25/4/98

Dave, I see you're getting involved with the Murray Mouth - I forget if I sent you this paper (2 yrs old)
regards
Nick

# The Significance of Coastal Processes for Management of the River Murray Estuary

NICK HARVEY

*The tidal prism in the River Murray estuary has been reduced by over 85 percent since completion of the barrages in 1940 and regulation has diminished the rate and size of river flows through the estuary. Reduced fluvial flushing has emphasised the dominance of coastal processes at the river mouth. These are expressed in the accretion and stabilisation of a flood-tidal delta, the migration of the mouth, the erosion of Sir Richard Peninsula and the accumulation of new flood-tidal deltaic deposits. Inconclusive studies relating river flow to mouth migration indicate the importance of coastal processes such as littoral drift, tidal flux and sea state, particularly at times of low river flow, in explaining the position and morphology of the mouth. Previous management strategies have failed to consider coastal processes adequately.*

In a recent article in this journal, Bourman and Barnett (1995) examined the impacts of river regulation on both the terminal lakes and the mouth of the River Murray. In particular, they suggested that river regulation has transformed a migrating flood-tidal delta at the Murray Mouth into a permanently vegetated island. The formation of the flood-tidal delta has previously been described by Bourman and Harvey (1983), historical surveys and photographic sequences of mouth migration have been documented (Harvey, 1983) and analysis of the nature and rate of vegetation succession on the flood-tidal delta (Bird Island) has been reported (Carruthers, 1992). These studies all provide strong evidence of the rapid sedimentation, vegetation and stabilisation of Bird Island over the fifty year period since construction of the lower Murray barrages. However, there is less evidence of the impact of river regulation on shorter term geomorphic changes in the estuary, such as the migration of the Murray Mouth.

Attempts to assess the impacts of river flow on the morphology of the Murray Mouth have met with little success. There is disagreement about the role of river erosion in the migration of the mouth (Thomson, 1975; Walker, 1990) although results of flushing studies investigated by the Murray Mouth and Coorong Working Party suggest that the mouth is substantially cleared by a flow of 20,000 ML $day^{-1}$ for a month or more (Harvey, 1988). Walker (1990) referred to previous studies, mainly from the North America, which used inlet area, tidal prism, inlet velocity and littoral drift as parameters for describing inlet equilibrium. These

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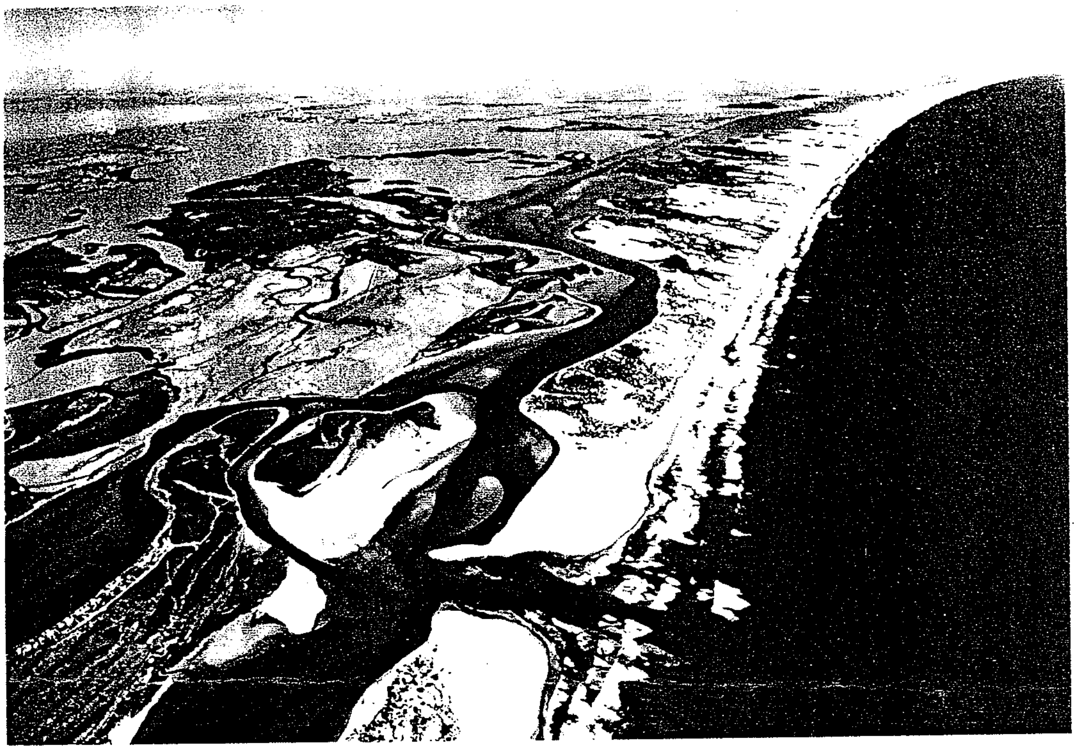
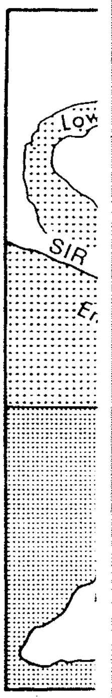


Fig 1 The River Murray estuary in 1989 looking southeast, with Sir Richard Peninsula and Murray Mouth in the foreground and Younghusband Peninsula and Coorong Lagoon in the distance. (Reproduced with permission of the Department of Environment and Natural Resources, South Australia, Mapland)

studies noted the importance of near-shore wave energy when inlet closure was being considered, but generally assumed that river flow was less significant than tidal flows. Walker and Jessup (1992) used time series analysis to demonstrate the relationship between river flow and mouth restriction at the Murray Mouth. They also used estimated freshwater flow across the barrages (since there are no measured flow data at the barrages) to investigate the relationship between patterns of flow through different barrages and the direction of mouth migration. Walker's (1991) data could not substantiate the view that mouth migration responded differently to flow from the southeast, through the Tauwitchere barrage, as compared with flow from the northwest through the main Goolwa barrage. He did note, however, that none of the short-term changes associated with high river flow was to the southeast. Walker concluded that littoral drift was more likely to be the dominant factor in migration of the river mouth.

Recent proposals to release drainage waters from low-lying agricultural land into the Coorong Lagoon (Natural Resources Council, 1993; 1994) required environmental impact studies to investigate the effect of such flows on salinity in the lagoon. These reports concluded that there is very little water exchange between the north and south lagoons. In the north lagoon the tidal influence decreases dramatically south of Tauwitchere barrage. Similarly, freshwater flows from that barrage are short-lived, but can



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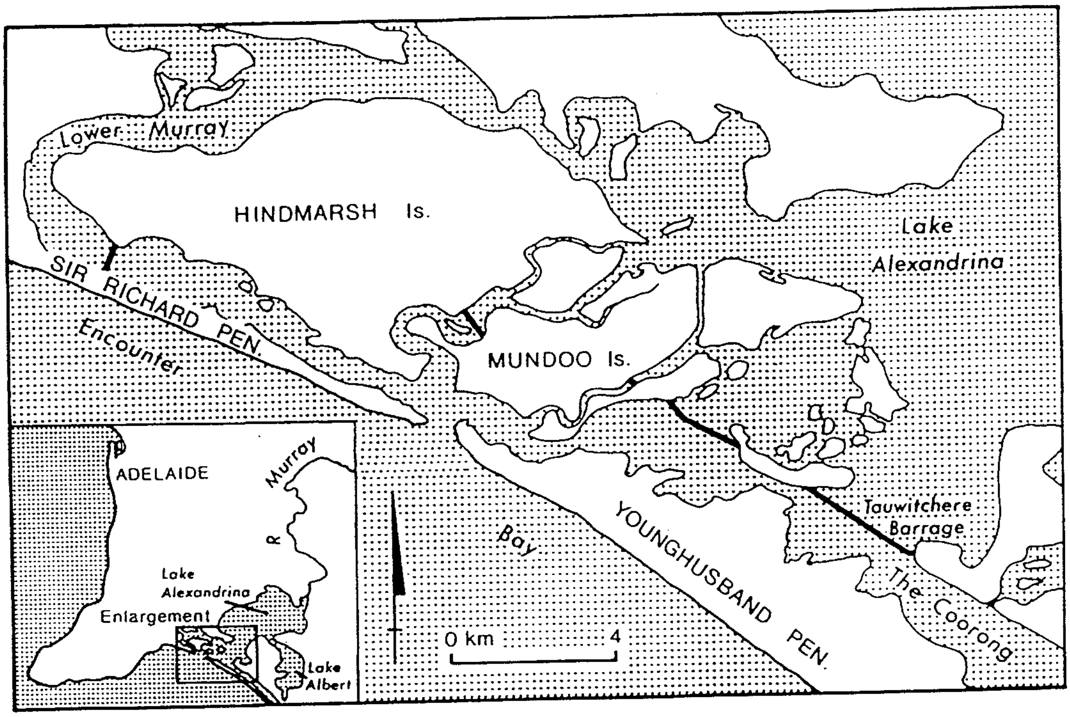


Fig 2 The River Murray estuary

extend as far as the southern end of the northern lagoon. Hydrological modelling studies for the Coorong Lagoon are currently being extended into the river mouth region by the South Australian Water Department.

It is clear that the River Murray estuary has been heavily modified by progressive river regulation. In particular, there have been 20 to 30 periods of no flow when the barrages have been closed for 100 days or more consecutively. The barrages have also resulted in a physical restriction of the area of tidal influence (Fig. 2). In 1914 the lake area affected by tides was 97.3 km$^2$ and the tidal prism at the Murray Mouth was estimated to be 16,900 ML (Johnston, 1917). This contrasts with recent estimates of the tidal prism ranging between 643 and 2,200 ML (Murray Mouth Advisory Committee, 1987). These figures suggest that an 87-96 per cent reduction of the tidal prism has resulted from the construction of the barrages in the late 1930s.

The importance of coastal processes in the management of the estuary was demonstrated by the rapid development of the flood-tidal delta, which closed off the Murray Mouth, in April 1981 (Bourman and Harvey, 1983). The management responses to this event, the problems of overlapping management jurisdiction and the lack of environmental management coordination have been detailed by Harvey (1988). Since that time there has been very little evidence of a more integrated approach. However, the South Australian government has renewed its interest in the area because of its studies of drainage flow into the Coorong Lagoon and the presence of increased flood-tidal deltaic deposits forming within the river mouth. The government has not yet, however, commissioned any new coastal process studies.

## Coastal evolution

The geological setting of the region has been described by Bourman and Murray-Wallace (1991), who summarised results of previous geological and geomorphological studies. The River Murray estuary is located within the Murray Basin, a Tertiary embayment. During the Quaternary period, fluctuating sea-levels, together with differential tectonic uplift in the region, stranded a series of more than twenty coastal barrier systems. These ranges extend inland up to 100 km in the southeast but are progressively warped downwards towards the Murray Mouth (see Fig. 1 in Bourman and Barnett, 1995). Bourman and Murray-Wallace (1991) indicated that the position of the lower Murray channel between Points Sturt and McLeay, and the Narrung Narrows, has not changed for the past 780,000 years. This is not the case for the Murray Mouth, however, where there is evidence of significant migration throughout the Holocene.

The coastal geomorphology of the Coorong area has been described in broad terms by Harvey (1981). The coast is dominated by a major coastal barrier system of Holocene dunes (Fig. 1), which have formed in response to modern sea-level following the post-glacial marine transgression. The barrier system is unbroken apart from the Murray Mouth, which separates the Younghusband Peninsula to the southeast from the Sir Richard Peninsula to the northwest. The Younghusband Peninsula is a Holocene coastal dune barrier on an older, calcreted inlier related to high sea-level stands of 80-100,000 BP, during the last glacial period (von der Borch, 1976; Harvey, 1981). Archaeological data (Leubbers, 1978; 1982) related to three pre-historic settlement phases on the northern part of Younghusband Peninsula provides a framework for its geomorphological development. The first phase (6,000-4,500 BP) indicates sporadic use of the incipient barrier system when it was a chain of islands (Leubbers, 1982). An early settlement phase between 4,500-2,000 BP is significant, representing initial colonisation and settlement by cohesive land-using groups. This evidence, together with a change in predominant shell-midden type in the southeast, indicates that the dominant marine influence in that area ceased as the islands became linked to form a continuous barrier around 2,000-3,000 BP. After this time there was a major settlement phase with large sedentary or semi-sedentary populations on the peninsula; the shell mound at one habitation site contains the refuse from an estimated 9,000-150,000 meals (Leubbers, 1982). The current Younghusband Peninsula is about 160 km in length, up to 3 km in width opposite the Tauwitchere barrage (see Fig. 2) and has dunes of up to 30-40 metres in height.

The Holocene evolution of Sir Richard Peninsula during the last 6,000-8,000 years has been described by Bourman and Murray-Wallace (1991). Using geomorphic evidence from aboriginal middens and former flood-tidal deltas, together with $^{14}$C and amino acid dating of sediments on the peninsula they suggested that the Murray Mouth had migrated over some 6 km during the last 3,000 years. The peninsula has formed from the accumulation of Holocene and modern sand dunes over washover-fan deposits (Bourman and Murray-Wallace, 1991), but unlike the Younghusband Peninsula there is no evidence of an older calcrete inlier. The resultant dune barrier system is 10 km in length and increases in age towards Goolwa. It varies in height from up to 15 m near Goolwa to 5-10m near the Murray Mouth. Historic surveys and photographic records of the modern Murray Mouth (Johnston, 1917; Bourman, 1974; Thomson, 1975; Harvey, 1983) indicate that it has migrated over a distance of about 1.4 km since its position was first surveyed.

## Modern coastal processes affecting the River Murray estuary

Investigations of coastal processes have so far produced little satisfactory information on the cause of recent changes in the mouth of the estuary. Short and Hesp (1980) provided data on wave energy for the area derived from Cape Northumberland, 40 km southeast of Kingston. They indicated that the region experiences a modal swell wave of 2-4 m for 62 per cent of the year with superimposed storm waves of greater than 1 m for 68 percent of the year. High energy storm waves (>2.5 m) occur for 12 per cent of the year and high swell (>4.0 m) for six per cent of the year (Short and Hesp, 1980). They also suggested that the steep offshore gradient at the Murray Mouth results in only a 20 per cent loss of wave energy, so that the consistent moderate to high energy wave climate is significant with respect to sediment supply to the mouth.

Bourman and Murray-Wallace (1991) have demonstrated the importance of the onshore wave component of wind data from Victor Harbor and Meningie. They show that winds of >28.8 km $hr^{-1}$ (capable of generating longshore transport) have resultants trending from the southwest. Bourman (1986) also reported active aeolian sand drift to the east, towards the Murray Mouth, under conditions of strong westerly winds and calculated that more than 5,000 tonnes of sand were incorporated, in a single storm event, into migrating sand ridges up to 20 cm in height. He concluded that similar conditions occurred, on average, for about two per cent of the year (Bourman, 1986). Bourman and Murray-Wallace (1991) reviewed the comments of previous authors on the role of littoral drift at the Murray Mouth with some discounting its role altogether and others suggesting that the mouth is at the convergence of two drift directions.

### *Littoral Drift*

Littoral drift studies have provided data for the period between 1940-1990 (Chappell, 1991). Preliminary discussion of these results has been presented by Harvey and Chappell (1992) and Reissen and Chappell (1993) and their implications are reported on more fully below. Wave climate was hindcast along the coastline at the Murray Mouth using US Army Coastal Engineering Research Centre (CERC) methods detailed in their Shore Protection Manual (1984).

Wind data for all storms capable of affecting the Murray Mouth were calculated from archival synoptic charts compiled at three-hour intervals. This included all storms from the west around to the SSE. The study did not include a direct comparison with land-based wind data from sites such as Victor Harbor, Cape Borda and Meningie. Refraction diagrams were constructed for waves with periods from 6 to 15 seconds, although Chappell (1991) gave no indication of the directional spacing of the refraction runs. On the basis of one refraction diagram for a 15-second swell wave from the WSW, generated below 40$^{o}$ latitude (Chappell, 1991), it was assumed that the swell waves arrive parallel to the coast and are insignificant in calculations of littoral drift. However, given the importance of swell in this area it would be useful to have more accurate calculations of the swell angle and it is possible that the littoral drift component of the swell is more important than Chappell (1991) assumed. The Murray Mouth, which is open to the sea from the west around to the south and south-east, is protected from the bulk of the westerlies by Kangaroo Island, but refraction allows some of the longer waves to reach the mouth. Westerly waves of 6-8 seconds are occluded by Kangaroo Island.

Wind velocity, direction and fetch were calculated for each significant storm, of which there were 3,849, for the period 1940-1990 (Chappell, 1991). These data were analysed using wave energy flux methods to provide estimates of the potential amount of sand that could be moved along the beach, given adequate supplies. However, it should be noted that these types of calculations can have error margins of up to 200 per cent (Harvey and Bowman, 1987).

The study by Chappell (1991) indicated an average nett littoral drift of 260,000 $m^3yr^{-1}$ between 1940 and 1990, a figure about half that of the potential sand movement on the Gold

Coast in Queensland. The nett sand movement for each year is shown in Figure 3. These data reveal two important points. One is the high rate of sand movement in any one year, such as 1941 or 1942, both of which had a potential westerly movement of over 1,000,000 m$^3$. Second, the figures reveal major directional shifts in potential sand movement. Between 1940 and 1950 the movement was predominantly to the west, between 1951 and 1968 predominantly to the east and between 1969 and 1989, predominantly to the west.

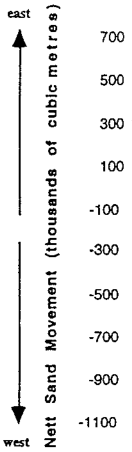
Chappell (1991) attempted to correlate littoral drift with mouth movement based on measurements from the historic photographic record. These measurements appear to be consistent with those of Walker (John Botting and Associates, 1990), but Walker noticed differences between his calculations and those of both Thomson (1975) and the Murray Mouth Advisory Group (1987). These differences probably relate to inaccuracies in measurement from aerial photographs. Chappell (1991) concluded that there is a correlation between mouth migration and the predominantly westerly littoral drift between 1974 and 1990, but there was not a similar correlation for the earlier years.

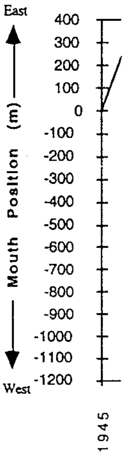
There are inherent dangers in interpreting mouth movements from aerial photographs where there are large gaps and inconsistencies in the record. Between 1945 and 1978 the photographic record is irregular, with gaps of up to four years between successive photographs. Since 1978 there is a better coverage with yearly photographs between 1980 and 1986 and again between 1989 and 1995 when there was a monitoring programme by the South Australian Department of Engineering and Water Supply (E&WS). The photographic data on the changing mouth position are shown in Figure 4 as variations east or west of the arbitrary mouth position on the first available photograph (24/4/45). A number of conclusions can be drawn. First, the position of the mouth was to the east of its 1945 position for a period of 33 years up to 1978 and subsequently it has remained to the west of the 1945 position. Second, the direction of movement between years is highly variable, although there appears to be have been a number of periods of four or more consecutive years with a consistent direction of movement. Third, the most recent period of westerly movement (1981-1995) appears to be the longest consistent movement in one direction since photographic records have been kept. Fourth, the recent period of movement appears to be the most rapid average yearly movement on record.

### Tides and Flow Through the Mouth

Encounter Bay has a micro-tidal, spring high-water range of 0.8 m at Victor Harbor, although storm surges may raise sea level by up to 1.5 m above the predicted astronomical tide (Bourman and Harvey, 1983). As noted above, the barrages when closed reduce the tidal prism by around 90 per cent of its original pre-barrage size (16,900 ML) as estimated by Johnston (1917). A more recent estimate of the original spring tidal prism by Walker (1990), based on measurements at the barrages, suggested an even higher figure of 20,000 ML.

Walker (1990) used a linear model to demonstrate that the variation in relative tidal amplitudes recorded inside the mouth at Goolwa Barrage and outside the mouth at Victor Harbor, was associated with a variation in the restriction of the mouth. Walker's model indicated a lag time of two months between changes in barrage flow and a change in relative tidal amplitude. However, it was not possible to relate the rate of restriction of the mouth to physical dimensions such as mouth width, area or conveyance (Walker, 1990). Elsewhere, empirical relationships have been demonstrated between the tidal prism and the inlet area below mean sea level, although most of the case studies refer to larger, less restricted tidal inlets than the Murray Mouth. The restricted and highly variable nature of the mouth limits the useful-





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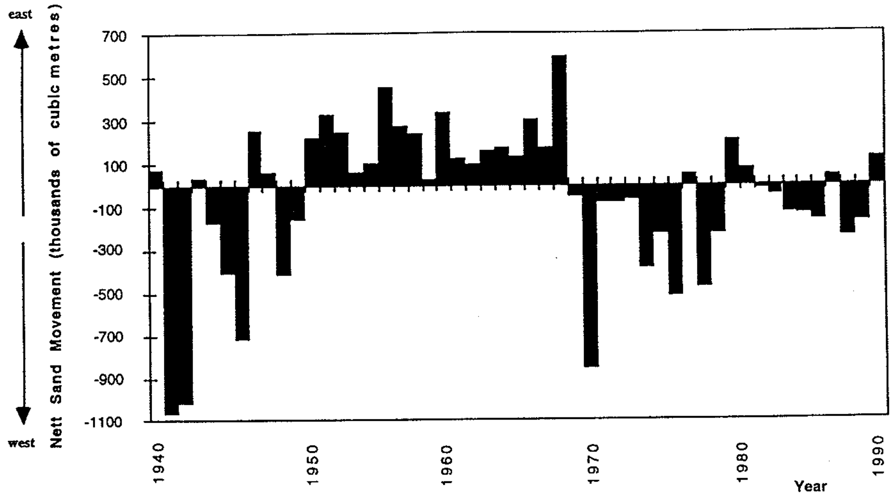

Fig 3 Nett potential sand movement ($10^3$ $m^3$) in an easterly or westerly direction in the vicinity of the Murray Mouth between 1940 and 1990. (*Source:* Chappell, 1991)

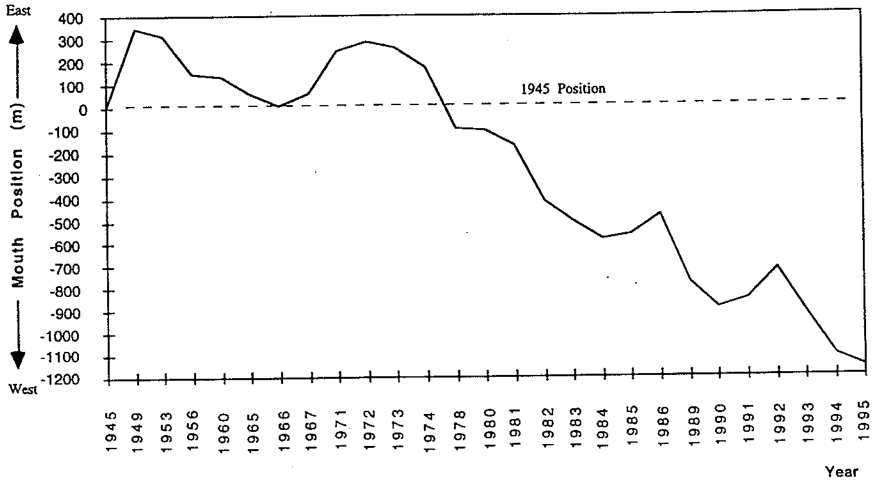

Fig 4 Cumulative movement of the Murray Mouth (m) in an easterly or westerly direction relative to its 1945 position. (*Source:* Department of Environment and Natural Resources, aerial photographs)

ness of detailed models based on physical parameters within the inlet.

The relationship between tidal amplitude inside and outside the mouth can be seen during periods of low or no flow such as 1980-1981 and the recent 1994-1995 event (Fig. 5) when the mouth restriction was associated with decreasing tidal amplitude downstream of Tauwitchere Barrage. Similar events occurred in 1967-1968 and 1982-1983 when a declining tidal amplitude inside the mouth was associated with barrage closure. Another factor is the relative height of the tides outside of the mouth. These can be represented by the maximum monthly sea tides, which were low at the time of the 1981 closure (Fig. 6a) and were associated with a long period of no river flow through the barrages. The closure of the barrages not

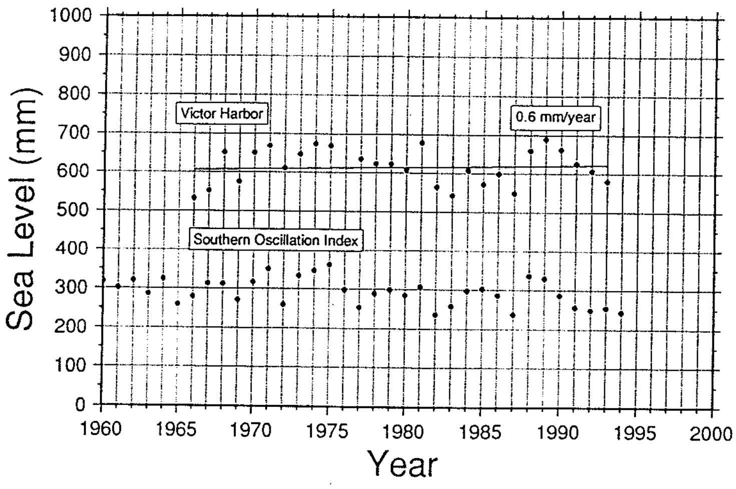

Fig 7 Annual mean sea-level at Victor Harbor compared with the Southern Oscillation Index. (*Source:* Bill Mitchell, National Tidal Facility)

pered by the overlapping jurisdictions of management authorities in the area (Harvey, 1988). Although none of the authorities at the time appeared to have responsibility for keeping the mouth open (apart from the Department of Marine and Harbors, for which it was not a priority), the Department of Engineering and Water Supply undertook to dredge a channel to re-open the mouth (Fig. 8). In addition, E&WS commissioned a management plan for Sir Richard Peninsula, for which it did have responsibility (E&WS, 1987). As noted by Harvey (1988), the management plan did not appear to allow for the dynamic nature of coastal processes at the Murray Mouth.

An expensive ($180,000) fencing system was proposed for Sir Richard Peninsula in 1988 as a method of off-road vehicle control.

Fig 8 Artificial opening of the Murray Mouth in 1981 by the Department of Engineering and Water Supply. (*Source:* Advertiser Newspapers)

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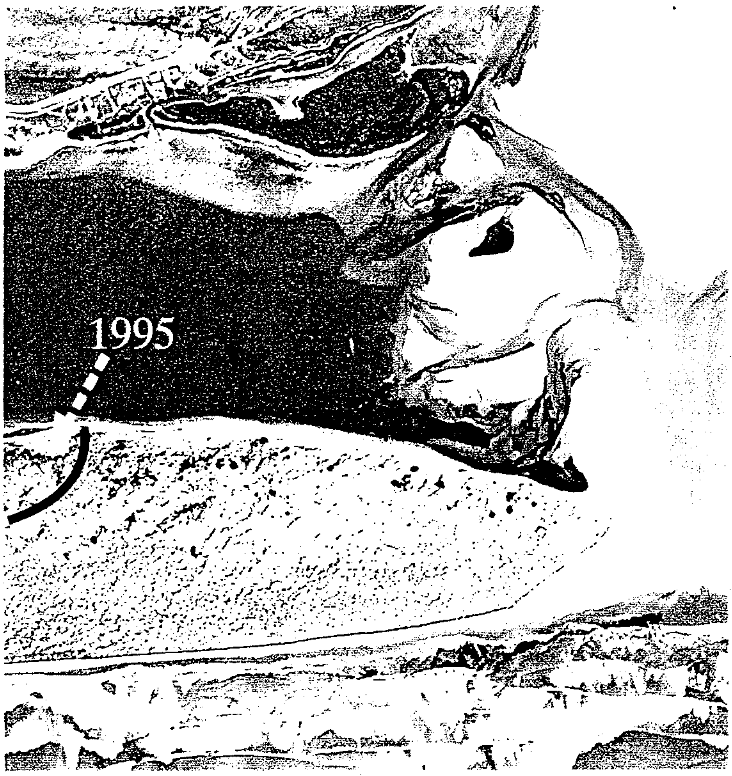

Fig 9 Aerial photograph of Sir Richard Peninsula at the time of the blockage in April 1981 showing the extent of erosion between April 1981 and September 1995 (1995 position of the tip of the peninsula superimposed on photograph). The area of vegetated dunes lost is approximately 45 ha. (Reproduced with permission of the Department of Environment and Natural Resources, South Australia,)

Subsequently, a considerably cheaper fencing system, using second-hand ferry cables, was put in place. It is gradually being lost as Sir Richard Peninsula erodes to the northwest. The peninsula has been eroding at an average of 80 m a year with an estimated loss of 45 hectares of vegetated dunes and about 3,000,000 $m^3$ of sediment since the mouth was artificially opened in 1981 (Fig. 9). At the same time, the south coast of Hindmarsh Island, opposite the migrating mouth, was exposed to wave attack in front of the shacks, although by late 1995 new flood-tidal deltaic deposits at this location appeared to be gradually dissipating the wave energy reaching the island.

A number of conclusions can be drawn from the data presented in this paper. The littoral drift studies, although inconclusive in their correlation with mouth migration, indicate the potential for large nett sand movements of up to 1,000,000 $m^3$ in any one year. The figures also indicate major periods of littoral drift direction (1940-1950 to the west, 1951-1968 to the east and from 1969 to 1995 to the west). Of these the most recent westerly littoral drift direction appears to be associated with a migration of the mouth to the west. This period of mouth migration is the most consistent and most rapid in the historic record and is the only period of migration following an artificial opening of the mouth.

The 1981 artificial channel, which re-opened the mouth, was an *ad hoc* second attempt following the failure of a first channel excavated immediately adjacent to the Younghusband Peninsula. The second channel adjacent to Sir Richard Peninsula was successful, but allowed river flow from the Goolwa Channel to erode the tip of the peninsula. The subsequent rapid erosion of Sir Richard Peninsula was in part related to the exposure of cliffed dunes adjacent to the channel, which became exposed to strong south-easterlies. In addition, it has been suggested (Bourman and Barnett, 1995) that waves entering the Murray Mouth reflected from Hindmarsh Island and eroded the landward side of Sir Richard Peninsula. It is clear that the timing and location of the channel opening in 1981 resulted in greater exposure of Sir Richard Peninsula to coastal erosion.

As noted by Harvey (1988) a number of mouth-maintenance strategies was considered by the Murray Mouth Advisory Committee (1987) and included modifying water management to allow an outflow of at least 20,000 ML day$^{-1}$ for one month. Other options proposed by the Committee in 1983 involved dredging a channel at a cost of $225,000, temporary or permanent groynes (not costed), installation of drift fencing on the Younghusband Peninsula at a cost of $15,000 and artificial closure of the mouth to prevent sand movement into the lagoon. The sand drift management option appears to have been overlooked in the preparation of the subsequent Coorong National Park Management Plan (1990). The groyne options were costed by the Committee in 1987 at $500,000, but were not considered to be viable.

There has been a recent renewal of interest in the River Murray estuary. This is related to government responses to the potential impacts of stormwater inflow into the Coorong lagoon, because of the environmental importance of the region as a wetland of international significance and the need to demonstrate effective management. Most of the current government studies relate to water movement in the Coorong lagoon and estuary, but there is a need to include coastal parameters in the environmental modelling of the estuary. The lack of co-ordinated management of the region, noted by Harvey (1988), appears not to have changed in the ensuing eight years.

Various groups currently have investigations into the behaviour of the Murray Mouth and the lower Murray estuary. For example, in 1995, a Murray-Darling Basin Commission funded project investigated hydraulic flow inside the mouth following the South Australian Natural Resource Council investigations into flow patterns in the Coorong, and a recent Ocean Rescue 2000 project has researched biological characteristics of the estuary. Furthermore, Walker (1995) has carried out computer-modelling of coastal morphology and the growth of a flood-tidal delta at the Murray Mouth. Finally, a project by the Environmental Modelling Research Group, headed by Professor Jerzy Filar at the University of South Australia, is involved in modelling tidal flow patterns between the lakes and the mouth. Preliminary results of this project (Frick *et al.*, 1995), which also include some data on wind and wave effects, indicate that the model predictions closely match measured characteristics. The expansion of this type of model to incorporate coastal processes more fully, especially those of wave energy and littoral drift, offers the opportunity to provide a more comprehensive management tool for the estuary.

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