River, Coastal and Estuarine Morphodynamics: RCEM 2007

VOLUME 1 & 2

Editors

C. Marjolein Dohmen-Janssen & Suzanne J.M.H. Hulscher
University of Twente, Faculty of Engineering Technology, Department of Water Engineering and Management (WEM), Enschede, The Netherlands
Trends of bathymetric variations at a tidal inlet

S. Plecha, S. Rodrigues, P. Silva & J.M. Dias
CESAM, Universidade de Aveiro, Aveiro, Portugal
A. Oliveira & A.B. Fortunato
Laboratório Nacional de Engenharia Civil, Lisbon, Portugal

ABSTRACT: This work aims at establishing the trends of erosion and deposition in the Ria de Aveiro inlet and surrounding area. Bathymetric changes were evaluated through two different methodologies: analysis of bathymetric field data and results from numerical modeling. The numerical results of bathymetric changes obtained show deposition trends at the centre of the navigation channel, and erosion close to the north jetty. These erosion trends show that the stability of the part of the north jetty located in the inlet might be threatened. The comparisons of the numerical results with the observed data allow establishing the performance of the model in simulating bathymetric variations for the period under study.

1 INTRODUCTION

Ria de Aveiro is a coastal lagoon located in the NW of the Iberian Peninsula, connected with the Atlantic Ocean through an artificial narrow channel (about 350 m wide, 2 km long) fixed by two jetties (Figure 1). The morphodynamic behaviour of this channel and coastal surrounding zones is complex due to highly energetic oceanic wave climate conditions and strong tidal currents (up to 3 m/s), whose interaction is not well understood/studied.

An important harbour is located within the lagoon, and its operation requires regular maintenance dredging of the inlet channel. Recent bathymetric surveys reveal erosion at the entrance of the channel close to the north jetty and sand deposition close to the south jetty. With persistence of these trends, the stability of the north jetty located in the inlet might be threatened in the future.

This study aims at establishing trends of erosion and deposition in the tidal inlet and surrounding area, in order to understand the morphological changes that are occurring in this inlet. With this purpose the results of bathymetric changes obtained from the bathymetric data and from numerical modelling are analysed and compared.

2 METHODOLOGY

2.1 Bathymetric data

The bathymetric data were obtained by the Aveiro Harbour Administration (A.P.A.) and correspond to surveys performed between 1987 and August 2006. The available data are irregular in time: there is a time span of 14 years between the first survey, representative of the bathymetry in 1987/88 (Figure 2), and the second one in 2002. The time spans between the following bathymetries vary between several months and one year.

The bathymetric changes were calculated by subtracting the values of depth corresponding to succeeding surveys.

2.2 Numerical modelling

A two-dimensional horizontal morphodynamic modelling system – MORSYS2D – (Fortunato & Oliveira, 2004, 2007) is applied to simulate the morphodynamic behaviour of the Ria de Aveiro lagoon inlet.

The modelling system MORSYS2D integrates a hydrodynamic model (ELCIRC, Zhang et al. 2004), which calculate tidal elevations and currents, a wave model (REF/DIF1, Kirby and Dalrymple 1994), which computes the wave climate, and a module that computes sand fluxes and updates the bottom topography (SAND2D, Fortunato & Oliveira 2004, 2007).

ELCIRC is an open-source three-dimensional baroclinic shallow water model that combines finite volumes, finite differences and Eulerian-Lagrangian concepts to obtain stability, accuracy, and mass conservation to solve the shallow water equations. The horizontal domain is discretized with a triangular mesh for flexibility, and z-coordinates are used in the vertical. The numerical stability is ensured by a semi-implicit time-stepping algorithm and by an
Eulerian-Lagrangian method to solve the convective terms. For the present application a single vertical layer is used.

REF/DIF1 is a stationary model of wave propagation and transformation in areas of irregular bottom bathymetry and around islands. This model propagates the waves in the presence of currents considering the effects of refraction, diffraction, shoaling and energy dissipation. This wave model is based on the parabolic approximation of the mild-slope equation.

In SAND2D sediment fluxes are computed at each element centre and integrated in time using a 4th order Runge-Kutta method. The net sediment fluxes are then used to solve the bed continuity equation through an element-centered finite volume technique based on a triangular unstructured grid. The morphodynamic time-stepping is performed with a multi-step predictor-corrector algorithm (Fortunato & Oliveira, 2007). Several formulae are used to calculate sediment fluxes in different types of flows: waves, currents and combined waves and currents.

In the present study, the computational domain used for the hydrodynamic model ELCIRC extends from the upstream limits of the lagoon to the continental shelf, and was discretized with an unstructured grid with 18851 nodes (Figure 3a). The computational domain used in SAND2D is a sub-domain of the ELCIRC grid with 1812 nodes (Figure 3b).

Extending the hydrodynamic computational domain to the whole coastal lagoon ensures that more realistic tidal currents at the inlet channel are simulated.

The morphodynamic simulations of the Aveiro lagoon inlet were forced by tides at the oceanic open boundary, neglecting the influence of waves and riverflow. The hydrodynamic model was forced by the semi-diurnal harmonic constituent M2. The hydrodynamic results at each grid point are condensed through
harmonic analysis for the M2 and its major over-
tides (Z0, M4 and M6) and constitute the forcing of
the transport model SAND2D. No sediment fluxes
are imposed at the open boundaries (e.g. longshore
transport).

The initial bathymetry considered in the present
simulations corresponds to data surveyed in 1987 by
Aveiro Harbour Administration (A.P.A.). A detailed
description of the hydrodynamic model application
and calibration, together with a preliminary applica-
tion of MORSYS2D, is presented in Oliveira et al.,

The morphodynamic simulations were performed
for a one year period with a morphological time step
of 1 tidal cycle.

Different simulations were performed in order to
establish the dependence of the numerical solution
on some important parameters: the formula used to
compute the sediment fluxes and the sediment char-
acteristics. Sediment fluxes were computed with the
formulae of van Rijn (1984), Ackers and White (1973)
and Karin and Kennedy (1990). The median sediment
diameter used in the simulation is considered uniform
in the whole domain. This represents a great simplifi-
cation because recent surveys show a high variability
of the bottom sediments in this area, from very coarse
at the centre of the inlet channel to fine sediments in the
nearshore zone. In order to assess the response of the
sediment fluxes and bottom variations to the sediment
characteristics, two values of d50 were considered:
0.4 mm and 1 mm.

3 RESULTS

3.1 Bathymetric data

Figure 4 represents the bathymetric variations between
2002 and 1987/88. The results show a generalized
deepening of the inlet channel greater than 4 m. At the
entrance zone, near the side walls of the inner north
jetty and in the central part of the channel, the erosion
rates show higher erosion rates. Outside the inlet chan-
nel, a well defined track showing erosion may reveal
dredging activities for navigation purposes. Accretion
zones are identified in different zones: near the south
jetty, at its head (for the higher depths, see figure 2) and
at the inner “shadow” zones; at the head of the north
jetty; in some spots near the side walls of the inlet chan-
nel and near the triângulo das marés (for the higher
depths, see figure 2).

The subsequent bathymetric changes do not show
the same patterns as the one represented in figure 4.
As an example, figures 5 and 6 present the bathymet-
ric variations calculated between 2002 and July 2003
and between July 2003 and October 2004, respectively.
Both figures show generalized erosion at the centre of
the inlet channel, but different tendencies near the side
walls. The intermittence of erosion and accretion in
the same spots (e.g., at the side walls of the inner north
jetty, at the entrance of the Mira channel, near the head
of the south jetty) are probably a consequence of dredg-
ing activities. Note the large bathymetric variations
observed in one year (figure 5 and 6) when compared
with the ones observed in 14 years (figure 4).

A correct interpretation of the bathymetric varia-
tions from the surveys requires a cross correlation with
the dredging activities; unfortunately this information
is not available.

3.2 Numerical modeling

The first results analyzed are those obtained by varying
the formula used to compute the sediment fluxes. Fig-
ures 7, 8 and 9 present the variations of bathymetry, in a
one year simulation using the van Rijn (1984) formula,
the Ackers-White (1973) formula and Karin-Kennedy
Figure 6. Bathymetric changes (m) between July 2003 and October 2004.

Figure 7. Bathymetric changes (m) after one year of simulation, using the van Rijn (1984) formula.

Figure 8. Bathymetric changes (m) after one year of simulation, using the Ackers-White (1973) formula.

Figure 9. Bathymetric changes (m) after one year of simulation, using the Karin-Kennedy (1990) formula.

Figure 10. Bathymetric changes (m) after one year of simulation, for a sediment diameter of 0.4 mm.

All these results show the same trends of erosion and deposition. Close to the north jetty we have trends of erosion as well as in the east side of the domain, in the S. Jacinto and Mira channels (in the last one more pronounced near the sidewalls). Trends of deposition are present in the centre of the navigation channel and at the head of the south jetty. At the centre of the inlet, between the heads of the jetties, trends of erosion and deposition outward are observed. The bathymetric changes for the van Rijn and Karin-Kennedy formulae are also similar with maximum erosion (~12 m) and maximum deposition values (~10 m). The Ackers-White formula results in a smoother bathymetric variation.

The simulations made to analyze the sensitivity of the numerical results to the variation of the sediment diameter were performed using the van Rijn formula to compute the sediment fluxes. The results obtained for these simulations are presented in Figures 10 and 11. Figure 7 and 10 illustrate the same numerical solution, the only difference is the scale represented.

In Figure 10, the sediment diameter used for simulation is 0.4 mm and in Figure 11 is 1 mm. Results show that the greater variations are obtained for the finer sediment. The same trends of erosion and deposition are obtained in these two simulations.
3.3 Comparisons of the numerical results with the observed data

This analysis is performed by comparison of the numerical results with the bathymetric variations computed between 1987/88 and 2002. The other results depicted in figures 4 and 5 are not comparable with the numerical results because the latter were obtained by initializing the model with the 1987/88 bathymetry.

The comparison between Figure 4 (selected area) and 7 shows different scales of bathymetric changes, although the numerical solution obtained with the formula of Ackers and White shows bathymetric variations more similar to the ones observed. The trends of erosion and deposition simulated are similar to the ones observed in some zones: at the entrance zone between the south and north jetties; at the inner zone of the south jetty; at the beginning of Mira and S. Jacinto channels. At the centre of the main channel the surveys indicate the occurrence of erosion, while the model results show a large area of deposition. This might indicate the occurrence of dredging at this zone. Discrepancies are also observed near the side walls of the main channel.

4 CONCLUSIONS

The morphodynamic modelling system MORSYS2D was applied to the Ria de Aveiro lagoon to compute the bathymetric changes and the results were compared to those obtained through bathymetric data.

Several trends of erosion and deposition were observed in the Ria de Aveiro lagoon inlet. Most of these trends are similar in the numerical results and bathymetric data, in spite of the quantitative differences. The differences may be due to: (a) the simulations were forced by tides alone, omitting the influence of the highly energetic oceanic wave climate conditions and riverflow, and (b) the bathymetric data include regular dredging of the sand that accumulates at the inlet, made by the Aveiro Harbor Administration, which is not presented in the numerical modeling.

The results show trends of erosion close to the north jetty as well as in the east side of the domain, in the S. Jacinto and Mira channels and in the triângulo das marés. Trends of deposition are present in the centre of the navigation channel and in the head of the south jetty. In the centre of the inlet, between the heads of the jetties, trends of erosion and deposition outward are obtained.

ACKNOWLEDGEMENTS

This work has been supported by FCT funding in the frame of the research project POCI/ECM/59958/2004 – EMERA – Study of the Morphodynamics of the Ria de Aveiro Lagoon Inlet.

The authors would like to thank Profs. A.M. Baptista and Joseph Zhang for the model ELCIRC and Aveiro Harbour Administration (A.P.A.) for providing the bathymetric data.

REFERENCES


