost through evaporation is not replenished.

The *tides* along the coast of Encounter Bay are micro-tidal in range and semi-diurnal with a moderate diurnal inequality. Tidal ranges vary between ~1 m during spring tides to ~0.2 m during neap tides. When the Murray Mouth is open, the tides cause water level variations, but the amount of tide that penetrates into the Northern Lagoon or to Goolwa depends on the degree of sediment build-up in the Mouth and interconnecting channels. Tides penetrating through the Murray Mouth are further diminished by bottom friction as they propagate along the Northern Lagoon.

The mouth opening index (MOI) is a measure of how much tide penetrates to Goolwa and varies both seasonally and from year to year. Over the last 20 years, the MOI has varied between 1 (unconstricted) to almost 0 (severely constricted). In the last five years, the MOI has been relatively reduced even when barrage flows have been elevated.

Whilst the penetration of tides into the Coorong is strongly dependent on the degree of Murray Mouth opening, the penetration of sea level variations is not dependent, unless the Mouth is completely closed. Little tidal energy reaches the southeast end of the Northern Lagoon and even less reaches the Southern Lagoon. We would expect that the water level response of the Coorong system to barrage flows would also depend on the MOI.

The currents associated with processes causing water level changes cause mixing and exchange throughout the system. Mixing along the Northern and Southern Lagoons and between lagoons is partly caused by the winds and tides (in the Northern Lagoon) which cause water to 'slosh' back and forth. In the process, some water is left behind and mixes with the 'local' water. The net effect of such a process is for salinity to become more uniform along the Coorong. Under steady wind conditions, water tends to flow in the downwind direction near the water surface and in the opposite direction deeper in the water column. This process adds to that contributed by wind, enhancing mixing along the Coorong.

Salinity

Salinity distribution along the Coorong (Figure 5) is determined by:

- the balance between fresh water coming into the system, and flow through the barrages and precipitation;
- loss of water through evaporation;
- the exchange (mixing) of water along the lagoons and between the lagoons; and
- impact of USE drainage water into the southern lagoon at Salt Creek.

Input of freshwater tends to lower salinities at the north-western end of the Coorong. Excess of *evaporation* over precipitation tends to increase salinity everywhere. Depending on flow through the barrages, salinities can be near that of the Lower Lakes at the north-west end. Typically salinities are several times that of seawater at its other end due to the high excess of evaporation over precipitation. All the factors affecting salinity combine to set a significant seasonal cycle.

Release of freshwater (peaking in August) causes the water off Pelican Point to become relatively fresh (<5 dS/m). At other times, salinities have been at or above those of seawater (~35 dS/m). Salinities in this zone appear dependent on the volume and duration of the flow through the barrages and it is probable that they also depend on the degree of opening of the Murray Mouth. A relatively open mouth would allow more vigorous mixing of seawater through the Murray Mouth and along the Coorong by the tides and would tend to increase salinities.

Salinities are impacted by the relative rates of *precipitation* and *evaporation*. Pan evaporation rates tend to be at a minimum during winter (rates ~2 mm/d) and at a maximum in summer (~7 mm/d). Rainfall shows the inverse pattern in winter (~3 mm/d) and summer (<1 mm/d).

Although *long-channel mixing* tends to homogenise salinities, the *exchange of water* between the Southern and Northern Lagoons and mixing of water past Parnka Point is restricted, allowing evaporation to concentrate salinities in the Southern Lagoon to well over those of seawater.

The seasonal variation in salinity and the mean salinities in the Southern Lagoon may be determined by *seasonal variations in water level* in the system. The inflow of relatively low salinity water into the Southern Lagoon when the water levels rise in autumn–winter is responsible for the relatively low salinities in the lagoon in winter–spring. Evaporation from the lagoon during the following six months causes salinities to be at their highest in autumn. Salinities within the Southern Lagoon will also be mediated by two-way exchange past Parnka Point associated with wind-driven water level fluctuations and currents.

The *discharge* of large volumes of relatively freshwater from Salt Creek (*USE drainage*) will impact significantly on salinities and exchange both within the Southern Lagoon, and between it and the Northern Lagoon. With a volume of the Southern Lagoon (at AHD) being ~140 GL, the projected inflow from Salt Creek of up to 40 GL per season represents a replacement of approximately 30% of the lagoon volume in one year. However, unless discharge of the Salt Creek water takes place over a very short period or during the time (summer) when Southern Lagoon levels drop below those in the Northern Lagoon, a minimal impact on water levels in either lagoon from this discharge would be expected.

Sediment transport/Murray Mouth opening

The Murray Mouth once connected a large coastal lagoon area of approximately 97.3 km^2 to the ocean. Although relatively narrow, it has been and continues to be extremely dynamic. Its width has varied from several hundred metres during flood flows, to being completely closed in 1981 and 2003. It has a deltaic structure that restricts water exchange between the mouth and the estuary on its landward side. Given micro-tidal conditions and domination of wave energy along the coast, a flood-tide delta is to be expected in such a system. The tendency for the entrance of such coastal lagoon systems to close has been observed in many seasonally open lagoons around Australia, but it is clear that the construction of the barrages and the regulation of the River Murray have exacerbated the constriction of the River Murray Mouth over the last century.

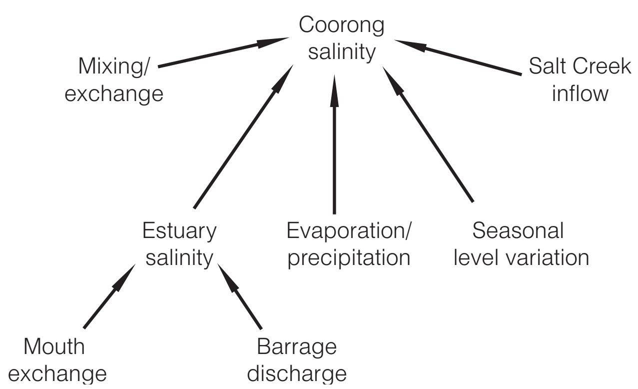
Prior to barrage construction, the tidal prism (the volume of water moving in and out of the estuary during the tidal cycle) was estimated to be ~20 000 ML during spring tides, but has since been reduced by an estimated 87 to 96%. Since regulation and increased water abstraction over the last century, the freshwater flows through the mouth have also been greatly curtailed.

Reduced tidal and freshwater flows appear to have resulted in major geomorphological changes in the channels near the mouth. These changes include the stabilisation of the flood-tidal delta (Bird Island) and the sedimentation and increased constriction of the channels through the mouth and estuary region including Goolwa Channel, Tauwitchere Channel and the Murray Mouth itself.

Key factors determining the current geomorphological condition of the Murray Mouth and its adjacent channels are the freshwater flow past the barrages and the coastal conditions, including wave climate, littoral transport, seasonal variations in sea level and tides. Aeolian processes are of unknown significance as contributors to sedimentation.

The dominant sediments in the Murray Mouth area are sands of mineral material and shell fragments. Bed-load transport and sand suspension rates are typically considered to be proportional to the amount by which the critical shear stress is exceeded raised to the power of 1.5 or greater. This implies that sediment transport increases by the 'excess' flow speed raised to at least the third power. Consequently, sand transport is very much more effective during times of energetic currents or waves than during times when the flows are close to the critical thresholds.

Figure 5. Main factors affecting salinity distribution within the Coorong.



During times of low or no flow through the barrages, water flows through the Murray Mouth are dominated by tidal flows. The pattern of tidal water level and currents is highly asymmetric through the Murray Mouth and the entrance region, with the flood tide having higher current speed and shorter duration than that of the ebb tide (WBM Oceanics Australia and Lawson & Treloar 2003). As sand transport is such a strongly increasing function of flow speed, then the flooding tide transports more sand than the ebbing tide even though its duration is less. Consequently, under zero or no flows through the barrages, there is a tendency for sand to be transported through the Murray Mouth and to be deposited in a sand delta inside the Murray Mouth where current speeds are reduced. This transport is likely to be particularly intensive under conditions of high waves and spring tides.

Significant freshwater flows through the barrages alter the sediment transport dynamics in the Murray Mouth. In particular, barrage flows add to the ebbing tidal flow and subtract from the flooding flow. Provided the freshwater flow is large enough, the outward transport of sand on the ebb tide through the Murray Mouth will be larger than the inward transport on the flood. As a result, the Murray Mouth and inner channels will tend to clear. Historical data have been used to develop on empirical relationship between the MOI described above and barrage discharge. Curiously, the MOI for a particular month is best described by the discharge two months previously rather than the previous month (Walker 2000). It may be that the neglect of other factors that might affect the MOI have altered its apparent relationship with discharge. For example, it is likely that sand transport along the open coast on either side of the Murray Mouth plays an important role in morphology and sand supply to the Murray Mouth. Coastal winds drive long-shore currents (littoral drift). Also, swell waves that arrive on a beach at an oblique angle can contribute to littoral drift. High waves during storms suspend sediments and these are carried by the littoral drift, resulting in long-shore sand transport. The role longshore sand transport might play in the sedimentation dynamics of the Murray Mouth is not known.

Stratification

Stratification in water bodies occurs when either the water temperature or the salinity vary with depth through the water column. The presence of stratification (or non-uniform properties) in the water column means that the water column is not completely mixed or perhaps that mixing is not occurring vigorously. Decomposition processes in the water column or on the bottom can deplete oxygen in the water column. If the water column is actively mixing then this water can be replenished with oxygen through transfer across the water surface. In stratified conditions, the absence of vigorous vertical mixing may allow the water to become seriously depleted in oxygen (hypoxic) or perhaps even anoxic. Hypoxic or anoxic conditions can be deleterious to benthic dwelling organisms. Also, anoxic conditions can lead to the release of phosphorus and ammonia from bottom sediments and thereby exacerbate eutrophication.

Significant stratification is not commonly observed in the Coorong, due in part to there being a paucity of suitable measurements. One study using continuously recording moored instrumentation in the Northern Lagoon over a year has shown that this lagoon can stratify in both temperature and salinity (Holloway 1980a,b). Thermal stratification typically occurs on a diurnal basis. Early in the morning, the water column may be isothermal, but the temperature of the near surface waters heats up during the day and stratification is established. Sea breezes later in the day are often sufficiently strong that the water column becomes fully mixed. Such short-term stratification is not likely to be significant for biogeochemical processes in the lagoon. Even if night-time cooling and afternoon sea breezes are not capable of destroying the stratification established during the day, it is unlikely that thermal stratification would persist in a shallow system such as the Coorong for longer than a few days at a time.

On several occasions during the year-long study, significant salinity stratification was measured in which a relatively fresh surface layer overlays a more salty layer. Presumably, the saltier layer originated from the south-eastern end of the Northern Lagoon and perhaps even from the Southern Lagoon, whereas the fresher layer would have originated from the other end of the Northern Lagoon. On one occasion this salinity stratification persisted for nine days, a period which may be long enough to allow bottom waters to go anoxic (depending on oxygen utilisation rates).

The few measurements of the salinity structure in the Southern Lagoon (Geddes & Butler 1984; Geddes & Hall 1990) do not show evidence of stratification. However, it is probable that stratification does occur periodically when relatively fresh water flows into the more saline Southern Lagoon through the Narrows mid year. Other freshwater inputs from Salt Creek or through precipitation could also result in stratification. Stratification could also occur due to the inflow of relatively high salinity water from the shallow areas along the sides of the lagoon and from the shallow Bul-Bul Basin to the south of Salt Creek. In shallow depths, evaporation would tend to increase salt concentrations more than in the deeper sections of the lagoon.

Conceptualisation of the Coorong ecology and biogeochemistry

The salinity gradient and its impact on primary production, fish and bird distribution is the defining feature of the ecology of the Coorong (Figure 6). The significance of the salinity gradient for bird and fish habitats have also been reviewed in Geddes and Butler (1984a, high salinity), Geddes (1987, low salinity) and Boon (2000). In summary, the Coorong is best considered as having three parts: the hypersaline Southern Lagoon, the estuarine Northern Lagoon (which can become moderately hypersaline in its southern end) and the Barrages/Murray mouth region where salinities vary from freshwater to seawater. In common with many estuaries and hypersaline salt lakes worldwide, the Coorong is highly productive biologically but the source of the primary production can change dramatically across the salinity gradient. In the Coorong, there are four groups of primary producers:

- *Ruppia*: two different species of angiosperms which have different salinity requirements—*Ruppia megacarpa* has a lower salinity tolerance and is dominant in the northern lagoon, *Ruppia tuberosa* has a higher salinity tolerance and grows in the southern lagoon;
- pelagic (free floating) phytoplankton;
- benthic (bottom dwelling) and mat-forming algae; and
- seagrasses.

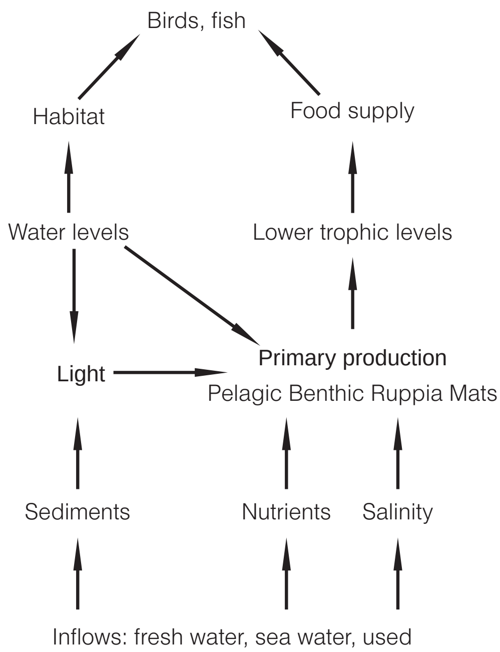
The keystone primary producer appears to be the *Ruppia* community which forms the basis of the food-chain for waders and waterfowl. However, under hypersaline conditions the *Ruppia* community disappears and primary production would probably be dependent on phytoplankton and benthic algae. Similarly, fish species diversity declines dramatically once salinity moves from the saline to hypersaline range. These abrupt changes in the structure of the food-chain highlight the vulnerability of the Coorong ecosystem to changes in salinity because of a limited species redundancy in certain key ecological functions in the hypersaline salinity range.

In addition to salinity, turbidity (through its impact on the light climate) and nutrient availability should be the second-most important factors controlling the rates and the form of primary production in the Coorong. Under turbid conditions, primary production rates would be more likely to be light-limited and a greater proportion of the primary production would be through phytoplankton. The main external sources of nutrients would include River Murray flow, USE drainage and atmospheric deposition. However, internal nutrient recycling is probably very significant in the Coorong because (being a terminal system) nutrient stores should have accumulated and it is shallow and well wind-mixed. However, the internal nutrient regeneration is also sensitive to changes in salinity with key processes such as nitrification ceasing at salinities above about twice seawater.

Typical for many estuarine systems, if any nutrient limitation occurs, it would be more likely due to nitrogen (N) than phosphorus (P) because of high expected rates of denitrification at the sediment-water interface (although this will be controlled indirectly through 'switching off' nitrification at high salinities). The possibility of N-fixation by transient cyanobacterial mats is unquantified at present. In addition, the high rates of sulfate reduction in the Coorong (a probable cause of the famous 'Coorong smell') would favour P recycling (Waite 1997). However, the overall internal recycling of nutrients within the Coorong is currently poorly understood.

Nutrient cycles in the Coorong are probably not only driven by 'bottom-up' processes. Nutrient regeneration by birds and fish would tend to return to the environment nutrients in forms (phosphate and amonia) that are easily available for uptake by plants and algae. Migratory fish and birds, or species that use the Coorong only as hunting or roosting habitats could also be significant sources or sinks for nutrients (Kerekes 1994; Kitchell et al. 1999). For example, pelicans roost in the Coorong because of the availability of safe habitats from terrestrial predators but they can forage elsewhere. This would tend to result in a net import of nutrients to the Coorong. To our knowledge, the significance of these 'top-down' processes have not been quantified in the Coorong but it has been shown to be significant in wetlands with a high biomass of fish and birds.

Figure 6. Schematic showing the interactions between the various biogeochemical and physical processes and the major biological characteristics.



System model for the Coorong and Murray Mouth

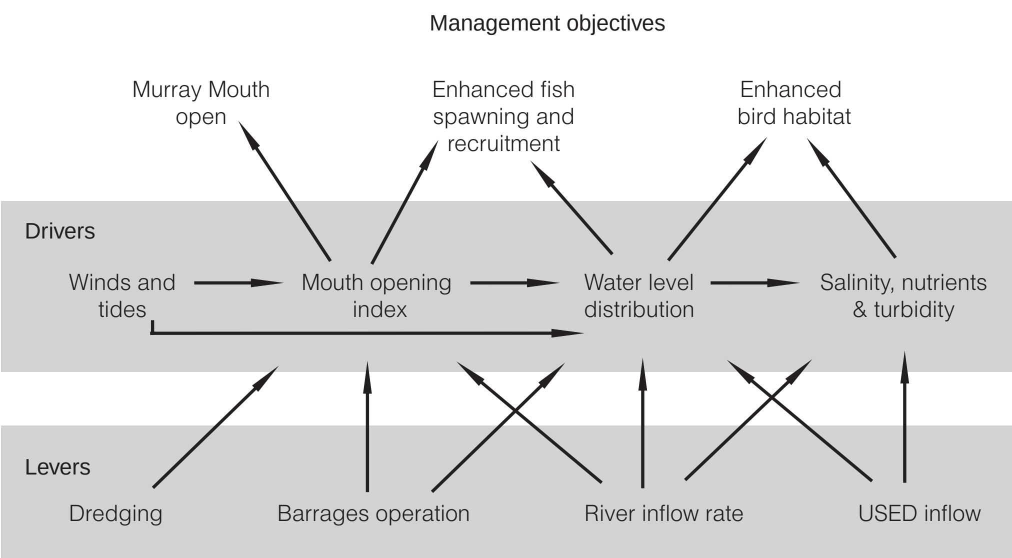
Drivers

Winds and tides, the Murray MOI, water levels and salinity, and other water quality parameters (nutrients and turbidity) appear the four main drivers of Coorong and Murray Mouth region ecosystem processes. Three of these drivers (degree of Murray Mouth opening, water level and water quality) can be at least partially controlled through management actions. As described in previous sections, some of the drivers have important interactions with one another. For example winds and tides influence the MOI and the distribution in water level and salinity within the Coorong and the Murray Mouth environment (summarised in Figure 7).

Levers

Unlike for the Lower Lakes, a greater range of options may be available to optimise environmental flows for the Coorong and Murray Mouth region. For example, to change salinity in the Southern Lagoon, all four levers could have a significant degree of impact. However, flexibility in the use of many of the levers is limited. The flexibility in using USED inflows for environmental purposes is also untested. There is currently no integrative tool that enables us to forecast the impact of different environmental flow scenarios using all four levers.

Figure 7. Conceptual model of the key management goals, drivers of ecosystem processes and levers available to control ecosystem processes for the Coorong and Murray Mouth. For simplicity, only flow-related issues and management options are included.



4. Knowledge gaps and initial progress

The knowledge gaps that limit the optimisation of flow management initiatives can be separated as a function of the different levers available to manage flows in the CLLAMM (Table 2). These knowledge gaps can be separated into understanding:

- how the physical and chemical environment changes during flow manipulations; and
- how biota responds to changes in the physical and chemical environment.

In the short term, we suggest that the key knowledge gaps that need to be addressed before further management actions can be made in the CLLAMM are:

- better water and salt balances; and
- an integrative tool that can provide realistic predictions of changes in the physical and chemical environment (mainly water level, salinity and turbidity) for different scenarios of lever manipulation.

The need for the latter is especially pressing due to a requirement to make management decisions about how to release water from the Upper South East Drainage Scheme and the ongoing closure of the Murray Mouth. Knowing how the physical environment will change under different scenarios does not guarantee that ecological objectives will be reached because the relationships between environmental and biological parameters are not always known. However, knowing the impacts on the physical environment would constrain the range of options most likely to provide significant environmental benefits.

Table 2. Summary of knowledge gaps as a function of the decisions required for the management of levers for the CLLAMM area.

Management levers and decisions	Knowledge gaps
Operation of barrages ▮ Release water over summer ▮ Release water through Goolwa and/or Tauwitchere Barrages	1. Predictive capability of how water levels in the Southern and Northern Lagoons respond to barrage flows, Murray Mouth clearance and Salt Creek flows 2. Verification of the relationship between barrage flows and Murray Mouth opening and an assessment of the roles that wave conditions and littoral transport play in the sediment dynamics in and near the mouth 3. Understanding how wind, tides, and seasonal water level changes cause the mixing and transport of nutrients, sediments, salt and other contaminants along the Coorong system. 4. Nutrient budgets for different sections of the Coorong in relation to different sources 5. Spatial distributions of different primary producers, the relative biomasses and turnover times for different functional groups, the rates of primary production by the different primary producers and their linkages to bird and fish populations. 6. Sensitivities to the various nutrient regeneration processes to salinity and quantitative relationships between external conditions and rates of nutrient production/uptake. 7. Role of stratification in physical and biogeochemical dynamics in Southern and Northern Lagoons. 8. Understanding long-term climatic variability in relation to ecological status
Delivery of water from upstream ▮ Enhance spring flows ▮ Increase summer flows ▮ Source water from Darling or Murray	1. Sources and dynamics of turbidity in the Lower Lakes 2. Light and water regime requirements for many species of macrophytes 3. Inundation model to assess impacts of different water level regime on floodplain, lake edge and submerged macrophytes 4. Further understanding of the factors determining the occurrence of algal species in the Lower Lakes, including potentially toxic species. 5. Hydrodynamic model for improved understanding of salinity and algal distributions 6. Persistence of stratification in the Lower Lakes during calm periods 7. Sources of carbon driving the Lower Lakes' food-chain 8. Habitat requirements of native fishes, including migrants 9. Contribution of groundwater seepage to Lower Lakes' salinity. 10. Better water balance of River Murray and Lower Lakes 11. High-resolution, short-term (~300 – 500 years) paleolimnological reconstruction of past Lower Lakes and Coorong environments.
Delivery of water from Morella Basin –	12. As in 1–6.
Dredging –	13. Verification of the relationship between barrage flows and Mouth opening and an assessment of the roles that wave conditions and littoral transport play in the sediment dynamics in and near the mouth

WORKSHOP PRESENTATION AND OUTCOMES

A workshop was held on 9 June 2004 to discuss a draft of a preliminary situation report and the various knowledge gaps that it had identified. The workshop included participants from most research organisations and management agencies involved in the CLLAMM area. The specific objectives of the workshop were to:

- confirm or otherwise the conceptual models developed for the Coorong and the Lower Lakes;
- discuss the knowledge gaps; and
- discuss possible ways forward to address these needs.

Lower Lakes

There was general agreement among the participants that the issues and knowledge gaps raised in the situation report for the Lower Lakes were close to the mark. In summary, these were:

- the problem of the plurality in the management goals for the lakes;
- the lack of offshore monitoring;
- the importance of turbidity in the lake's ecology;
- the poorly constrained water balance; and
- the lack of understanding of the hydrodynamics of the Lower Lakes (i.e. 'short-circuiting' of flow, dynamics of stratification).

A number of issues not identified or incompletely covered in the situation report were also highlighted, including:

- the recent occurence of a new potentially toxic blue-green algal species in the lakes (*Cylindrospermopsis raciborskii*);
- the incomplete knowledge of the conditions suitable for the occurrence of different blue-green algal species;
- when setting management goals for biodiversity, it may be necessary to separate the littoral/lake periphery component (where most of the biodiversity value is currently thought to be) from the offshore component;
- overall, the offshore component of the Lower Lakes is not well understood and it is difficult to assess its significance for the conservation of native fish;
- a poor understanding of the impact of past and ongoing changes in stream and groundwater management in the vicinity of the Lower Lakes;
- the vital attributes (e.g. environmental conditions suitable for spawning) for many of the native fish are not known;
- the possibility that large predatory estuarine and marine fish will soon be able to access the lakes through the fish ladders may have some significant impact on lake fishes, especially for the smaller species; and
- the reconstruction of past environmental conditions in the Lower Lakes and Coorong is still incomplete.

It was also generally agreed that, of all possible research projects targeting the Lower Lakes, a review of the existing information available on turbidity in the system should be undertaken immediately and ways to improve on the water balance be further scoped. In addition, some steps should be undertaken to paliate for the virtual absence of monitoring data for any offshore lake locations.

Coorong and Murray Mouth

The Coorong and Murray Mouth were the main areas of interest for many (but not all) workshop participants. For managers, this was driven by the immediate need to manage USE drainage releases in the Southern Lagoon, the ongoing problem of mouth closure and an ongoing review of the Ramsar management plan for the area. Overall, the participants agreed that the issues and knowledge gaps in the situation report were consistent with their own experiences and consistent with other similar review exercises. In addition, they were impressed by the insights gained from the review of the hydrodynamics of the Coorong and Murray Mouth. There was a general agreement that a tool was needed to predict the movement of water and the distribution of salinity across the Coorong and Murray Mouth under different management scenarios. Such a model could eventually be linked to models describing biogeochemical and ecological processes across the Coorong. However, there is currently insufficent knowledge available to predict with much certainty how biological systems will respond to various flow and salinity scenarios, even if these could be modelled successfully.

5. Proposed research

During the second year of the program, a plan of research activities for the next four years will be defined in collaboration with funding agencies, stakeholders and research collaborators. Our vision for the overall end-product for the program is a system model to guide environmental flow management activities in the CLLAMM area (Figure 8). We anticipate that significant advances can be made on the 'Hydrodynamic' and 'Biogeochemical' aspects of the model over the four-year program as some of this information is already available. However, the development of the 'Ecological Function' component will probably require a sustained effort over a longer time period. In part, this is due to the paucity of long-term ecological records for the Coorong and Lower Lakes.

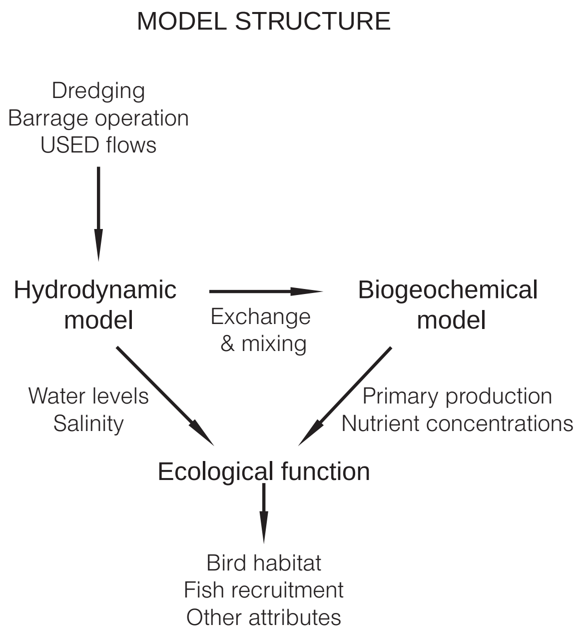
We anticipate that the program plan will be divided into four activities. These are:

1. Salt, water balance and hydrodynamics;
2. Nutrients and primary production;
3. Ecological responses to change in flow;
4. Integration and communication.

We anticipate that CSIRO will be a significant contributor to activities 1 and 4. However, activities 2 and 3 will be developed in collaboration with the other research agencies and universities involved in the CLLAMM area. This collaboration will be fostered, in part, through the funding of post-graduate scholarships. Work is already underway to scope the different activities of the program.

We recognise that the political and management environment in the Lower Murray is evolving rapidly and that our program will need to be adaptable and flexible enough to accommodate the changing needs of managers. This will be achieved through our ongoing participation in management committees in the CLLAMM area and regular reporting to our technical reference panel. In addition, we hope to regularly update the system model during the course of the study rather than provide a fixed package by the end of the program. This should provide an opportunity to test the usefullness of the model against 'real' management opportunities to generate environmental flows.

Figure 8. Conceptual representation of a system model for the management of environmental flow related issues in the Coorong and Murray Mouth area.



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