

Analysis of the Dynamic Aspects of the River Murray Mouth, South Australia

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ABSTRACT

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Much of the work on tidal inlets carried out to date has been devoted to the determination of time-independent equilibrium criteria for the inlet dimensions. The relationships have generally been defined in terms of tidal prism, inlet velocity, littoral transport and mouth area. In the case of the River Murray Mouth it has been found that river flows play a major role in maintaining the inlet, and that the inlet dimensions are directly affected by the magnitude of those flows. The emphasis of the present study has been to utilise Time Series Analysis techniques to analyse and quantify the dynamic aspects of the inlet behaviour. The work presented includes results of the analysis leading to the identification of a linear system between the river flows and the mouth restriction. It is proposed that the use of Time Series Analysis has enabled a clear understanding of the role of river flow in maintaining the inlet to be gained and has provided a tool which is proving useful in managing the mouth.

ADDITIONAL INDEX WORDS: *Tidal inlet, Time Series Analysis, river mouth management.*

INTRODUCTION

The River Murray, Australia's main river system, travels a distance of some 2,500 km and drains an area of over 1,000,000 km² before it makes its way to the sea in South Australia near the coastal town of Goolwa, 100 km southeast of Adelaide. The mouth and environs are shown in Figure 1.

Immediately prior to entering the sea the river flows through a large freshwater lake, Lake Alexandrina. Lake Alexandrina also supplies water to an adjacent freshwater lake, Lake Albert. In an effort to keep the lakes fresh and to allow the discharge of fresh water to be regulated, a series of barrages were completed in the early 1940's. Prior to the construction of the barrages saline water had been known to travel as far as Murray Bridge, 113 km upstream of the mouth.

The fact that Australia is so arid and the river has a low run-off, considering the size of its catchment, means that the flows entering the lakes are often not sufficient to keep pace with diversions and evaporation. There are often long periods when no fresh water at all is discharged over the

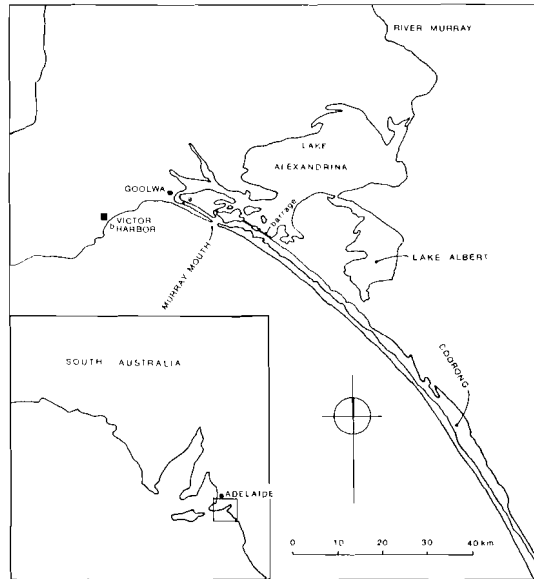


Figure 1. Murray Mouth and environs. Barrages are shown as bold lines. The location of the Goolwa Barrage water level recorder is shown as "a", and the Victor Harbor tide station as "b".

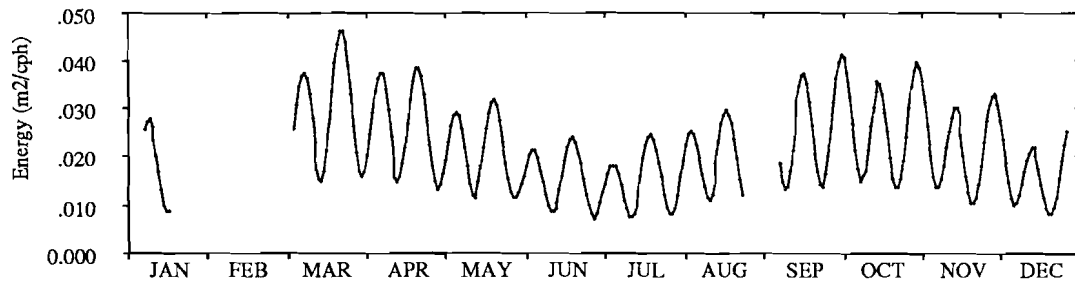


Figure 2. Tidal energy in the 12 hour band for Victor Harbor—1981.

barrages. In 1979–1981, for example, a period of 19 months passed when the barrages remained effectively closed. This lack of river flow meant that the mouth was then deprived of its fresh flushing water and it proceeded to shoal and close. It was subsequently re-opened with the aid of human intervention, and, with the benefit of quite high winter flows, was able to stay open naturally. The closing of the mouth raised a number of concerns including the possibility of flooding around Lakes Alexandrina and Albert, the effects on water quality in the nearby coastal lagoons (the Coorong), and the impact on the local fishing industry. The closure highlighted the fact that a better understanding of the mouth behaviour would be required if further closures were to be avoided. This paper contains the results of a study that was undertaken to investigate the effects of the river flows on the mouth size. The approach taken was statistical, rather than one concentrating on the physics of the mouth behaviour. It is hoped that a future study of the area will focus more thoroughly on the latter.

EQUILIBRIUM CRITERIA FOR TIDAL INLETS

There is a wealth of literature concerning the stability of tidal inlets. The emphasis, however, to date has been on studying inlets that were in some form of equilibrium, and determining the parameters to describe that equilibrium. BRUUN and GERRITSEN (1958), O'BRIEN (1969), BRUUN *et al.* (1974), BRUUN (1978) and others have proposed various quantities that have been chosen to describe inlet stability. The more frequent have been inlet area, tidal prism, inlet velocity and the rate of littoral drift. Nearshore wave energy has also been suggested by BRUUN (1968) and O'BRIEN (1969) as relevant when inlet closure is being considered. River flow, where present, has been assumed to be of lesser significance, due to the generally lower flow rates and shorter durations when compared with the tidal flows. ESCOFFIER and WALTON (1979), however, investigated the effect of river flow on the stability of simple inlets and derived relationships that included such flows.

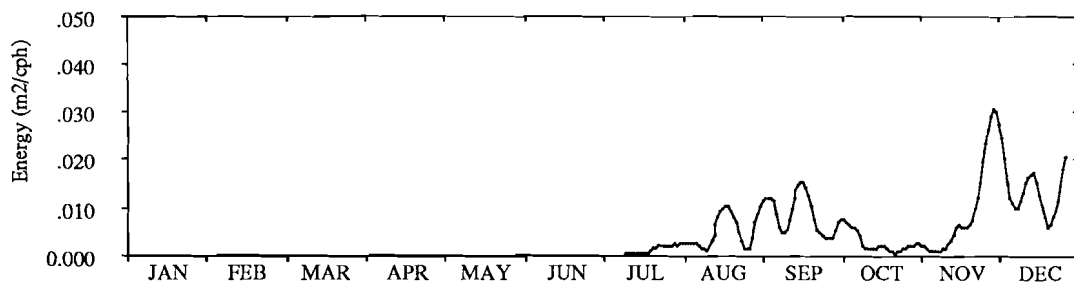


Figure 3. Tidal energy in the 12 hour band for Goolwa Barrage—1981.

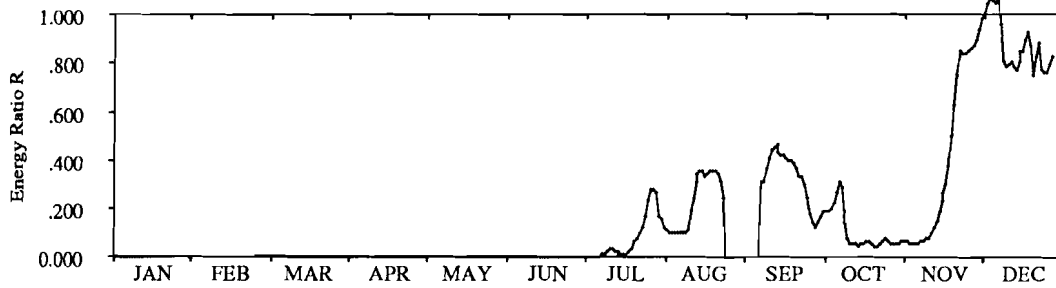


Figure 4. Tidal energy ratio for Goolwa Barrage and Victor Harbor—1981.

The situation at the Murray Mouth had been investigated by applying many of the stability criteria. Although these provided some confirmation as to the state of the inlet, none of the methods was able to be used to predict the changing mouth dimensions and therefore its flushing characteristics for the waters of the adjacent coastal lagoons.

ESTIMATION OF MOUTH RESTRICTION

Although there have been a number of surveys of the mouth area taken over the years, the information on its own was insufficient to allow any relationships between the mouth dimensions and the river flows to be determined. The South Australian Engineering and Water Supply Department (E&WS) has collected continuous water level data at three of the barrages, Goolwa, Mundoo and Tauwitchere (both upstream, in the lakes, and downstream, on the ocean side), over the last decade.

There is also a tide recording station at Victor Harbor which is near Goolwa and some 25 km from the mouth. The data from this station are collected and analysed by the Tidal Laboratory, Flinders Institute for Atmospheric and Marine Sciences at Flinders University, on a routine basis. The raw data from this station were obtained from the Tidal Laboratory for the period 1981–1984. The relative tidal amplitude between the records taken at the Goolwa Barrage and the Victor Harbor gauge was found to give the best indication of the relative restriction of the mouth.

The tide data were digitized in hourly intervals and it was found that the 12 hour spectral component of the tidal energy gave a useful measure of the tides. Figure 2 illustrates the spectral energy for the Victor Harbor Tide Station while

Figure 3 shows the results for the Goolwa Barrage Water Level Recording Station. The use of the spectral components filtered out much of the short period waves that were present at the barrage gauges due mainly to wind effects.

To specify the capacity of the mouth to pass the tidal component, an energy ratio factor, R , has been defined:

$$R = E_b/E_o \quad (1)$$

where E_b is the tidal energy inside the mouth and E_o the tidal energy in the ocean adjacent to the inlet. The energy ratio, R , should vary between 0.0 (complete restriction) and 1.0 (no restriction). Figure 4 shows the calculated values for 1981 based on the Goolwa and Victor Harbor data.

It is evident in the plot that there was considerable variation in the capacity of the mouth to pass the total tidal component. This method of analysis assumes that the mouth can be considered as a simple inlet where all the restriction will be in the inlet throat and not in the adjoining channels leading to the water level recording stations. This is a simplification of the actual situation but based on surveys of the mouth the assumption is considered reasonable in this case.

RELATIONSHIP BETWEEN MOUTH RESTRICTION AND RIVER FLOWS

The reason for the variation in mouth restriction becomes clear if the restriction is compared with the estimates of flow over the barrages for the same period. This is illustrated in Figures 5 and 6 where the data are plotted monthly for the years 1981–1984. It can be seen that there appears to be a direct relationship between the mouth restriction and the river flow. Time Series Analysis allowed the form of this relationship to be determined.

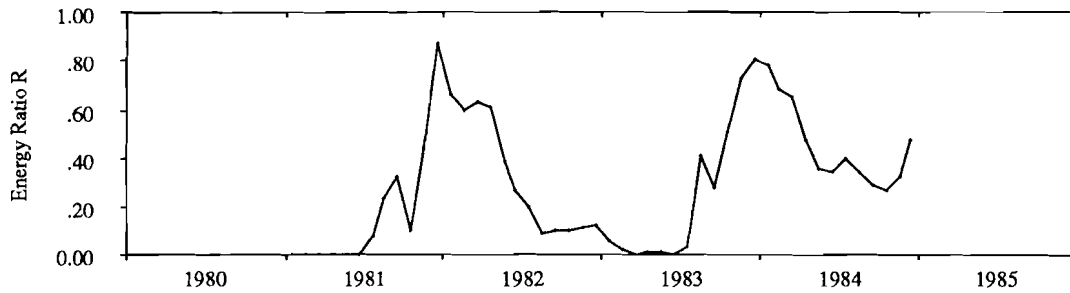


Figure 5. Tidal energy ratio for Goolwa Barrage and Victor Harbor—1981–1984.

To enable the analysis to proceed two data sets were prepared, one containing the monthly barrage flow estimates and the other the average monthly mouth restriction. There were 48 data points in each set. It was unfortunate that such a large timestep as a month had to be used but the flow estimates, which were provided by the E&WS, were only available on a monthly basis.

TIME SERIES ANALYSIS

Time Series Analysis is a method of analysing a continually changing phenomenon where a position of stability may never be reached. Time Series Analysis can be used where two time series can be regarded as related, due to the fact that one can be considered as an input to a system and the other the output from that system. It is the identification of such a system between the river flows and the mouth restriction that was the major task of the study. Details of the methods described here can be found in BOX and JENKINS (1976). A simpler introduction to the subject is presented in CHATFIELD (1984).

The analysis was conducted using an in-house statistical package based on the algorithms pro-

vided in BOX and JENKINS (1976). The PEST (Parameter ESTimation) computing package from the Key Centre for Statistical Sciences, Melbourne, Australia was also used. No doubt there are numerous other sources of programs and packages that would carry out the required analysis.

The barrage flow data were analysed and the resulting model can be written:

$$F_t = 1.550F_{t-1} - 0.640F_{t-2} + Z_t \\ (\pm 0.120) \quad (\pm 0.120) \\ - 0.301Z_{t-1} - 0.629Z_{t-2} \quad (2) \\ (\pm 0.160) \quad (\pm 0.160)$$

where F represents the flow over the barrages, the subscripts refer to time (in months), and Z is a white noise (random) time series. Shown also are the standard errors. The 95% confidence limits for the coefficients are 1.96 times the standard errors. It is evident that the coefficients are generally at better than this level of confidence. This model was used to filter the input (flow) and output (mouth restriction) series to remove any autocorrelation. The cross correlation of the filtered

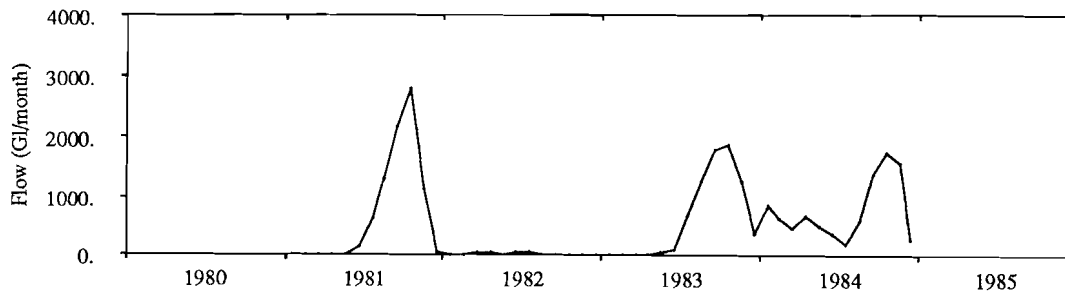


Figure 6. Estimated freshwater flow over the barrages, 1981–1984.

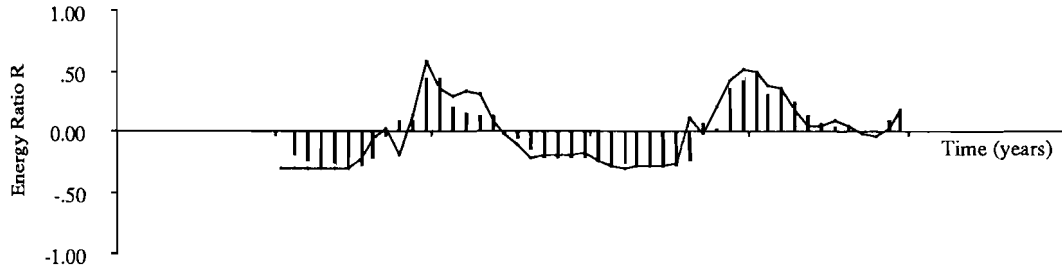


Figure 7. One month forecasts of tidal energy ratio. The vertical bars are the numerical estimates. The solid line is the measured series. Note that the mean has been removed from both series.

series was then determined. The Box-Jenkins approach allows this information to be parameterized so that the relationship can be described more compactly.

The resulting model can be written:

$$R_t = 0.734R_{t-1} + 0.000132F_{t-2} + N_t \quad (3)$$

$(\pm 0.070) \quad (\pm 0.000020)$

where R_t is the mouth restriction at time t (where t is in months) and F is the river flow in Gl/month. N_t represents the noise in the system. It should be noted that since R varies between 0 and 1 and F can be of the order of 2,000 the two quantities on the RHS of the equation will be of the same order, and therefore of equal importance.

It is evident that the degree of restriction R for a particular month is based on the restriction from the previous month and on the river flow from two months previously. There is therefore a basic lag in the system of 2 months. The performance of the model can be illustrated by looking at numerical forecasts generated using the model. The first check is shown by calculating one month

forecasts. For each month the flow and mouth restriction values are assumed known and the next month's mouth restriction is calculated based on Equation 3. The results of this are shown in Figure 7. In the plot the vertical bars are the numerical predictions of Equation 3 and the solid line is the observed mouth restriction. It is evident that the model accounts for most of the observed variation in the mouth restriction. Note that the mean has been removed from the series. This is a precondition of the method of analysis used. Actual predictions could be generated by adding back in the calculated mean.

The derived model can be used to predict further ahead than one month. This is illustrated in Figure 8 where the mouth restriction was forecast 24 months ahead. Use of the model can be seen to give reasonably good predictions of the behaviour up to two years in advance. This of course assumes that the river flow could be predicted as far ahead as this. In the case of the Murray two years is excessive but certainly three month flow predictions would not be unreasonable. Due to

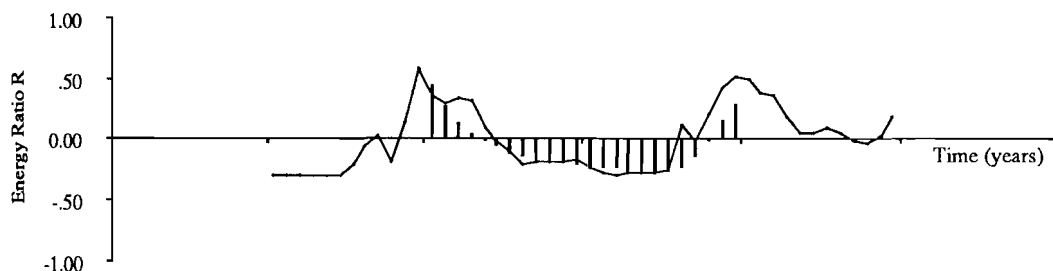


Figure 8. Twenty-four month forecast of tidal energy ratio from January 1982. The vertical bars are the numerical estimates. The solid line is the measured series. Note that the mean has been removed from both series.

the lag in the behaviour of the mouth the model is capable of predicting what the mouth restriction will do in the following five months.

SUMMARY AND CONCLUSIONS

A method for analysing the dynamic aspect of tidal inlets using Time Series Analysis has been presented. The method has proved useful in deriving the relationship between river flows and the mouth restriction at the Murray Mouth in South Australia. The method is a statistical one which determines and quantifies the relationships without attempting to explain them. It is anticipated that the results of this study will be useful in predicting future mouth closures and in developing a barrage operation strategy which would assist in avoiding such events.

It is hoped that future work will include an investigation of the importance of the littoral processes on the mouth and a phenomenological study of the inlet which will seek to investigate the factors behind the behaviour of the inlet and flow

systems that have been determined as part of this work.

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□ RÉSUMÉ □

La plupart des travaux sur les goulets de marée effectués jusqu'à ce jour, ont été consacrés à la détermination de critères d'équilibre des dimensions du goulet, indépendants du temps. Les relations avaient généralement été définies en termes de prisme littoral, vitesses dans le goulet, transport littoral et surface de l'embouchure. Dans le cas de l'embouchure de la River Murray, il a été montré que les débits jouaient un rôle essentiel dans le maintien du goulet, et que les dimensions de celui-ci étaient directement affectées par leur magnitude. La présente étude tente d'utiliser des techniques d'analyse de séries temporelles pour quantifier les aspects dynamiques du comportement d'un goulet. On y trouvera les résultats de l'analyse conduisant à l'identification d'un système linéaire entre le débit fluvial et le rétrécissement de l'embouchure. L'utilisation de l'analyse de séries temporelles a permis une bonne compréhension du rôle du débit fluvial dans le maintien du goulet et a fourni un outil permettant l'aménagement de l'embouchure.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

Viele der bisherigen Arbeiten über gezeitenbeeinflusste Seegats dienen der Bestimmung zeitunabhängiger Kriterien für einen Gleichgewichtszustand der Gattdimensionen. Die Bezugsgrößen wurden generell in Ausdrücken wie Gezeitenprisma, Einlaßgeschwindigkeit, Küstentransport und Mündungsgebiet definiert. Im Falle der Mündung des Murray zeigte sich, daß der Abfluß des Flusses eine Hauptrolle bei der Erhaltung des Gatts spielt und daß die Dimensionen des Gatts unmittelbar von der Größe dieses Abflusses abhängen. Der Schwerpunkt der vorliegenden Studie war es, die Zeitreihen-Analysetechnik zu benutzen, um die Dynamik des Gatts zu analysieren und zu quantifizieren. Die Untersuchung stellt die Ergebnisse dieser Analyse dar und erarbeitet eine lineare Beziehung zwischen Abfluß und Mündungsdimension. Es wird deutlich, daß die Anwendung der Zeitreihenanalyse auf ein klares Verständnis der Bedeutung des fluvialen Abflusses für die Erhaltung des Gatts führt und daß sie sich als ein nützliches Instrument zur Erhaltung und Bearbeitung des Mündungsgebietes erwies.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, Germany.*