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Effect of flooding the salt pans in the Ria de Aveiro

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ABSTRACT

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The Ria de Aveiro, a mesotidal lagoon located on the Northwestern Portuguese coast, is characterized by large areas of intertidal flats and a web of narrow channels. The lagoon has a large area of mostly abandoned salt pans, whose progressive degradation is caused by the lack of maintenance and by the strong currents which erode their protective walls. The shallow water model ELCIRC was implemented and calibrated for the Ria de Aveiro in order to study its hydrodynamics, with special emphasis on the effect of the destruction of the salt pans protective walls. The calibration was performed by adjusting the bottom friction coefficient, through the comparison between measured and computed time series of surface water elevations at several stations within the lagoon. Harmonic analyses of these data were performed in order to evaluate the models accuracy. An assessment of root mean square errors and skill showed that a good calibration was achieved.
Once calibrated, ELCIRC was used to characterize the hydrodynamics of the entire lagoon and the channels around the salt pans under different scenarios (present bathymetry and a projection of the bathymetry resulting from the walls destruction). An extreme destruction of the salt pan walls would result in a significant increase of the inundation area in Ria de Aveiro, as well as in changes of the global and local hydrodynamic regimes. In summary, this study reveals how the increase of the flooded area in estuarine lagoons can affect tidal propagation, including the increase of tidal currents, tidal prism and tidal asymmetry. The long-term implications of the salt pans inundation are discussed based on the results.

ADITIONAL INDEX WORDS: *ELCIRC, tidal asymmetry, tidal prism*

INTRODUCTION

The Ria de Aveiro (Figure 1) is a coastal lagoon located on the Northwestern Portuguese coast, with a surface area of about 83 km^2 at high tide (DIAS *et al.,* 1999). The lagoon has a very irregular geometry, being characterized by narrow channels and extensive intertidal flats areas, namely mud flats and salt marshes. The Ria de Aveiro has a large area of abandoned salt pans, whose degradation is caused by the lack of maintenance and by the strong currents that erode their protective walls.

The main aim of this study is to understand the consequences of the salt pan walls collapse on the Ria de Aveiro hydrodynamics, that results in an increase of the flooded area. To evaluate the impact of bathymetric changes in systems like this, several future scenarios were simulated, in which salt pans walls destruction was assumed. These simulations were performed with the shallow water numerical model ELCIRC (ZHANG *et al*., 2004). The model was previously implemented in Ria de Aveiro (OLIVEIRA *et al*., 2006), in order to study its inlet dynamics in terms of tidal propagation, as well as the variability of tidal asymmetry in the upper and lower lagoon. The horizontal grid developed by these authors is inadequate for the present study, because the central area of the Ria de Aveiro has low resolution. Hence, the existing grid was improved by adding and refining several channels, mainly in the central area of the lagoon, where salt pans are located.

The paper is divided into five sections besides this introduction. The second section describes the characteristics and problems of the study area. The next section presents the methodology. The hydrodynamic model calibration is presented in the fourth section and the evaluation of the hydrodynamic changes under the partial collapse of the salt pans walls of the Ria de Aveiro is presented in fifth section. The paper closes with some concluding remarks.

STUDY AREA

The Ria de Aveiro is a shallow water mesotidal lagoon located in Northwest coast of Portugal (40º38'N, 8º44'W). The lagoon has a maximum width of 10 km and its length measured along the longitudinal axis is 45 km (DIAS AND LOPES, 2006a,b). The average depth of the lagoon relative to the chart datum is about 1 m, except in navigation channels where dredging operations are frequently carried out. Due to the small depth and to the significant tidal wave amplitude there are zones, especially along the borders of the lagoon and its central area, which are alternately wet and dry during each tidal cycle.

The lagoon is mesotidal (tidal amplitude at the inlet ranges from 0.6 m in neap tides to 3.2 m in spring tides – average range of 2

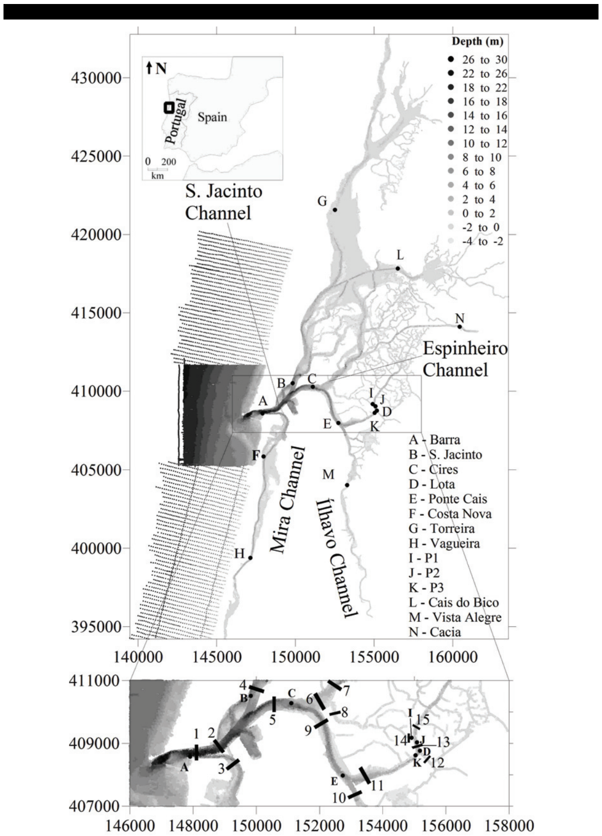

Figure 1. The Ria de Aveiro bathymetry (UTM coordinates), with depth in meters relative to the chart datum (2.00 m below the mean sea level) and with locations of the stations where field data are available. Cross-sections location where tidal prism were computed are also presented (numbers in inset).

m) (DIAS *et al.,* 2000). Semidiurnal tides constitute the major hydrodynamic forcing (DIAS *et al.,* 2000).

The major fluvial input comes from the Vouga (50 m^3s^{-1} average flow) and the Antuã rivers (5 m^3s^{-1} average flow). The Vouga River contributes around 2/3 of the fresh water entering the lagoon (MOREIRA *et al.*, 1993; DIAS *et al.*, 1999). However, river flows into the lagoon were neglected, because the total mean fresh water discharge into the lagoon during a tidal cycle is about 1.8 Mm^3 (MOREIRA *et al.*, 1993) while the tidal prism is 137 Mm^3 for maximum spring tide and 35 Mm^3 for minimum neap tide (DIAS *et al.*, 2000).

The salt pans of the Ria de Aveiro occupy about 15 km^2. The number of active salt pans has decrease from about 500 in the 15^{th} century, to 270 fifty years ago, and only 8 remain nowadays. The salt pans currently occupy the marsh areas, which are islands in the lagoon and only few have access by land.

The salt pans in the Ria de Aveiro are divided into five groups: S. Roque, Sul, Mar, Norte and Monte Farinha. Due to the large extension of the salt pans of Aveiro, it was impossible to perform an integrated study of all salt pans. Therefore, this study will focus on the Mar group and the southern part of the Norte group, that are the most vulnerable to strong currents.

METHODOLOGY

The main goal of this paper is to evaluate the hydrodynamic changes of the Ria de Aveiro lagoon associated to the destruction of the salt pan walls. Thus, the hydrodynamic model ELCIRC was implemented and calibrated for the Ria de Aveiro lagoon. The model calibration was performed at 14 stations within the lagoon, with a depth-dependent Manning coefficient, whose values were based on the ones presented by DIAS and LOPES (2006a,b). The Manning values were locally adjusted until the models outputs agreed satisfactorily with the field data.

Data available for this study are from two distinct field campaigns, from 2003 and 2006. Sea surface elevation and vertical profiles of velocities were measured, in the framework of the project SAL – Sal do Atlântico (INTERREG III B ESPAÇO ATLÂNTICO, 2004-2007), at stations I, J and K (near the salt pans) and were available for this study. At these stations, data were measured hourly. Sea surface elevations at the other stations were measured every six minutes, except at Torreira, where measurements were performed every half hour. These data were collected in the framework of the Phd Thesis of ARAÚJO (2005).

Once calibrated, ELCIRC was used to characterize the response of the lagoon hydrodynamics to the increase of the flooded area. Thus, distinct grids were generated representing a sequential flooding of the Ria de Aveiro central area. Several simulations were performed in order to evaluate possible changes in overall and local lagoon's hydrodynamic regime. This evaluation was performed through the analysis of tidal currents, tidal prism and tidal asymmetry for each case study.

Figure 2 represents a detail of the grid in the central area of the lagoon: present configuration and a projection of the configuration resulting from the salt pans walls destruction. The inundation was achieved through the partial collapse of the salt pans walls, whose dimensions are in accordance with the ones presented in INTERREG III B (2008) and with Google Earth images. For lack of information, depth in the flooded area was set to 1 m above to the mean sea level (, i.e. 3 m above chart datum).

NUMERICAL MODEL

ELCIRC (ZHANG *et al.* 2004) is a fully non-linear, three-dimensional, baroclinic shallow water model. The model ELCIRC uses a finite-volume/finite difference Eulerian-Lagrangian algorithm to solve the shallow water equations, written to realistically address a wide range of physical processes and of atmospheric, ocean and river forcings.

For the Aveiro lagoon model, a single vertical layer is used, so ELCIRC reverts to two dimensions. Due to the shallow depths and minor freshwater inputs into this system, circulation can adequately be simulated with a depth-averaged model.

The model was forced by fourteen harmonic constituents (Z_0, M_{SF}, O_1, K_1, P_1, Q_1, N_2, M_2, S_2, K_2, M_4, MN_4, MS_4 and M_6) taken from the regional model of FORTUNATO *et al.* (2002), without any wind and freshwater input. The largest time step that prevents the appearance of oscillations was set to 90 s. The initial conditions of

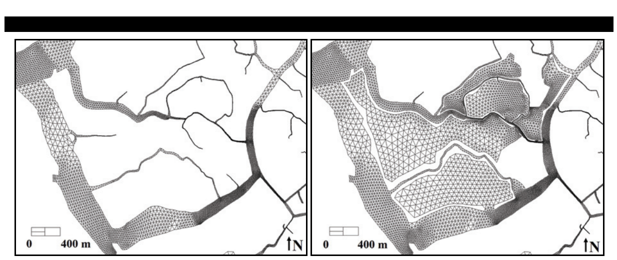

Figure 2. Detail of the horizontal finite element grid of the Ria de Aveiro lagoon near the study area Left: present configuration; Right: configuration resulting from the salt pan walls partial collapse.

levels and velocities were specified from the repose and a ramp function of 1 day was used.

Model Calibration

Initially the calibration was performed by comparing model results with observed sea surface elevation (SSE) (Figure 3). The hydrodynamic model was forced in the oceanic boundary by tides only, so in order to compare model results with measurements, the low frequency signal was removed from the data, considering a cut-off frequency of 0.0000093 Hz (30 h).

The calibration was quantified through the determination of the root mean square (RMS) errors and the predictive skill, as well as through the comparison of the harmonic constants determined from the model and the data at 11 stations.

According to DIAS *et al*. (2009), the RMS errors should be compared with the local tidal amplitude. If they are lower than 5% of the local amplitude, the agreement between model results and observations should be considered excellent. If they range between 5% and 10% of the local amplitude, the agreement should be considered very good. Perfect agreement between model results and observations will yield a skill of unity and complete disagreement yield a skill of zero. Skill values higher than 0.95 should be considered representative of an excellent agreement between model results and observations (DIAS *et al.*, 2009).

RMS errors range from 3% to 10% of the local amplitude for the stations A, B, C, E, F, I and K, and therefore the predictions range from very good to excellent. However, RMS errors exceed 10% of the local amplitude at the other stations.

A RMS error of about 7 cm was found for the station located at the lagoon mouth (station A), i.e., around 4% of the local mean tidal range. Thus, the errors found at the other stations may be partially explained by this difference. The best model results were obtained for the stations closer to the lagoon's mouth (e.g. station B with a RMS of 9 cm) and the highest disagreements were found for stations G, H and L with RMS errors around 15% of tidal range and with skill values lower than 0.95.

There is a large disadvantage on the direct comparison of RMS and skill errors, since phase and amplitude errors are considered together. In addition, tidal asymmetry, which we will analyse below, is mostly determined by the relative importance of the major tidal constituent (M_2) and its first harmonic (M_4). Thus, harmonic constants were computed for both predicted and observed SSE in order to quantify separately the amplitude and phase differences for all stations, with exception of I, J and K stations because the available data only have the duration of 11 hours. This procedure was performed using t_tide matlab® package of PAWLOWICZ *et al*. (2002).

For the major constituent (M_2), the mean difference between predicted and observed amplitudes is about 10 cm (Figure 4). This value was amplified by the errors found for stations G, H and L, that presents a mean difference of about 16 cm. The mean phase difference for the semidiurnal constituent is about 12º, which means that the average delay between the predicted and observed tide is about 24 minutes. This delay is higher than was expected, mainly due to the phase difference at stations L and M.

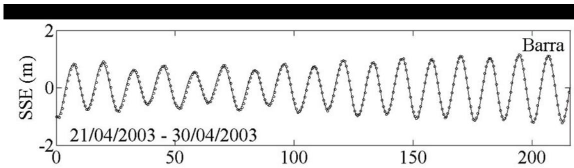

Figure 3. Comparison between predicted and observed sea surface elevation for the station A (solid line: model results; circles: measurements).

The M_4 constituent was not simulated with the expected accuracy (Figure 4). The errors found in the M_4 reproduction may be due to bathymetric errors that can not be corrected by the adjustment of the friction coefficient.

The relatively large errors associated with M_4 are not surprizing, as overtides are typicaly much more difficult to reproduce correctly than the major astronomic constituents. In this particular case, the correct reproduction of overtides is further hampered by the changes in bathymetry over the years, which significantly affect tidal propagation. For M_2, an average increase of 0.245 m in amplitude and an average decrease of 17.4º in phase were observed over 16 years (ARAÚJO *et al.,* 2008). Since there is a discrepancy of about 16 years between the bathymetric and the tidal data used herein, similar discrepancies should be expected between the tidal data and the model results. While these discrepancies are partially mitigated by the calibration for the major constituents, non-linear constituents are affected by friction diferently, and therefore do not match the data as well. Still, as the M_4 constituent is generated through the advective and finite amplitude terms, which are correctly represented by the model, the results for M_4 are expected to be realistic enough to reproduce tidal asymmetry.

RESULTS

To achieve the final goal of this work, the model ELCIRC was run for the entire Ria de Aveiro and possible changes in the global and the local hydrodynamic regime are evaluated in the next sections. This evaluation is performed through the analysis of tidal currents near the lagoon mouth, the tidal asymmetry along the axis of the main channels of the lagoon and the tidal prism for several cross-sections along the lagoon, determined for each simulation.

The grid total area and volume relative to the mean sea level increase about 5.6% and 3.5%, respectively, from the present bathymetry to the flooded case.

Tidal Currents

In this section, the response of the magnitude of flood and ebb velocities to the increase of the lagoon area is evaluated. The velocities are only represented near the lagoon mouth on maximum ebb at spring tides (Figure 5).

Generally, tidal velocities increase for the new configuration. For both configurations, the model results also show that velocities are systematically stronger on ebb than on flood, revealing ebb-dominance of the inlet.

According to the model results, at spring tides, maximum ebb and flood velocities are 1.94 ms^{-1} and 1.85 ms^{-1}, respectively, for the present configuration, and 2.06 ms^{-1} and 1.96 ms^{-1} for the new one, which corresponds to increases of about 5-6%. This increase of tidal currents corresponds to an increase of about 5.6 % in the lagoon area. At neap tides, the growth of the maximum velocities increases to about 6-9%.

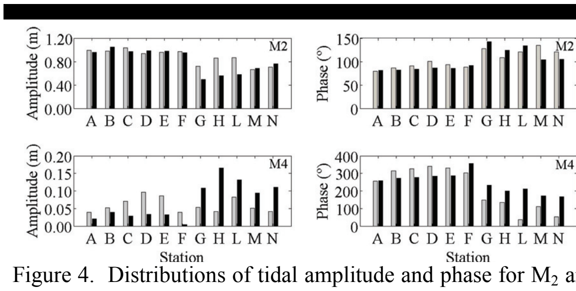

Figure 4. Distributions of tidal amplitude and phase for M_2 and M_4 (black: model results; grey: measurements).

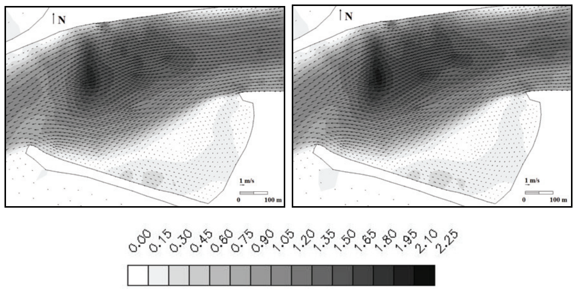

Figure 5. Magnitude of velocity in ms^{-1} during spring tide near the inlet of the lagoon. Left: present configuration; Right: configuration resulting from the salt pan walls partial collapse.

Tidal Asymmetry

In Ria de Aveiro, the amplitude of the M_4 constituent increases from the lagoon mouth toward the end of channels. The most important consequence of this growth is the differentiation of the ebb and flood durations, leading to an asymmetric propagation of the tide.

A direct measurement of non-linear distortion, the M_4 to M_2 sea-surface amplitude ratio indicates the magnitude of the tidal asymmetry generated within the estuary. An undistorted tide has an amplitude ratio of zero. The larger the amplitude ratio, the more distorted the tide is, and the more strongly flood or ebb dominant the system becomes. The sea-surface phase of M_4 relative to M_2 is defined as $\varphi = 2\theta_{M_2} - \theta_{M_4}$ and determines the type of tidal distortion ($0° < \varphi < 180°$ indicates flood dominance and $180° < \varphi < 360°$ indicates ebb dominance).

The amplitude and phase of M_2 and M_4 were analyzed for the present configuration and for the one resulting from salt pan walls destruction. According to model results, an increase of the lagoon total area leads to a decrease in the amplitude and an increase in the phase of the major tidal constituent, M_2, along the Ria de Aveiro, as well as in their first harmonic, M_4 (ARAÚJO *et al.,* 2008).

The amplitude ratio, the relative phase and the difference between ebb and flood durations were computed along the axis of the four main channels of the Ria de Aveiro. In Figure 6, these parameters are represented only for the Espinheiro and the Ílhavo channels, in order to evaluate the response of these parameters to an increase in the lagoon total area. These parameters were also computed for the Mira and S. Jacinto channels, however changes reveals negligible (more details in PICADO, 2008). Because tidal levels exhibit very small variations across the channels, all these parameters were computed along the axes of the channels.

For the ebb-flood differences, the negative values indicate ebb durations lower than flood ones (currents are higher on ebb than on flood), which leads to ebb dominance. Conversely, positive values indicate flood dominance.

The relative phase of M_4 with respect to M_2 in the Espinheiro channel shows a slight decrease with the expansion of the lagoon area, indicating that the characteristics of the tidal asymmetry are changing along this channel. In fact, the increase of the lagoon area results in the decrease of the ebb-flood differences along the Espinheiro channel, which means that this channel becomes more ebb dominated.

At the beginning of Ílhavo channel (~6 km away from the lagoon mouth) ebb-flood differences decrease around 12% with the expansion of the lagoon area by 5.6%.

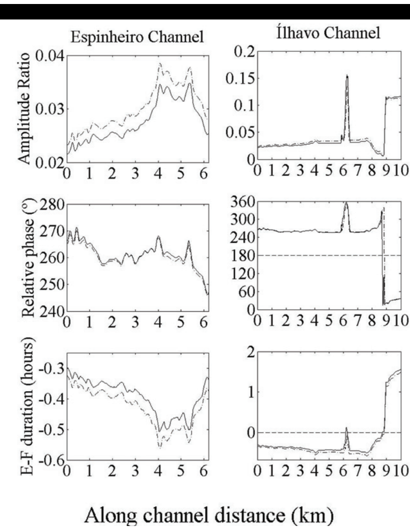

Figure 6. Amplitude Ratio, Relative phase (º) and the difference between ebb and flood durations along the Espinheiro and Ílhavo channels. Solid line: present bathymetry; dash dot line: bathymetry resulting from the salt pans walls partial collapse.

Furthermore, if the amplitude and phase of the major tidal constituent and its first harmonic change with the increase of the lagoon area, tidal asymmetry should also be altered.

The results of ebb and flood currents obtained in the previous section corroborate the increase of the ebb dominance in the lagoon central area.

Tidal Prism

The tidal prism was determined for several cross-sections of the lagoon using the model results. In this study, the tidal prism is defined as the volumetric flux passing a cross-section in a flooding cycle. Clearly, the tidal prism depends not only on the location of the cross-section, but also on the tidal range.

The tidal prism was computed for fifteen cross-sections in the central area of the Ria de Aveiro lagoon (Figure 1). Simulations were performed for extreme spring and neap tides (~3 m and ~0.7 m of tidal range, respectively), as well as for an average tide (~1.2 m of tidal range). In Figure 7, only the tidal prism for a maximum spring tide is represented. According to the model results, an increase of 5.6% in the lagoon area leads to an increase of 2.3% for the maximum spring tide, for the tidal prism at the inlet. For the average tide, the tidal prism increases 4.6%, and 3.2% for the neap tide condition. The highest relative increase of the tidal prism was found near the flooded area, which is induced by the large increase of the lagoon area near the cross-section 14, due the salt pan walls collapse around that channel.

Generally, the increase of the lagoon area, due to the salt pans walls collapse, results in an increase in the tidal prism, with the higher values at the cross-sections close to the flooded area. The results agree with previous studies. For instance, HARVEY (1988) showed that the reduction of the flooded area associated with the construction of a dam in Murray estuary led to a significant decrease in tidal prism.

CONCLUSIONS

The main goal of this study was to contribute to understand the consequences of the partial salt pan walls destruction on the entire Ria de Aveiro hydrodynamics. With this purpose, a finite volume

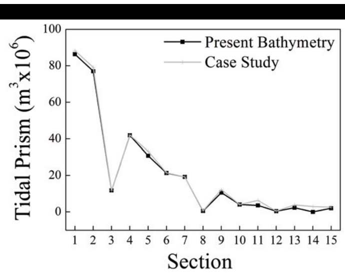

Figure 7. Computed tidal prism at 15 cross-sections of the Ria de Aveiro at a maximum spring tide.

shallow water model (ELCIRC) was implemented and calibrated for the Ria de Aveiro.

According to the final results, the model was considered successfully calibrated for a very complex system as Ria de Aveiro. Indeed, the RMS values range from 3% to 10% of the local amplitude and skill values higher than 0.95 were found for most stations located in lagoon central area. However, differences between model and field data exist. These differences are due to several factors, such as very narrow lagoon channels that are not well resolved by the horizontal model grid, and some possible uncertainties in the field data, as well as due to possible inaccuracies in the bathymetry. The fact that there is a 16-year time span between the measurement of the bathymetry and most tidal data should also explain part of the discrepancies between the model and the data.

Once calibrated, ELCIRC was used to characterize the Ria de Aveiro hydrodynamics under different scenarios: present configuration and configurations resulting from the salt pan walls destruction and consequent increase of the flooding area in Ria de Aveiro.

In order to study the hydrodynamic responses of the Ria de Aveiro to the increase of the lagoon area, tidal currents, tidal asymmetry and tidal prism were analysed for each configuration. Hydrodynamic results suggest that tidal propagation in estuarine lagoons depends strongly on the bathymetric configuration.

According to the model results, velocities are higher on ebb than on flood, showing ebb-dominated channels. This pattern is enhanced with the increase of the flooded area, which induces higher velocities, mainly in the lagoon central area during the ebb. Thus, the increase of tidal currents with the lagoon flooded area expansion is more significant as the distance from the inlet increases and with largest changes in neap tide condition.

Generally, the increase of the lagoon area also results in an increase in the tidal prism, with the higher changes at the cross-sections close to the flooded area and on neap tide. In fact, the more significant increase of tidal currents and tidal prism in the lagoon central area is induced by the large increase of the lagoon flooded area near these channels.

The numerical results suggest that the response of the harmonic constants of the M_2 and M_4 constituents is affected by changes in the lagoon total flooded area. The growth of the lagoon area reduces their amplitudes and increases their phases. Therefore, if the amplitude and phase of the major tidal constituent and its first harmonic change with the increase of the lagoon flooded area, tidal asymmetry should also be affected. In fact, an increase of the lagoon flooded area leads to an increase in tidal asymmetry, mainly in the beginning of the Ílhavo channel, in the S. Jacinto and the Espinheiro channels. Along the Mira channel, the effect of the flooded area expansion in tidal asymmetry pattern is negligible. Thus, tidal asymmetry is mainly modified in the channels close to the flooded area.

In summary, an extreme destruction of the salt pans walls will result in a significant increase of the flooding area in the Ria de Aveiro, and therefore will affect the lagoon's hydrodynamic regime.

LITERATURE CITED

ARAÚJO, I.G.B., 2005. *Sea level Variability: Examples From the Atlantic Coast of Europe*. Phd Thesis, School of the National Oceanography Centre, Southampton, UK.

ARAÚJO, I.G.B., DIAS, J.M., PUGH, D.T., 2008. Model Simulations of tidal changes in a coastal lagoon, the Ria de Aveiro (Portugal). *Continental Shelf Research* 28, 1010-1025.

DIAS, J.M. and LOPES, J.F., 2006a. Implementation and assessment of hydrodynamic, salt and heat transport models: the case of Ria de Aveiro lagoon (Portugal). *Environmental Model. Softw.* 21, 1-15.

DIAS, J.M. and LOPES, J.F., 2006b. Calibration and validation of hydrodynamic, salt and heat transport models for Ria de Aveiro lagoon (Portugal). *Journal of Coastal Research* SI 39, 1680-1684.

DIAS, J.M., LOPES, J.F., DEKEYSER, I., 1999. Hydrological characterization of Ria de Aveiro, Portugal, in early summer. *Oceanologica Acta* 22 (5), 473-485.

DIAS, J.M., LOPES, J.F., Dekeyser, I., 2000. Tidal propagation in Ria de Aveiro lagoon, Portugal. *Phys Chem Earth* (B) 25, 369-374.

DIAS, J.M., SOUSA, M.C., BERTIN, X., FORTUNATO, A.B., OLIVEIRA, A., 2009. Numerical modeling of the impact of the Ancão Inlet relocation (Ria Formosa, Portugal). *Environ. Model. Softw.*, doi:10.1016/j.envsoft.2008.10.017, *in press*.

FORTUNATO, A.B., PINTO, L., OLIVEIRA, A., FERREIRA, J.S., 2002. Tidally generated shelf waves off the western Iberian coast. *Continental Shelf Research* 22/14, 1935-1950.

HARVEY, N., 1988. Coastal management issues for the mouth of the River Murray, SA. Coastal Management, 16, 139-149.

IH, 1991. Instituto Hidrográfico. Recolha e processamento de dados de marés, correntes, temperaturas e salinidades na Ria de Aveiro. Tech. Rep. Relatório FT.MC. 5/87, Instituto Hidrográfico, Lisboa, Portugal.

INTERREG III B, 2008. Projecto SAL – *Sal do Atlântico. Acção6b – Protótipo de recuperação dos muros das marinhas, Relatório Final* (in Portuguese).

OLIVEIRA, A., FORTUNATO, A.B., DIAS, J.M., 2006. Numerical modelling of the Aveiro inlet dynamics. J.M. Smith (ed.), Proc. of the 30th Int. Conf. on Coastal Enginnering, Vol. 4, 3282-3294, World Scientific Publishing Co..

PAWLOWICZ, R., BEARDSLEY, B., LENTZ, S., 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. Canada. *Computers & Geosciences* 28, 929-937.

PICADO, A., 2008. Degradation of the salt pans in Ria de Aveiro: An Hydrodynamical Study. MSc. Thesis, University of Aveiro, Portugal, 50 p.

ZHANG, Y., BAPTISTA, A.M., MYERS, E., 2004. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: I. Formulation and skill assessment. *Continental Shelf Research* 24, 2187-2214.

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