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TIDAL INLET FUNCTION

Jon J. Williams[1]; Ana Vila Concejo[2]; Brad Morris[2]; Shunqi Pan[3] ; Luciana S. Esteves[4].
[1] *Proudman Oceanographic Laboratory, Bidston Observatory, Bidston Hill, Prenton, CH43 7RA, UK,*
Phone ++ 44 151 653 1549, jjw@pol.ac.uk
[2] *Universidade do Algarve, Campus de Gambelas, Faro, Algarve, Portugal, aconcejo@ualg.pt*
[3] *Department of Civil Engineering, Liverpool University, Brownlow Street, Liverpool L69 3BX, UK, S.Pan@liv.ac.uk*
[4] *Curso de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, IG/CECO, CP 15001,*
Porto Alegre, RS 91509-900 Brazil lsestev@terra.com.br

RESUMO

Com o objetivo de melhorar o conhecimento atual sobre a hidrodinâmica e transporte sedimentar nos canais de maré e áreas adjacentes, este estudo examina um pequeno canal de maré natural localizado em Ria Formosa, Algarve, Portugal. As últimas novidades em equipamentos e métodos de sensoriamento remoto e modelos numéricos foram empregadas para estudar os processos atuais e ampliar a cobertura espacial e temporal das medições. Com base no estudo de vários anos sobre a evolução do canal de maré e associação do conhecimento de outros sistemas semelhantes, um modelo conceitual descrevendo a evolução de médio e longo termo do canal de maré é apresentado. Tendo como suporte evidências históricas da evolução do canal de maré, elementos-chave do modelo são examinados em função das observações de campo e de simulações numéricas de marés, ondas, sedimentos e morfologia.

ABSTRACT

In order to improve present knowledge of hydrodynamics and sediment transport in and adjacent to tidal inlets, the present study has examined a small natural tidal inlet located in the Ría Formosa, Algarve, Portugal. The project has made use of novel instrument deployment methodologies, remote sensing, and a range of numerical models to study present day processes and extend the spatial and temporal range of the measurements. Underpinned by knowledge of inlet evolution over several years and by knowledge of other inlet systems, a conceptual model describing the medium- to long-term evolution of the present inlet is presented. Supported by historical evidence of inlet evolution, key elements of the model are then examined with reference to field observations and to numerical simulations of tides, waves, sediments, and morphology.

Palavras-Chave: canal de maré, hidrodinâmica, Portugal
Key-words: hydrodynamic, sediment transport, Portugal

1. INTRODUCTION

Tidal inlets and barrier islands are dynamic coastal features occupying around 12% of the world's coastlines. They have been the subject of many investigations (e.g. Pilkey et al., 1989; Komar, 1996). Coastal erosion in and around tidal inlets is commonly observed and frequently threatens adjacent communities and industry. Therefore, careful management to maintain environmental quality is required. Europe spends around £150 million on mitigation of inlet erosion and, in the USA, over U$100 million is spent annually simply to dredge about 75 million m^3 of sediment from inlet channels. Inlets are frequently artificially stabilised, and sediment-bypassing intervention is often used to restrict the growth of the ebb shoal and to nourish the downdrift coast. In the case of a single discharge source, management, although costly, is relatively simple. In multiply inlet systems, changes in the hydrodynamic properties caused by engineering work may give rise to instabilities and promote morphological change. In extreme cases, intervention may lead directly to the opening and/or closure of further inlets. Developing management strategies for inlets requires therefore detailed understanding of inlet dynamics.

With this in mind, the INDIA Project (INlet Dynamic Initiative - Algarve) has attempted to understand the fundamental physical drivers of change at a natural tidal inlet and to develop and assess methodologies to predict the medium- to long-term morphodynamic behaviour. The work encompasses detailed process studies and wide-area measurements of wave conditions and surface currents, numerical modelling of small-scale hydrodynamics, sediment transport and bed features, and wide-area temporal changes in morphology. The present paper outlines a conceptual model of the inlet that aims to explain key features of inlet behaviour based upon evidence from the present site and from other inlets. Field data and numerical modelling results from the INDIA project are used to assess the validity of this model.

2. THE FIELD SITE

The Barra Nova inlet is located at the western end of the Ría Formosa, in the Algarve, southern Portugal (Figure 1) and was created by dredging in June 1997. This artificial inlet was found to quickly naturalise and function in the same way as other inlets previously located at this position in the Ría Formosa system. In total the islands span approximately 50 km of the coastline and extend up to 6 km offshore from the mainland at the widest point. Here, the meso-tidal regime is in the range 2 m to 3.5 m and the site is exposed to Atlantic swell waves and local wind sea. The islands conform to the classical shoreface transgression model and are maintained by a sediment supply from the west. The unusual arcuate shape sustains the required pattern of wave refraction to maintain the system. The beaches are reflective to intermediate at the western end of the system and predominately dissipative at the eastern end and are characterised by rapid alongshore changes in morphology attributable principally to cycles of inlet opening, migration, and closure. Bathymetric charts and topographic maps show the inlets to be subject to cyclical changes associated with opening, migration, and closure.

Figure 1 - Barra Nova field site, Algarve, Portugal

3.INLET EVOLUTION

Evolution of inlets at the western end of the Ría Formosa system results from processes operating at three temporal scales: 1) response to sea-level changes O(10^3 years); 2) response to changing hydrodynamic conditions at different locations in the system O(10^0 to 10^2 years), and 3) response to storms O(10^{-1} years). Migration of the inlet will lengthen the drainage pathways and thereby reduce hydraulic efficiency leading directly to a reduction in tidal flow velocity and volume. As the inlet migrates eastwards, the wave incidence angle will become progressively more acute owing to the natural curvature of the coastline and lead to an increase in alongshore sediment transport. Also the migrating inlet will leave behind it a low spit, which is overwashed under storm and/or spring tidal conditions. Together, these processes will act to eventually close the inlet at some critical position to the east of the present location. A schematic illustration of the principal morphological units associated with the Barra Nova is shown in Figure 2.

4. CONCEPTUAL MODEL OF THE INLET

Williams et al. (2003) proposed a conceptual model to explain the dynamic behaviour of the Barra Nova, which attempts to explain inlet function and morphological evolution in terms of wave or tidal flow dominance. They draw attention to the fact that the dynamics of the Barra Nova cannot be considered in isolation from other inlets in the Ría Formosa system and note that flood tide inflows through the larger inlets to the east (Figure 1) result in an elevation of water levels inside the lagoon to a height known to be much greater than could be achieved by flow through the Barra Nova alone.

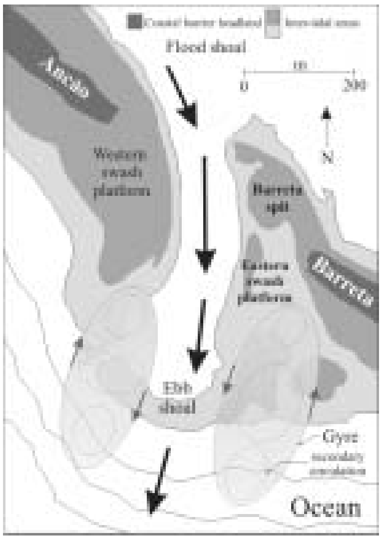

Figure 2 – Morphological units in the Barra Nova

As a result, the discharge of water during the ebb tide is both stronger and of greater duration than the proceeding flood tide, leading to an asymmetry in discharge. The balance between flood and ebb tide dominance in the Barra Nova and other inlets also depends critically upon the drainage supply and thus the location of the inlet is a critical factor in determining functionality and must be accounted for in any model. The essential components of the model are illustrated in Figure 3 and describe the dominant hydrodynamic forcing and inlet response. Principle among these are: H1, ebb-dominated, fair-weather conditions ($90^o < \psi_w < 270^o$, $H_s < 1$ m, $4s < T_P < 10$ s); H2, Atlantic storm, flood-dominated conditions ($245^o < \psi_w < 275^o$, $H_s > 3$ m, $8 s < T_P < 18$ s); and H3, Levante[1] storm, flood-dominated conditions ($120^o < \psi_w < 140^o$, $H_s > 3$ m, $6 s < T_P < 14$ s) where ψ_w is the wave direction and H_s and T_P are the significant wave height and peak wave period offshore, respectively.

In a normal year[2], regime H1 dominates for at least 99% of the time with regimes H2 and H3 occurring with varying degrees of severity for 0.6% and 0.4% of the time, respectively. Whilst regime H1 persists for most of the time, infrequent weak Levante conditions also occur

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[1] Levante is the term used for the strong easterly wind emanating from the Gibraltar area and affecting the Gulf of Cádiz.

[2] Here we refer to average annual wind speed, precipitation, sea state and storm frequency and intensity observed over a period of 30 years.

with rather different consequences for inlet evolution and migration.

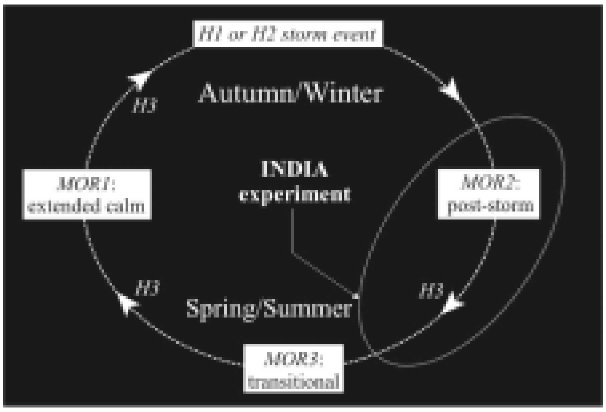

Figure 3 - Conceptual model of the Barra Nova

Thus H1 conditions are further sub-divided between the southwesterly Atlantic conditions, $H1_A$, occurring approximately 85% of the time in a typical year, and the easterly Levante conditions, $H1_L$, occurring for only 15% of the time during a typical year. It is known that the underlying first order driver of Barra Nova evolution is related to storm events, which transform the inlet from an ebb-tidally-dominated condition to a wave-dominated condition. After the storm, the inlet adjusts back to a configuration determined by the fair-weather hydrodynamics. In responding to storms and subsequently reverting to an ebb-tidally-dominated state, the present model considers that the inlet may widen and/or migrate, the channel may realign and the ebb and flood shoals may accrete or erode.

The three hydrodynamic regimes give rise to and modify three possible morphological states (Morris et al., 2001): MOR1, an ebb-tidally dominated period characterised by low waves and slow morphological change during an extended period of calm weather; MOR2, a post-storm, wave-produced morphological state following an H2 or H3 event; and MOR3, a transitional state, when the inlet morphology adjusts back to the MOR1 condition over a period of time. Field evidence shows that the length of time this takes is governed by the extent to which inlet morphology was perturbed from the initial condition by the storm. MOR1 dominates under the H1 regime. MOR2 occurs after one or more storm events with southwest storms having the greatest effect owing to their duration and to the wave approach angle. Clear boundaries between MOR2 and MOR1 are difficult to define, as an equilibrium condition is never met.

5. SELECTED RESULTS AND SUPPORTING EVIDENCE

5.1 Hydrodynamics

The RMA-2V model (Salles, 2000) shows that the Faro, Armona, and Barra Nova inlets carry 60%, 31% and 9%, respectively, of the total tidal prism of the western cell of the lagoon and that width of the Barra Nova maintains an approximately 'stable' condition. The closure curve of the Barra Nova and field data showed that the maximum velocity under present conditions was approximately 1.35 m/s, a value approximately in accord with the widely used equilibrium velocity of 1 m/s indicating that the Barra Nova may still be in a phase of growth. However, Vila-Concejo et al. (1999) show that the width of the Barra Nova has now reached a state of relative stability and thus it is suggested that the ‘excess’ velocity may either increase the depth of the inlet, or trigger other processes known to occur in natural inlets, such as enlargement of the ebb tidal delta or inlet migration.

A fine grid version of the LAGOON model (25 m) demonstrated the ebb dominant nature of the inlet under spring tide conditions and showed reduced tidal distortion during neap tides attributable to reduced phase speeds between high and low water and reduced bed friction. Although Coriolis force will tend to straighten the channel to a more shore-normal orientation as it travels seaward, the strong pull of water from the northwestern part of the lagoon explains in part why the inlet axis is inclined. The model also shows the generation of two gyres either side of the main outflow jet with gyre circulation to the west of the thalweg reinforcing further hydrodynamics driving swash bar construction at the eastern end of Peninsula do Ancão. A Q3D model showed the measured effect of depth limitation in the vicinity of the Barra Nova and the blocking effect to wave by the strong outflow during the ebb tide (Figure 4).

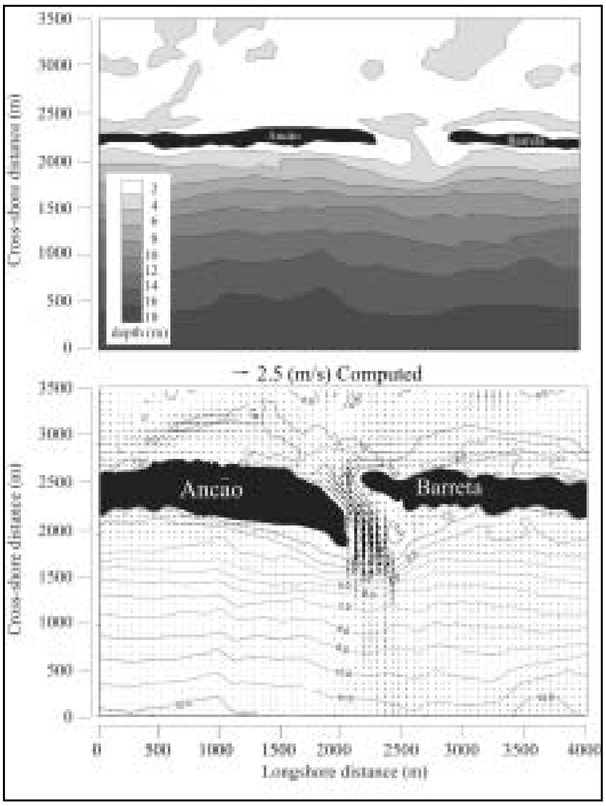

Figure 4 – Inlet bathymetry (top) and ebb tide simulation fromQ3D.

5.2 Morphology

Field evidence showed that the morphology of the inlet evolved in a step-like fashion, with major changes occurring during storm events which caused breaching of the ebb delta and erosion of the inlet margins and adjacent shorelines as described in the conceptual model. Morphological changes occurring during low to moderate energy wave conditions were small by comparison and were manifest by the accretion of spits and bars which slowly deflected the channel eastwards.

Historically, the Peninsula do Ancão inlet has migrated in an easterly direction of the inlet with variable migration rates, I_m (Vila-Concejo et al., 1999). These range from O(50 m/year) to an extreme value of O(700 m/year). Vila-Concejo et al., (1999) estimated I_m = 53 m/year for the period 1976 to 1985. This increased subsequently to 130 m/year during the period 1985-1989 before final closure of the inlet circa 1996. This latter value for inlet migration rate is consistent with model predictions for I_m using an SPM-type of bulk alongshore transport formula with corrections for grain size. The model also predicts that storm events have a profound impact on inlet location with migration distances O(300 m) possible in the 1 in 50 year event for this location.

Data pertaining to the width of the inlet, the location of the channel and the morphology of the flood and ebb shoals were obtained from the video images. Selected results are shown using plan-view composite video images in Figure 5 for the period 3 December 1998 to 20 January 1999. Simplified sketches showing the principal morphological features in the video images are shown in the lower panels of each figure. Figure 5 shows that most erosion of Ilha da Barreta (80%) occurred during storms with the most significant event occurring between 29th December 1998 and 1st January 2000 when swell from the south west (H_s O(4 m); T_p O(9 s), Ψ_w O(220^o)) was coincident with peak spring tides O(2.7 m) on 31 December 1999. During this time, the width of the inlet increased from 360 m to 425 m. This moderate storm event shifted the inlet from the extended calm MOR1 state to the post-storm MOR3 state, described in the conceptual model. Changes to inlet morphology were also brought about by another H2 event on 12th March 1999 (H_s O(3 m); T_p O(8 s), Ψ_w O(220^o). Again the shore of Ilha da Barreta was eroded and the width of the inlet increased from 430 m to 470 m and the channel shifted by approximately 10 m eastwards without change in orientation. The remaining spit extending from Ilha da Barreta from the proceeding storm was completely eroded during this time.

In the case of this second H2 event, the storm was coincident with neap tides O(1.4 m); thus, wave penetration into the inlet was less effective. Further, storm duration was only two days, reducing further wave impact upon morphology. On 23rd March 1999, during Levante conditions, the Barra Nova was subjected to an H3 event with swell emanating from the southeast (H_s O(3.5 m); T_p O(7 s), Ψ_w O(130^o)). The event resulted in only moderate amounts of erosion to the ebb delta, swash platform, and to the western shore of the Barra Nova; no change in the location of the channel was detected. In common with the second H2 event, this storm only lasted two days and coincided with neap tides O(1.8 m); thus, again reducing significantly the effectiveness of the waves. In the post-storm MOR2 recovery period, morphological changes were observed to occur gradually as sediments were slowly re-worked by the tidal currents and smaller waves from the southwest. Video evidence indicated that sediments lost from the bars on the western swash platform during the storm were slowly replaced by sediment transported alongshore by small waves from the southwest and by a net transport of sediments out of the lagoon by the ebb tide (Morris et al., 2001). Re-establishment of tidal ebb-dominance caused the ebb shoal to enlarge and to build further offshore using material transported seaward by the inlet channel. Field measurements show that, after a series of winter storms, the inlet takes approximately 3 months to adjust back to its preferred fair weather morphology.

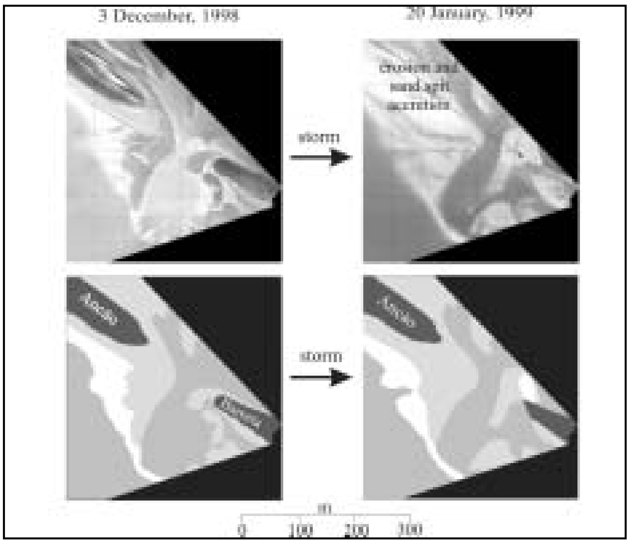

Figure 5 - Inlet response to H1 forcing showing shift from MOR1 to MOR3 morphology

6. CONCLUSIONS

The Barra Nova provides a good case study for assessing engineering intervention on a dynamic coastline. Field evidence and numerical modelling results provide compelling evidence to support the description of tidal inlet function in the conceptual model proposed here. The inlet is shown to respond to storm events in a predictable way and follows historical trends for inlets at this location in the Ría Formosa. If present trends continue, the inlet will continue to migrate eastwards before sedimentation forces closure some 2 km east of its present location by approximately 2020.

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