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Water for a Healthy Country

An Overview of the Hydrodynamics of the Coorong and Murray Mouth

Water levels and salinity – key ecological drivers

Ian T. Webster

CSIRO

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Glossary and Abbreviations

AHD	Australian height datum
CFMI	Computational Fluid Mechanics International
CLLAMM	Coorong, Lower Lakes, and Murray Mouth
continental shelf waves	waves of period days or longer propagating around the coast
E&WS	Engineering & Water Supply, SA State Department
geomorphology	the study of the origin, evolution, and configuration of the natural features of the earth's surface
hydrodynamics	the study of the dynamics of water flow
hypersaline	salinity above that of sea water
isothermal	of uniform temperature
MDBC	Murray-Darling Basin Commission
MOI	Mouth Opening Index
Murkey Model	water transport model for the River Murray in South Australia
stratification	layering of properties in water column
salinity	salt content of water in g/L (salinity of full sea water ~35)
shear stress	the force of water flowing over the sea bed
tidal prism	the volume of water exchanged between high and low tide
turbid	thick or opaque with suspended matter; not clear; cloudy, muddy
USED	Upper South East Drainage
WBM Oceanics	engineering and environmental consulting company
wind stress	the force of the wind on the water surface

Executive Summary

The Coorong, Lower Lakes, and the Murray Mouth form a terminal lake system at the mouth of the River Murray in South Australia. A line of barrages inside the mouth separate the Lower Lakes (Alexandrina and Albert) from the saline waters of the Coorong which exchange with the sea through the Murray Mouth. The Coorong and the Lower Lakes are of national and international conservation status especially for birds and are listed as Ramsar Wetlands.

Reduced river flows in the River Murray in recent years and the associated increased likelihood of Mouth closure are regarded as a threat to the ecological function of the Coorong through the propensity for higher salinities in the system, alterations to the water level regime, and blockage of fish migration pathways. Water level is a key environmental attribute that determines the availability of physical habitat for birds and for other aquatic life. Similarly, all aquatic organisms have tolerance limits to salinity levels and their degree of variation, so the salinity regime within the Coorong is a major determinant of where and how well such organisms can live and prosper.

The physical environment of the Coorong can be altered through human manipulation including dredging the Mouth and by altering the timing and magnitude of barrage discharges and releases from the Upper South East Drainage scheme (USED) into the South Lagoon. This report considers the factors that determine water levels and salinity within the Coorong as they are. The main results can be summarised as:

1. Water levels in the Coorong undergo a seasonal cycle of up to ~0.7m in range, higher levels tending to occur in late winter-early spring and lower in late summer-early autumn. This seasonal variation is due to a combination of variation in sea level outside the Mouth and back-up due to discharge through the barrages.

2. Shorter term water level variations of $\sim \pm 0.05\,\mathrm{m}$ typically are due to the tilting of the water surface by the wind. Tidal level variation is important near the Mouth.

3. Salinities increase along the Coorong from the Mouth through to the South Lagoon where salinity reaches several times that of sea water. The sloshing of water in and out of the South Lagoon associated with seasonal water level variation is a key determinant of the salinity there.

4. Salinity stratification has been observed to occur in the North Lagoon and has the potential for negative ecological consequences, but its causes are poorly understood.

5. Variations in water level and salinity and the exchange of other material within the Coorong are inextricably linked. Manipulation of water levels through discharge variation or Mouth dredging will have consequences for the salinity regime and for the concentrations of substances such as nutrients.

1. Introduction

The Coorong, Lake Alexandrina, Lake Albert, and Murray Mouth form a terminal lakes system at the mouth of the River Murray in South Australia (Fig. 1). A line of barrages inside the mouth separate the lower lakes (Alexandrina and Albert) from the saline waters of the Coorong which exchange with the sea through the Murray Mouth. The barrages prevent seawater from entering the Lakes and lower Murray, and maintain higher water levels in the naturally shallow Lakes. During times of high discharge in the Murray, significant volumes of fresh water pass the barrages and these flows have been deemed essential for maintaining the Murray Mouth in an open condition. Over the past decades, flows in the River Murray have been reduced to a fraction of previous volumes mainly due to irrigation abstraction and it would appear that the likelihood of Mouth closure has increased over this time as a consequence.

The Coorong is a lagoon system several kilometers wide that follows the coast for more than 100km from the Mouth. It is divided into two lagoons, the North and South lagoons (Fig. 1). The Coorong and the Lower Lakes are of national and international conservation status especially for birds, the Coorong being ranked within the top six waterbird sites in Australia. These waterbodies are Ramsar listed and are listed as one of six Significant Ecological Assets identified in the Living Murray Initiative (http://www.thelivingmurray.mdbc.gov.au/). Reduced river flows and the associated increased likelihood of Mouth closure are regarded as a threat to the ecological function of the Coorong through the propensity for higher salinities in the system, alterations to the water level regime, and blockage of fish migration pathways. Water level is a key environmental attribute that determines the availability of physical habitat for birds and for other aquatic life. Similarly, all aquatic organisms have tolerance limits to salinity levels and their degree of variation, so the salinity regime within the Coorong is a major determinant of where and how well such organisms can live and prosper.

There are a number of ways the physical environment of the Coorong can be altered through human manipulation. These drivers include dredging the Mouth when it is threatened by closure and altering the timing and magnitude of flows past the barrages and releases from the Upper South East Drainage scheme (USED) into the South Lagoon at Salt Creek. As a step in understanding the consequences of management manipulation on the physical environment of the Coorong and ultimately on its ecology, this report considers the dynamics of water level and salinity variations within the Coorong as they are. Water level variation in the Coorong is a key determinant of habitat suitability, but it is also shown to be an important driver of water exchange and salinity. Another result is that barrage discharges also have an impact on causing water level variations besides their role in providing fresh water to the system and maintaining an open Mouth.

The report has been prepared as part of the first stage of the Coorong, Lower Lakes, and Murray Mouth Project (CLLAMM) in the River Murray Theme of Water for Healthy Country. The aims, rationale, and context of the CLLAMM project are outlined by Lamontagne et al. (2004). Future work in the project will develop the links between the biophysical environment and ecological outcomes as well as assess the socio-economic benefits of alternative management strategies for the CLLAMM system.

Exchanges between the Murray Mouth and the Coorong are caused by sea level variations, tidal variation, winds, and freshwater discharge through the barrages. In turn, these factors, impact on salinity levels throughout the Coorong and on how other contaminants including nutrients are exchanged along its length. The following discussion presents features of the hydrodynamics of the Coorong itself including water levels, salinity and stratification all of which are important physical characteristics.

Figure 1. The Coorong, Lower Lakes and Murray Mouth.

2. The Murray Mouth

We address the dynamics of the opening of the Mouth first. As the connecting channel between the sea and the Coorong system, the degree of openness of the Mouth is of critical importance in the way that the system exchanges water with the sea and with setting water levels within the system.

2.1 Mouth geomorphology

The Murray Mouth once connected a large estuarine system covering almost 750 km^2, including the present Lake Alexandrina, Lake Albert and Coorong, to the ocean (Bourman and Barnett, 1995). The Murray Mouth has always been relatively narrow, but it has been and continues to be extremely dynamic. The width of the Mouth has varied from being several hundred meters during flood flows (Walker, 2002), but it closed off completely in 1981 and almost closed in 2003. In the 1830s, its position was 1.6km from the present mouth; it has been observed to move 14m in 12 h (Bourman 2000). Given micro-tidal conditions and domination of wave energy along the coast, a flood-tide delta (a delta landward of the Mouth) is to be expected in such a system (Harvey 1996). Since the 1830s, the Mouth has deposited and eroded significant volumes of sediment from this delta. The tendency of the entrances 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 this tendency over the last century.

Whereas prior to barrage construction the tidal prism was estimated to be ~20,000 ML during spring tides (Walker, 1990), the tidal prism has been reduced by an estimated 87-96% (Harvey, 1996). Further, since the regulation of the River Murray and greatly increased water abstraction over the last century the freshwater flows through the Mouth have also been greatly curtailed. Close (1990) reported that outflows through the Murray Mouth had reduced to a third of natural flows, but outflows have since reduced further. Reduced tidal and freshwater flows through the Mouth appear to have resulted in major morphological 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 estuary region including Goolwa Channel, Tauwitcherie Channel, and the Murray Mouth itself. There have been a number of descriptions of the alterations of the geomorphology of the Mouth and how it has changed over the years since barrage completion in 1940 (Bourman and Barnett 1995, Harvey 1996, Bourman 2000). Here, we focus on the hydrodynamics of the Mouth.

We expect that the key factors determining the morphological condition of the Mouth and its adjacent channels are the freshwater flow past the barrages and the coastal conditions. The latter conditions include the wave climate, littoral transport, and sea level including the tides. Aeolian processes may be of significance with large quantities of sand being in motion along the modern shoreline being blown off the dunes and into the channels contributing to sedimentation (Bourman 1986), but how important this mechanism is for restricting channel flows has not been addressed.

2.2 Sediment dynamics

The dominant sediments in the Mouth area are sands comprised of mineral material and shell fragments. Such sediments are transported by the action of saltation or by suspension into the water column and advection by the water flow. Saltation occurs when the current is not strong enough to lift the sediment grains into the water column, but is strong enough to cause grains to ‘bounce’ along the bottom causing bed-load transport. Other contributors to bed-load transport are rolling and sliding of sand grains over the bed surface. Both bed-load transport and suspension require a minimum bottom shear stress to be exerted on the bed which means that the flow over the bottom must be vigorous. Such critical shear stresses for sand transport depend on the sand properties including grain size distribution and specific gravity. The shear stress of the flow over the bottom increases as approximately the square of the flow speed. When there is a mean current and waves together, the bottom stress increases as more than the sum of the stresses due to the waves and currents considered separately (Grant and Madsen, 1979). Thus the presence of waves in a coastal environment can enhance considerably the ability of currents to mobilise sediments.

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 more (e.g. van Rijn, 1993). 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. Being more dense than water, suspended sediment settles to the bottom under the action of gravity so that in a hydrodynamically active environment, sediment suspension and deposition occur simultaneously. If local suspension rates exceed the rate of settlement, then there is a tendency towards erosion of the bed and similarly if settlement rate exceeds suspension rate then the tendency is towards deposition. Bed-load transport can also resupply or remove sand from an area of the bed, so whether net erosion or net deposition occurs depends on whether the total rate of supply of sediment to the bed area (including suspended and bed-load transport) is less than or exceeds the rate of sediment removal. In coastal environments, erosion tends to occur in areas of high hydrodynamic energy (waves and currents) and deposition tends to occur in areas of lower hydrodynamic energy.

A modelling study has been undertaken by WBM Oceanics to examine the interplay between waves and flow in forming the Mouth and its connecting channels Goolwa and Tauwitcherie (WBM Oceanics 2003). This study models the hydrodynamics around the Mouth and the resulting sand transport. The sand transport model uses equations which incorporate the general principles of sediment transport that have just been described. The results of this study, which include comparisons between measurements and model simulations, are consistent with the following conceptual picture of the sediment dynamics in the vicinity of the Mouth.

During times of low or no water flow through the barrages, flows through the Mouth are dominated by tidal flows. The tidal water level and tidal current pattern is highly asymmetric through the Mouth and the estuary region with the flood tide having higher current speed and shorter duration than that of the ebb tide. Because 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. The consequence is that under zero or no flows through the barrages there is a tendency for sand to be transported through the Mouth and to be deposited in the sand delta inside the Mouth where current speeds are reduced. The modelling and measurements presented by WBM Oceanics (2003) show that this transport is likely to be particularly intensive under conditions of high waves and spring tides. In a two-week period between 14-28 May 2002, which included a storm having offshore significant wave heights of ~4m and spring tides, approximately 46,000m^3 of sand was deposited in the sand shoals and channels inside the Mouth. Some of this sand appears to have come from scouring and widening of the Mouth itself. In effect, the oscillatory currents associated with the high waves serve to help mobilise and suspend the sediments so they can be more effectively transported by the tidal currents.

It is certain that the nature of sand transport along the open coast on either side of the Mouth plays an important role in geomorphology. 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. A study by Chappell (1991) estimated that between 1940 and 1990, 3,849 significant storms transported an average of 260,000 m^3 of sand along the coast near the Murray Mouth. Such sand transport has the potential to supply sand for transport through the Mouth as well as to cause changes to the position and geomorphology of the Mouth itself. Chappell (1991) estimates that the volume and direction of sand transport along the coast is quite variable between years and Harvey (1996) shows that the direction of migration of the position of the Mouth is also highly variable between years. However, Harvey (1996) notes that the correlation between littoral sand drift and Mouth migration is inconclusive.

2.3 Mouth Opening Index

Significant freshwater flow through the barrages alters the sediment transport dynamics in the Mouth. In particular, this flow adds to the ebbing tidal flow and subtracts from the flooding flow. Provided the freshwater flow is large enough, the outward transport of sand on the ebb tide through the Mouth will be larger than the inward transport on the flood and the Mouth and inner channels will tend to clear. Walker and Jessup (1992) and Walker (2002) have examined the degree of Mouth opening as it is affected by flows through the barrage. The index they use for degree of openness is the ratio of the square of the semi-diurnal tidal amplitudes measured at Goolwa Barrage and on the open coast at Victor Harbor (see section *Tides* below). An empirical relationship between the openness index in month t (R_t) and the discharge in GL in month t was determined as:

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

that is, the index depends on the index in the previous month and the flow through the barrages two months previously. It is not clear why the index should depend on flows two months previously and not those from the previous month, but it is empirical and does not include other factors such as waves or storm activity. The R^2 value of 0.46 obtained for the comparison between the measured and modelled index reflects the model's goodness of fit; the model captures the major features of the seasonal and interannual variation in the measured index. This index has since been incorporated into the MDBC Murkey Model as the Mouth Opening Index (MOI); that is, $\mathrm{MOI} = R_t$ (Close, 2002).

Figure 2 shows the calculated MOI and flows through the barrages estimated using the Murkey model from the beginning of 1980 to the end of 2003. An MOI near zero represents a Mouth which is nearly shut, whereas an MOI of unity signifies a Mouth that is sufficiently open that it represents little restriction to tidal exchange. The MOI typically starts to rise with increased barrage flows after mid-year and reaches a maximum when flows reduce substantially around the beginning of the next year. During the low-flow period between the beginning of the year and mid-year, the MOI gradually declines. Presumably this decline is due to the gradual sedimentation of the Mouth and channels inside the Mouth when the tides pump sediment into the system as we have described.

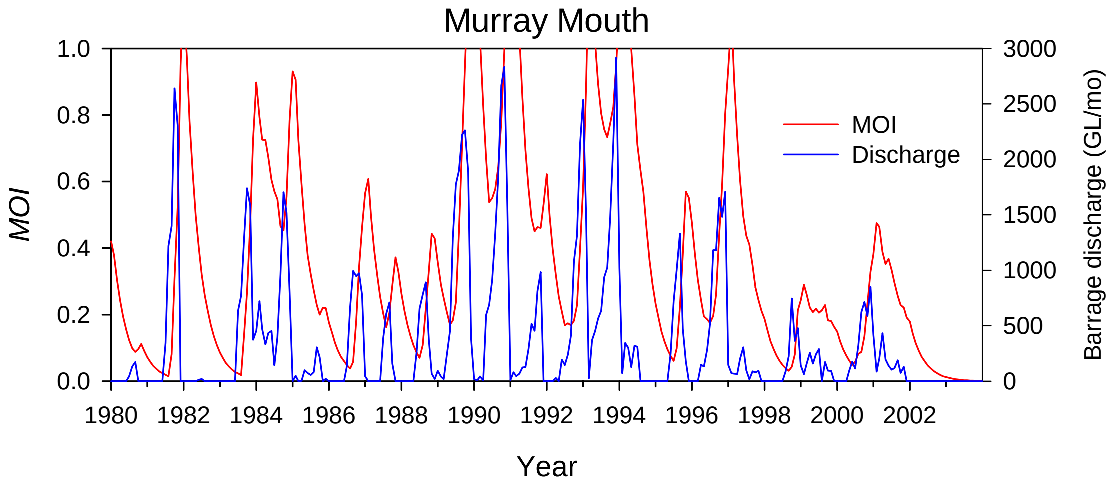

Figure 2. Mouth Opening Index (MOI*)* calculated using Eq. 1 and discharges through the barrages estimated using the Murkey model.

Despite periods of historically low flow, the Mouth has only closed once in 1981 and almost attained closure in 2002. In the latter instance, a channel was maintained to the sea by dredging. Figure 2 shows both these times as having a small MOI, but 1983 showed an MOI similar to that of 1981 and the Mouth did not close in that year. The year 1968 for example had an even smaller MOI. Close (2002) suggests that the MOI is best considered as an indicator of risk of Mouth closure and presents discharge scenarios that are designed to reduce the risk of Mouth closure.

Walker (2002) also considers the long-term conveyance of tidal flows through the Goolwa and Tauwitcherie Channels. The analysis just described represents the conveyance through the Goolwa Channel. A similar analysis for Tauwitcherie Barrage shows maximum yearly measured indices of mostly less than 0.3 which is considerably smaller than those measured at Goolwa Barrage. The latter are typically similar to the modelled indices shown in Fig. 2. Walker suggests that the difference in the tidal transmission indices is due to Goolwa Channel being used to carry most of the discharge from the barrages and resulting in it being an efficient channel to the ocean. This is certainly partly true, but Tauwitcherie Channel also connects to a body of water having a much larger surface area (the Coorong) and a larger volume of water would need to flow through it to cause a specified water level change. Walker also suggests that his analysis shows that tidal transmission through Tauwitcherie Channel shows an overall downward trend through the 1990s and attributes this to a consistent sediment build-up. Such a trend is also measured through Goolwa Channel, but it is not so marked.

3. The Coorong

3.1 Hydrodynamics

Largely in response of the need to investigate the long-term effects of drainage from the USED scheme into the southern end of the Coorong, Computational Fluid Mechanics International (CFMI) undertook modelling of the hydrodynamics and salinity levels in the Coorong lagoons at the beginning of July, 1992. The description and validation of this modelling are reported in CFMI (1992). Two further reports (Reports CFMI 1998, CFMI 2000) present further scenario simulations using the same model.

Much of the conceptual description presented in the following derives directly from the work reported in CFMI (1992). The models applied to the Coorong were ESTRAFPH for the hydrodynamics and SALTIE which simulates salt transport and salinity distributions. ESTRAFPH is a one-dimensional model which describes the time-dependent water levels and flows along the Coorong as they respond to measured water levels at Pelican Point (near the northern end of the North Lagoon, see Fig. 1) and to wind. SALTIE, also a one-dimensional model, integrates the salinity transport equation using exchange coefficients derived from ESTRAFPH.

The Coorong naturally splits into North and South Lagoons at Parnka Point (see Fig. 1). There are several channel sections on either side of Parnka Point (the Narrows) which are very narrow (~100m) and shallow which represent the main restriction for water exchange between the two lagoons. The length of the North Lagoon to Pelican Point is 48km vs a length of 40km for the South Lagoon if the effective end to the Lagoon is chosen to be 6km southeast of Sand Spit Point near Tea Tree Crossing as does CFMI (1992). At zero water elevation (AHD), the average widths of the North and South Lagoons are 1.5km and 2.5km, respectively, whereas the average depths are 1.2m and 1.4m, respectively (CFMI, 1992).

3.2 Water levels

According to Noye (1975), changes in the water levels in the Coorong can be “classified into three main types; wind-induced short period changes of a foot or so (sic), with a time scale of days, in which opposite ends of each lagoon move out of phase with each other; short period increases in levels in North Lagoon which occur when the barrages at the north end of the Coorong are opened for several days at a time; and seasonal variations of up to four feet (sic)”. Water level changes in Encounter Bay including tides are also acknowledged as penetrating through the Mouth to influence levels within the Coorong.

We first examine the relationship between water levels in Encounter Bay and in the Murray Mouth. Water level variations occur across a spectrum of timescales ranging from those associated with wind waves (~ seconds), swell (~10s of seconds), tides (~ 1day) and low frequencies (>1 day). Low-frequency water level changes in Encounter Bay are characteristically of two types according to Provis and Radok (1979). The first type is due to the passage of weather systems and associated continental shelf waves. These have periods between 1-20 days. The second type of fluctuation having periods between 20-365 days have an uncertain origin, but appear to be due to sources in the Southern Ocean or in the interaction between the continent and this ocean.

In general, the impact of water level variations imposed on the Coorong depends on the frequency of variation of these water levels and the degree of opening of the Mouth. For a given amplitude of water level fluctuation within an enclosed basin such as the Coorong, a high-frequency fluctuation must exchange the same volume of water more quickly than a low-frequency fluctuation. Since the friction associated with a current is approximately proportional to the flow speed squared, a greater frictional force must be overcome in a connecting channel (the Mouth) for a high-frequency level fluctuation to occur than for a low-frequency one. Consequently, low-frequency water level variations in Encounter Bay such as those associated with the passage of weather systems penetrate more effectively through the Mouth and along the Coorong than more rapid level fluctuations such as those due to the tides. Similarly the width and depth of the Mouth affect its ability to transfer water level fluctuations into the Coorong.

3.3 Tides

The tides along the coast of Encounter Bay are described as being micro-tidal in range and semi-diurnal with a moderate diurnal inequality (Short and Hesp 1975). Tidal ranges vary between ~1m during spring tides to ~0.2m during neap tides. When the Mouth is open the tides penetrate into the Murray estuary region and cause water level variations there.

Walker and Jessup (1992) have undertaken an analysis on the opening of the Murray Mouth and how it relates to flow through the barrages (see also section *Mouth Opening Index*). This analysis uses relative tidal energy of the semi-diurnal tidal component (12-h period) at Goolwa as a surrogate for Mouth opening. Relative tidal energy, R, is the ratio of the square of the tidal range between measurements obtained within the Coorong-Murray Mouth system and those on the coast at Victor Harbor 25km from the Mouth. Results presented by Walker (2002), which extends this analysis, show that R for Goolwa varies between 0 (Mouth closed) and 1.0 (Mouth ‘fully’ open). Visual inspection would suggest a median of ~0.4. However, for the limited measurements obtained at Tauwitcherie Barrage, the maximum value for R is ~0.5 and the indicated median would be less than 0.2. Further, Walker (2002) has suggested that a reduction in R after 1990 is indicative of sediment buildup in both the Murray Mouth and Tauwitcherie Channel. One would expect that R for the diurnal (24-h) period would be larger than that for the semi-diurnal component. Nevertheless, these results still suggest that the tidal ranges at the north-western end of the Coorong are much less than those on the open coast where daily tidal ranges vary between ~0.2-1.1m depending on whether one is experiencing the spring or neap tidal phase.

For a value of $R = 0.2$ say and a tidal range of 1m (amplitude of 0.5 m) at Victor Harbor, the amplitude of the tide at the north-western end of the North Lagoon would be ~0.2 m. Applying a simple model of tidal propagation using the calibrated friction parameters determined by CFMI (1992), the amplitude of this tide would be reduced by a factor of 5 at the south-eastern end of the North Lagoon if it is assumed to have a semi-diurnal period. By contrast, a water level oscillation of 0.2 m amplitude and having a period of 48 h would be reduced in amplitude by a factor of 0.6 illustrating the increase in efficiency of water level transmission along a water body as its period of fluctuation becomes greater. CFMI (1992) has noted that the tides do extend well down into the North Lagoon further south than Robs Point.

3.4 Wind-driven level changes

Wind blowing on the water surface exerts a force which pushes water in the downwind direction. This causes the water to pile up against the downwind shore and results in an upwards tilt of the water surface from the upwind to the downwind end. (Fig. 3). Once the wind has been blowing for long enough, an equilibrium is established in which the force of the wind on the water surface is counterbalanced by the pressure gradient associated with the water tilting in the opposite direction. If the wind speed drops to zero, then the system relaxes and the currents would flow along the Coorong in the opposite direction.

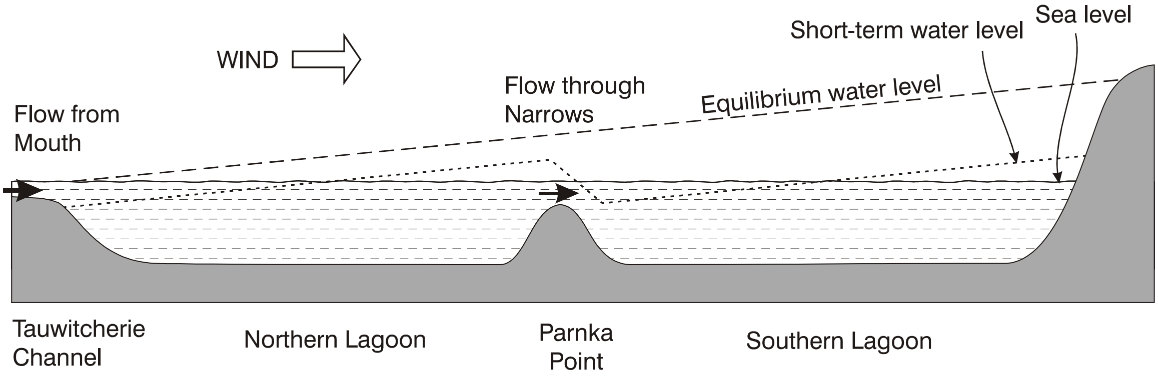

Figure 3. Schematic showing water level response in the Coorong to and along-channel wind stress.

In the short term (less than a few days), water levels in the North and South Lagoons respond individually, but eventually the entire length of the Coorong tilts in one direction due to flow between the lagoons. At equilibrium, the water level near the Mouth would be that of the sea.

For a simple lagoon closed off at the ends and of uniform width and depth, then a simple hydrodynamic analysis would suggest that the steady-state relationship between wind set-up (η) and wind speed along the lagoon (W) would be:

$$\eta \sim \frac{\rho_a L C_D}{2\rho_w g H} W^2 \qquad (2)$$

where $\rho_a \sim 1.2\,\mathrm{kg\,m^{-3}}$ is air density, $\rho_w \sim 1000\,\mathrm{kg\,m^{-3}}$ is water density, L is lagoon length, $C_D \sim 0.0015$ is the drag coefficient for wind over water, $g \sim 9.8\,\mathrm{m^2 s^{-1}}$ is gravitational acceleration, and H is water depth. Thus, the inverse proportionality with water depth makes the shallow Coorong susceptible to large wind setups.

Due to the constriction in the channels near Parnka Point, the initial response of the North and South Lagoons occurs as if these two basins had closed ends. In their analysis of the response of the North Lagoon to wind, Noye and Walsh (1976) treated this lagoon as a closed system and obtained good agreement between their model and measured water levels. Figure 3 (short-term water level) shows how such a two-lagoon system might respond to a wind blowing along its length. Using the above formula, a $5\,\mathrm{m\,s^{-1}}$ wind blowing along the Coorong would cause a setup in such a two-lagoon system of $0.09\,\mathrm{m}$ in the North Lagoon and $0.07\,\mathrm{m}$ in the South Lagoon. The time that the wind needs to blow for the setup to establish itself is of the order of 4 hours. Of course, the wind over the Coorong changes direction and speed with time, causing the water levels along the lagoons to vary in response. In CFMI (1992), measurements and model simulations show that the water level response of the lagoons is approximately in accordance with the response predicted by Eq. 2.

Figure 4 shows the high-frequency water level record for Sand Spit Point (near Salt Creek in the South Lagoon). These data were obtained by subtracting the low-frequency fluctuations having periods greater than 10 days (including the mean) from the time series of daily averaged water levels. Also shown are the water levels at Sand Spit Point 'predicted' using Eq. 2 with measured wind speeds at Meningie. It is apparent that the variations in the wind stress account for the majority of the water level fluctuations at this location in the South Lagoon. Further, the magnitude of these wind-driven fluctuations between 1-10 day periods are mostly of order $\pm 0.05\,\mathrm{m}$. The storm event in mid-September shows water levels at Sand Spit Point to rise above $0.15\,\mathrm{m}$ for about a day. Storm surges can increase water levels outside the Mouth by up to 1.5m (Bourman and Harvey 1983) and it is likely that such a surge would penetrate into the Coorong and cause substantial short-term increases in water levels there also.

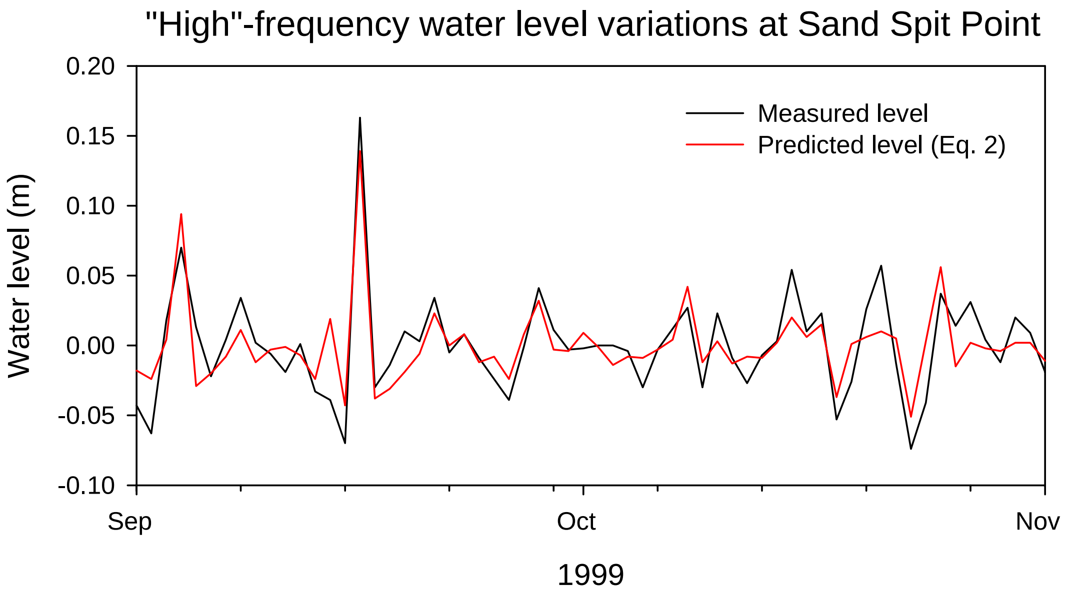

Figure 4. Comparison between measured and modelled "high"-frequency water level variations at Sand Spit Point (near Salt Creek, South Lagoon).

Treating the lagoons as separate waterbodies for wind response is likely to be reasonable provided the duration of the wind event is not longer than a few days or so. The difference in water level between the two sides of the connecting channel at Parka Point will cause water to flow from the lagoon on the upwind side to the lagoon on the downwind side at a rate that depends inversely on whether the water level at the Narrows is relatively deep (winter-spring) or shallow (summer-autumn). Eventually if the wind blows long enough, the water level on both sides of Parnka Point will equilibrate. Likewise, flow through the Mouth will eventually cause the water level at the northern end of the Coorong to equilibrate to that of Encounter Bay. In effect, the tilt in the water surface along the Coorong would respond as if the length of the lagoon were the total length of the Coorong rather than length of each of the North and South Lagoons taken separately. In this circumstance, one might expect that the water level response at the southern end of the Coorong would be augmented (Fig. 3: Equilibrium water level). The model results presented by CFMI (1992) did not address how long the wind would need to blow steadily for this circumstance to occur.

3.5 Lower frequency water level changes

Figure 5 shows monthly averaged water levels measured at Goolwa Barrage and at Robs Point in the North Lagoon. Also shown are the calculated monthly discharges through the barrages and the measured water levels at Victor Harbor. Monthly averaging removes most of the fluctuations associated with the passage of weather systems as well as the tidal fluctuations. Figure 6 shows the monthly averaged water levels averaged over the years 1985-2002. These Figures demonstrate the pronounced seasonal fluctuation in water levels in the Coorong. At Goolwa, the seasonal variation in water level was often ~0.5m and at Robs Point it was often ~0.7m. High water levels tend to occur in late winter-early spring at Goolwa (and at Robs Point), whereas lowest water levels tend to occur in late summer-early autumn.

It is apparent that the seasonal variation in water levels is associated with variation in the water level on the coast as well as variation in discharge through the barrages (Fig. 6). The lowest water levels in the Coorong occur when the flow through the barrages is a minimum and when the sea level at the Mouth is depressed. Highest water levels occur several months before the time of maximum discharge which occurs on average in spring. This phase shift is certainly due in part to the maximum of the coastal water level occurring in mid-year. Note that the period over which the monthly Victor Harbor water levels were calculated was 1998-2003 versus 1985-2002 for the monthly Goolwa levels and the barrage discharges. On the assumption that the average coastal water level variation would have been similar to that shown in Fig. 6, it would seem that on average the seasonal coastal water level variation has a similar importance to those induced by the barrage flows. Certainly, through the low discharge period between February and June, it is the change in the coastal sea level that appears to cause Coorong water levels to increase, whereas the levels later in the year may be more due to elevated barrage discharge at this time.

On an open coast such as that near the Mouth of the Coorong, waves running up the beach would be expected to cause an increase in average water level over that recorded at Victor Harbor of perhaps 10s of centimetres (Nielsen, 1988). The swell is dominated by waves from the south west and peak during April to September (Short and Hesp, 1980) so wave setup makes a contribution to the rise in water levels in the Coorong during this time. How such wave setup would interact with a channel through the beach such as at the Mouth is not known.

The flows through the barrages cause a water level change in the Coorong by increasing the outflow through the Mouth. The increased flow requires an increased hydraulic head (water level) in the landward side of the Mouth in order to overcome the increased friction. Thus, for a given channel cross section one might expect that higher discharges would be associated with higher water levels in the Coorong and this seems to be what happens. For example, the relatively large discharges of 1989 and 1990 are associated with water levels at Goolwa of ~0.5m, whereas during the low discharge years of 1994 and 1997 water levels were ~ 0.2m.

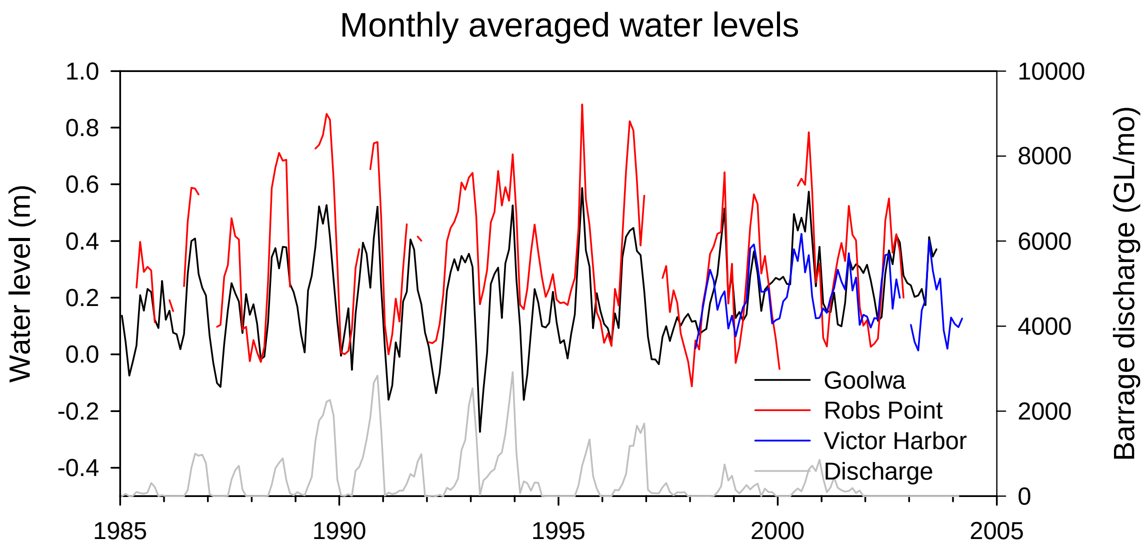

Figure 5. Measured monthly averaged water levels at Goolwa Barrage, Robs Point, and at Victor Harbor. Also shown are calculated discharges through the barrages.

Elevated flows appeared to cause even higher water levels at Robs Point. We suggest that this phenomenon must be due to the manner of discharge through the barrages. Discharge through Tauwitcherie Barrage would tend to elevate water levels at Robs Point above those caused by discharge through Goolwa Barrage due to the way in which the channels from the two barrages connect to the Mouth.

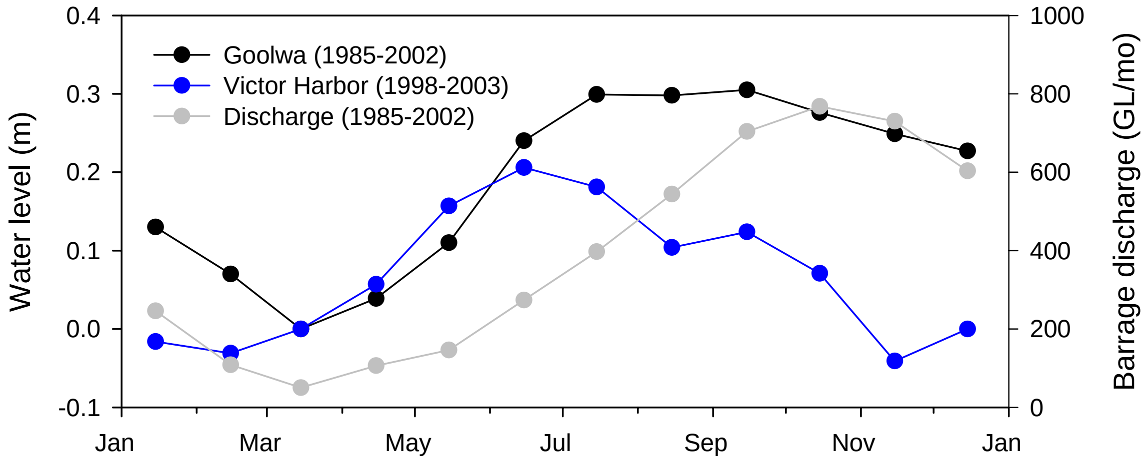

Figure 6. Measured monthly water levels at Goolwa and Victor Harbor averaged over the years shown in the legend. Also shown are averaged monthly discharges through the barrages.

Figure 7 shows the water levels measured at Robs Point in the North Lagoon and at Sand Spit Point in the South Lagoon with a 10-day running average applied. Both locations are near the southern ends of their respective lagoons. It is apparent that for most of the year, water levels at both sites track one another fairly closely. Variations in water levels at both sites occur due to variations in water levels imposed at the coast as well as by variations in barrage discharge. Differences in water level between the two locations would be due in part to tilt of the water surface caused by a component of the wind blowing along the length of the Coorong. Accordingly, Fig. 7 also shows the water level difference between the two locations that would occur due to wind tilt calculated using Eq. 2. For 10-day averaged wind stresses, the elevation difference due to calculated wind tilt shows a distinct seasonal variation. The dominant southerly or southeasterly wind directions of summer are estimated to cause water levels towards the southern end of the South Lagoon to be depressed by ~0.05m compared to the winter condition.

There is a consistent and significant difference between water levels at Robs Point and at Sand Spit Point that occurs through January-April in the record shown as well as in longer time series of levels at the two locations. The pattern of water level depression of ~0.2m at Sand Spit Point during this time is not consistent with it being simply due to wind tilt. This is the time of the year when water levels in the Coorong are at their lowest and the channel connecting the North and South Lagoons is most restricted. In fact, Noye (1975) states that "..this channel becomes very shallow and at one place during most summers the water level falls sufficiently for a sand bar (Parnka Crossing) to become completely exposed, thereby completely separating the waters of North and South Lagoon". A measured cross section near Parnka Point presented by CFMI (1992) shows a maximum water depth of ~0.3m AHD, so when the water level in the system reduces to this height, the flow through the channel at this time would be so restricted (if it occurs at all), that it would not be able to replace evaporative loss in the South Lagoon. The divergence of water levels between the North and South Lagoons would suggest their effective separation when water level reduces to ~0m AHD. A second possibility is that wind events in the South Lagoon would raise the level at its northwest end sufficiently to cause water to spill through the channel into the North Lagoon. Due to the prevalence of southerlies and southeasterlies in summer such spilling is likely to result in more water being transported from the South to the North Lagoon rather than the other way round. Either way water levels in the South Lagoon drop significantly below those in the North Lagoon at this time.

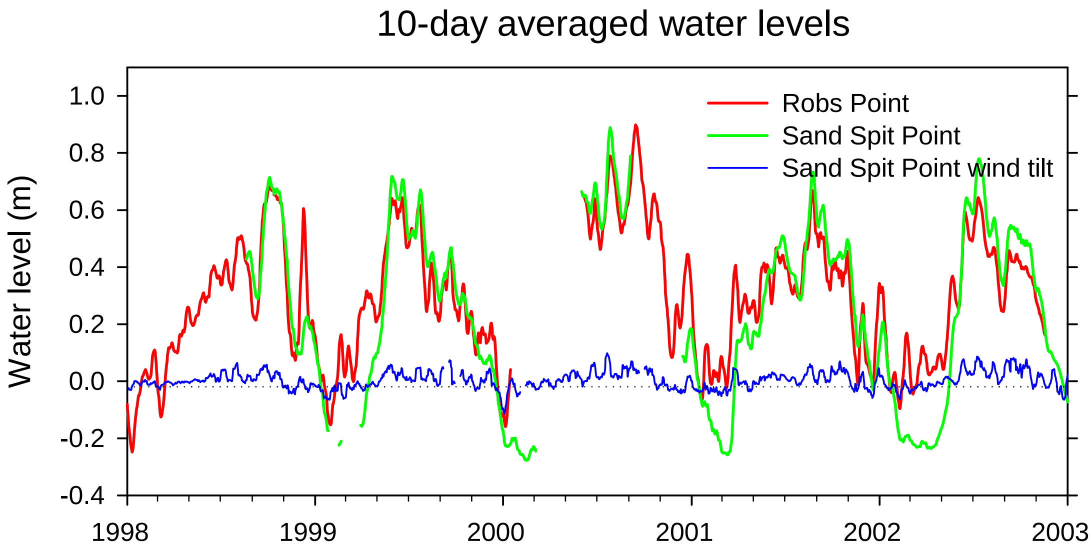

Figure 7. Measured water levels at Robs Point (North Lagoon) and at Sand Spit Point (South Lagoon) presented as 10-day running averages. Also shown are the water levels at Sand Spit Point due to wind tilt (Eq. 2).

3.6 Salinity

Salinities have been measured along the Coorong over a number of years. Salinity is an important parameter because it is an important component of the physico-chemical environment. Most aquatic flora and fauna thrive over limited salinity ranges. Also, salinity is an important indicator of the exchange processes that are occurring in a water body.

The salinity distribution along the Coorong is determined by the balance of freshwater input into the system by the flow through the barrages and by precipitation, by loss of water through evaporation, and by the exchange (mixing) of water along the lagoons and between the lagoons. Groundwater input also has a potential (but unknown) effect on salinity. The freshwater input through the barrages tends to lower salinities at the northwest end of the Coorong, whereas the excess of evaporation over precipitation tends to increase salinity along its length. The overall salinity pattern in the Coorong is for salinity to increase from its northwest towards its southeast end. Depending on the flow through the barrages, salinities can be near zero at the northwest end of the Coorong. Typically salinities can be several times that of seawater at its other end due to the excess of evaporation over precipitation. All of the factors affecting salinity combine to not only set the average yearly salinities along the Coorong, but also to cause a significant seasonal cycle. Geddes and Butler (1984) and Geddes (1987) described measurements of salinity along the North and South Lagoons and relate the distribution and variations in salinity to flows through the barrages.

Release of freshwater typically during June-October and peaking in August causes the water off Pelican Point to become relatively fresh with salinities of less than 5 measured on occasion. One might expect that the actual salinities in this zone to be dependent not only on the volume and duration of the flow through the barrages, but also on the degree of opening of the Murray Mouth. A relatively open Mouth would allow more vigorous mixing of sea water through the Mouth and would tend to increase salinities.

Along the length of the Coorong, salinities are impacted by the relative rates of precipitation and evaporation. Evaporation rates from the Coorong have been estimated from measured pan evaporation rates adjusted by a factor of 0.8 (CFMI 1992). Measurements presented for the region over 3 years by CFMI show that pan evaporation rates tend to be a minimum during winter (May-August) when rates are $\sim 2\,\mathrm{mm\,d^{-1}}$ and a maximum in summer (November-February) with rates of $\sim 7\,\mathrm{mm\,d^{-1}}$. Rainfall shows the inverse pattern with rates of $\sim 3\,\mathrm{mm\,d^{-1}}$ in winter and less than $1\,\mathrm{mm\,d^{-1}}$ in summer. Thus, except during winter months, the Coorong loses water across its surface due to the dominance of evaporation over precipitation. This imbalance causes the salinity to increase.

According to CFMI (1992), mixing along the North and South Lagoons and between lagoons is mainly caused by the winds 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 to tend to cause the salinity to become more uniform along the Coorong. However, the exchange of water past Parnka Point is restricted allowing evaporation to concentrate salinities in the South Lagoon to well over those of seawater.

We now consider some details of the salinity dynamics as illustrated by measurements obtained at three locations along the Coorong over a 4-year period and downloaded from the Surface Water Archive (2004). Figure 8 shows the measurements as 10-day running averages. Mark Point is near the northwest end of the North Lagoon and Sand Spit Point is near the southeast end of the South Lagoon. The general increase of salinity along the Coorong from north to south is very evident, but the salinity behaviour at the three locations is quite distinct. The salinity at Mark Point ranges from near zero near times when the elevation through the barrages is relatively high in the spring-summer of 1998/1999 and 2000/2001. Salinities increase to levels at or exceeding those of seawater (~35) when the discharge was near zero during the summer-autumn of 1998, 2000, and for most of 2002 when the discharge was zero.

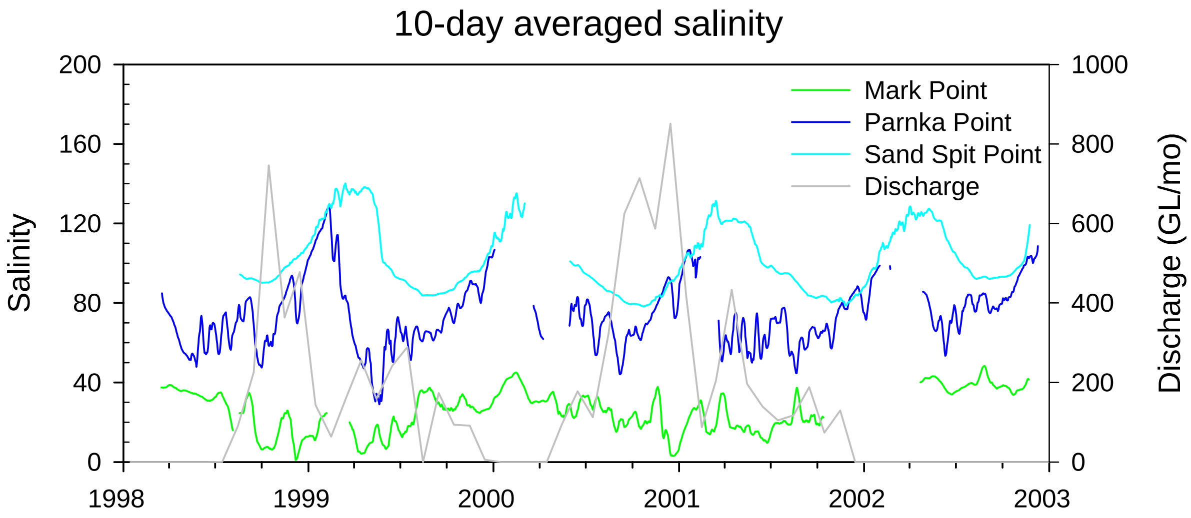

Figure 8. Measured salinity at Mark Point (North Lagoon) and at Sand Spit Point (South Lagoon) presented as 10-day running averages. Also shown is the discharge through the barrages.

During this time, salinity at Salt Spit Point varied between 80-140 with an average of 105; that is, salinities varied between over twice seawater salinity to four times seawater salinity. Salinity shows a pronounced seasonal cycle of ~40 with highest salinities occurring in March-April and lowest occurring in September-November.

Why does the salinity vary the way it does seasonally and what sets the overall salinity level? Near the middle of the low-salinity time in October 2001, the salinity in the South Lagoon is ~80 and it increases to ~125 in April 2002. Assuming an estimated average evaporation rate of $5\,\mathrm{mm\,d^{-1}}$ and an average precipitation rate of $1\,\mathrm{mm\,d^{-1}}$ over this 6-month period (measured at Salt Creek) would result in the net loss of ~700 mm of water. During October-December, 2001 there was inflow through Salt Creek of water having salinity 10-12. Averaged over the area of the South Lagoon, this inflow would contribute ~100 mm of water which is much fresher than the water already present so we could consider that the net loss of freshwater (including the inflow) was 600 mm during the October-April period. Assuming that there was no mixing between lagoons, then a loss of 600 mm from a water column of initial depth 1.9 m would cause the salinity in the South Lagoon to concentrate to 115 which is similar to what was measured in April 2002. Thus, evaporation is sufficient to explain the increase in salinity in the South Lagoon during the summer season.

We now consider the issue of how the salinity decreases again during the winter months. Consider the time period April 2002 to October 2002. For this period, evaporation (~400 mm) still exceeds precipitation (~300 mm), but the net loss to the system is reduced to ~100 mm. During this time, the water level in the South Lagoon increases from $\sim -0.2\,\mathrm{m}$ (AHD) to $\sim 0.4\,\mathrm{m}$, a change of $0.6\,\mathrm{m}$. Assuming that the water required to achieve this water level change comes from the North Lagoon with a salinity of ~40 and assuming that this water mixes with the water of salinity ~125 that was in the South Lagoon in April 2002, then the salinity of the mixture would be ~95. This salinity is similar to the salinity measured at Sand Spit Point in September-October 2002. During this time period, the flows recorded for Salt Creek were small.

Measurements made by E&WS (CFMI (1992) of salinity at Salt Creek near Sand Spit Point showed a similar seasonal cycle of salinities to those shown in Fig. 8, but with lower salinities overall. During 1985-1988, the average salinity was ~85 dropping to ~60 during 1990-1992.

Overall, barrage discharges in 1985-1988 were not dissimilar to those for the period shown in Fig. 8 (1998-2003), but discharges were unusually large in the early 1990s (Fig. 2).

The salinities measured at Parnka Point during the 4-year period largely fall in between those measured at Mark Point and Sand Spit Point. In effect, the salinity at Parnka Point largely reflects mixing and exchange between the relatively high salinity waters of the South Lagoon and the lower salinity waters of the North Lagoon and also illustrates a pronounced seasonal cycle. For a period in summer, salinities at Parnka Point reach and follow those at Salt Spit Point. Later in the summer, the North and South Lagoons become separated due to low water levels in the channel connecting them and the salinities in the two lagoons diverge.

This simple analysis demonstrates features of how the seasonal cycle of salinity variation within the South Lagoon are related to net evaporation rates, salinities in the North Lagoon and water level changes in the system. It is an approximate analysis only. Clearly if water was being evaporated from the South Lagoon and was simply replaced by an inflow of saline water from the North Lagoon during the winter months, there would be a net accumulation of salt in the South Lagoon every year and its salinity would keep on rising year after year. There was a net input of salt into the South Lagoon between 2001 and 2002, but the average salinity of the lagoon was less in 2001 than it was in 1999. The mechanisms that allow the lagoon to lose salt are two-way mixing between the North and South Lagoons which has been included in the hydrodynamic modelling of the Coorong (CFMI, 1992) and the outflows from the South Lagoon that would occur if the seasonal range in water level variation were greater than the net rate of water loss from the lagoon including evaporation, precipitation and Salt Creek inflows.

As with the seasonal variation in salinities, the average salinities in the South Lagoon will be determined by net evaporation rates, salinities in the North Lagoon, water level changes, and by long-channel mixing. Estuarine salinities, that is salinities of less than or equal to those of seawater, have not been recorded in the South Lagoon since the floods of 1975 (Geddes and Butler 1984, Geddes 2000) when salinities along the North Lagoon were lower than normal.

3.7 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 in the water column implies that the water column is not completely mixed or perhaps that mixing is not occurring vigorously enough to negate a stratifying tendency such as differential absorption of solar radiation. Further, the density of water is dependent on both its temperature and its salinity so that stratification in temperature and/or salinity indicates that the density of water changes with depth from the surface. Under normal conditions, the water column is either not stratified (indicating sufficiently vigorous vertical mixing) or it is stably stratified; that is, the density increases with depth. A stably stratified water column is more difficult to mix than a uniform water column because with stable stratification, energy is required to ‘lift’ parcels of relatively dense water upwards or equivalently to ‘push’ water of relatively low density downwards. Thus, stratification indicates incomplete mixing of the water column as well as being a condition that inhibits mixing.

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 bottom dwelling organisms. Also, anoxic conditions can lead to the release of phosphorus and ammonia from bottom sediments and thereby exacerbate eutrophication. In the hypersaline waters of the South Lagoon, the saturation concentration of oxygen would be low thereby increasing the propensity of serious oxygen depletion during stratified conditions. A second effect of stratification is to reduce the amount of friction between water layers. This reduction allows water layers to slide over one another more easily so that the response of the currents to wind blowing over the water surface is modified and so affect the way in which salinity and nutrients are transported along the Coorong.

The one study that describes the stratification behaviour of the Coorong is that by Holloway who undertook his PhD on the subject (Holloway, 1980a, 1980b). Holloway showed that the Coorong stratifies in both temperature and in salinity. Measurements over the period of a year demonstrated three types of stratification. The first, and most common, is the maintenance of isothermal conditions in the water column. The wind is sufficiently strong or the energy input across the water surface is sufficiently low that the wind is capable of maintaining the water column in a mixed condition.

The second class of stratification which Holloway calls stratification formation and decay typically occurs on a diurnal basis. Early in the morning, the water column may be isothermal, but as the sun rises the temperature of the near surface waters heats up and stratification is established. Sea breezes later in the day (or perhaps the passage of a weather system) are sufficiently strong that the water column becomes fully mixed. In his study, Holloway demonstrates that the destruction of stratification under these circumstances is largely predictable and typically occurs when an energy flux ratio exceeds a critical value. This ratio depends on the wind speed cubed divided by the buoyancy flux times the water depth. The buoyancy flux is calculable from the net input of heat energy across the water surface (solar radiation, thermal emission, heat conduction, evaporative heat loss) and the turbidity of the water column. The value of the ratio decreases with increasing water depth and increases with turbidity so that the susceptibility of the water column to remain stratified under a specified wind speed is greater in the deeper parts of the Coorong and increases when the water is more turbid. Application of this analysis demonstrates that under conditions of maximum summertime heating in a system that has a water depth of 3m and a light extinction coefficient of $1\mathrm{m}^{-1}$ (moderately turbid) stratification would be established in the water column for wind speeds less than $\sim 4\,\mathrm{ms}^{-1}$ or $\sim 14\,\mathrm{km\,h}^{-1}$.

During the night, the water surface cools due to evaporation, long-wave (thermal) emission to the sky and heat conduction with the atmosphere. More often than not, one would expect that the heat loss during the night would be similar to the heat gain during the day so that the net change in thermal energy of the water column over 24 h would be close to zero. In these circumstances, any stratification that had formed in the water column after the day’s heating would be eroded at night and that the water column would have mixed from top to bottom by dawn. If mixing does occur through the water column on a daily basis, then the likelihood of significant oxygen depletion in bottom waters is diminished. It is apparent from studies in slow flowing sections of the River Murray near Lock 1 (Bormans and Webster 1998) that thermal stratification can persist for several days in a row. This situation is associated with the passage of weather systems over the region. For example, if cold, cloudy conditions are followed by a change to finer, warmer weather, the net amount of heat absorbed by the water column can continue to increase so allowing for the maintenance of thermal stratification. Of course, if winds are sufficiently vigorous, thermal stratification might be destroyed despite favourable heating conditions. Condie and Webster (2001) provide an analysis that demonstrates how stratification might or might not be maintained under prescribed daily heat inputs and wind conditions.

The third class of stratification in the Coorong identified by Holloway is salinity stratification. Holloway (1980a) identified several occasions during a year-long study undertaken at Long Point when salinities in the surface layer were markedly different from those in the deeper part of the water column. Long Point is located approximately mid-way between the Mouth and Parnka Point. The stratification development is attributed to the advection of a relatively fresh layer on top of an existing brine layer or from the advection of a brine layer beneath an existing fresher layer. Overall, one might expect that the brine layer to originate towards the southeast end of the North Lagoon and perhaps even from the South Lagoon, whereas the fresher layer could result from either freshwater flows over the barrages or from seawater originating from the Mouth.

Holloway describes two occasions on which salinity stratification was evident. The first of these occurred in summer in January 1977 and lasted for at least a day (the near-surface salinity sensor failed after this time). The difference in salinity between the upper and lower parts of the water column was measured to be ~12. The second occasion occurred in July 1976 and lasted for ~9 days with a salinity difference of up to 20 through the water column. On this occasion, the bottom layer was measured to flow in an approximately northwards direction out of the Coorong, but the surface layer oscillated back and forth apparently following the direction of the wind. This behaviour illustrates how the stratification can cause the motions in the upper and lower parts of the water column to decouple from one another. On his more intermittent surveys, Geddes (1987) noted that the water column was usually isohaline, but there were occasions when significant stratification was measured. More recent measurements at a series of stations along the North Lagoon by Geddes (2005) showed the lagoon to be mostly vertically mixed in salinity during transects in September 2003 and July 2004, but significant vertical stratification along most of the lagoon length in April 2004.

The few measurements of the salinity structure in the South Lagoon (Geddes and Butler 1984, Geddes and Hall 1990) do not show evidence of stratification. However, we consider that it is probable that stratification does occur from time to time. There would be the opportunity for stratification to occur when relatively fresh water flows into the South Lagoon past Parnka Point in mid year. Other freshwater inputs from Salt Creek or through precipitation could 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.

Depending on the rate of bacterial degradation of organic matter in bottom water and on the sediment surface, stratification that persists for 9 days (or even longer) may be of sufficient duration to cause bottom waters to deplete in oxygen to a serious extent. At the stations with significant stratification in April 2004, Geddes (2005) measured bottom oxygen concentrations to have been up to $5\,\mathrm{mgL}^{-1}$ lower than those measured at the surface. Holloway (1980a) has also noted that salinity stratification was associated with ‘heat pooling’. Heat pooling occurs when the water column is sufficiently clear that bottom water heats up due to the absorption of solar radiation during the day. Unlike the case of thermal stratification for which the whole of the water column tends to cool and mix during the night, the salinity stratification may be sufficiently strong to prevent vertical mixing. The surface waters may cool during the night but the bottom waters don’t. The measurements of Holloway suggest that bottom water temperatures were several degrees warmer than they would have been without the stabilising effects of the salinity stratification. Since bacterial degradation processes increase with temperature, the heat pooling effect would tend to exacerbate the tendency of the Coorong to experience anoxic bottom waters under conditions of salinity stratification.

4. Summary and Conclusions

This report has considered features of the hydrodynamics of the Coorong and Murray Mouth particularly as these affect water level variations and salinity in the system which are both important elements of habitat. It is evident that longer period variations (> 5 days) in water level in the North and South Lagoons are affected by sea level variation as well as by discharges of fresh water through the barrages. As long as the Mouth is open, the seasonal variation in sea level appears to penetrate the length of the Coorong and is not likely to be strongly influenced by the degree of Mouth opening. Conversely, the water level response of the Coorong to barrage discharges is likely to be affected by which barrage is discharging and by the degree of channel constriction in the Mouth region. Significant shorter period water level variations are caused by the wind which tilts the water along the lagoon basins one way or the other and by the tides which penetrate into the northern end of the North Lagoon.

Salinity along the Coorong is affected by barrage discharges which supply fresh water to the northern end of the system. Other important drivers of salinity are evaporation, precipitation and drainage from the USED. The distribution of salinity along the Coorong is determined by flows and mixing processes in the system. It is certain that wind is an important agent for long-system exchange as are tidal flows near the Mouth, but so to is longer period water level variations associated with sea level changes and barrage discharges. The rise and fall of water level act to pump water from one part of the Coorong to another. The balance between evaporation and water exchange caused by water level change results in a seasonal cycle of salinity variation in the South Lagoon and determines overall salinity levels there. Thus, manipulation of water levels in the system through dredging of the Mouth or varying barrage discharges has implications for the salinity regime and for the exchange of other materials such as nutrients.

The occurrence of significant salinity stratification has been observed in the Coorong, but its dynamics are not well described. Through its potential to allow bottom water to become depleted in oxygen, persistent stratification could have significant deleterious impacts. Salinity stratification certainly arises as a consequence of waters of differing salinity sliding over one another and is diminished by vertical mixing including by the wind. Thus, it is likely that manipulation of water levels and salinity in the Coorong will also affect the propensity of the system to stratify, but how this would occur is not known at present.

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