

## Hydrodynamic and sedimentary characteristics of a small tidal channel in the Ria de Aveiro

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### ABSTRACT

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Owing to the decline of traditional salt production, a large number of saltpans in the Ria de Aveiro, Portugal, are currently abandoned and deteriorating. A study was undertaken to characterize the hydrodynamic and sediment transport conditions, in order to understand their role in the deterioration of the saltpan walls and to assist in the development of rehabilitation strategies. In a small tidal channel, samples of surface sediment were collected both in a saltpan wall and in the channel axis. Field measurements of water level, velocity, salinity, water temperature and suspended sediment concentration were made over two tidal cycles. It has been found that the sediment from the saltpan wall consists mainly of silt and clay material (about 80%), with median grain-size of the order of 0.018 mm. The sediment collected in the bottom of the channel is much coarser (median grain-size of 0.3-0.5 mm). The water levels indicate that tidal propagation between the inlet and the study area is not appreciably affected in terms of amplitude. Velocities showed maximum values of 0.40 m/s in the channel axis and 0.20 m/s near the bottom of the saltpan wall. Salinities (31.3-34.4‰) and water temperatures (17.1-27.9°C in July) reflected the strong marine influence and the shallow depth of the lagoon. The variation of suspended sediment concentrations (3.9-78.5 mg/l) was in agreement with previous studies. These findings, particularly regarding the nature of the sediment and the local tidal range, suggest that, in the absence of maintenance, the saltpan walls are significantly vulnerable to wave- and tide-induced deterioration.

**ADDITIONAL INDEX WORDS:** *saltpans, fine sediment, tidal range*

### INTRODUCTION

Salt production in the Ria de Aveiro, Portugal, has been an important economic activity for centuries, but declined sharply in recent decades (51,000 t in 1972, 25,000 t in 1982, 5,000 t in 1992, 500 t in 2002; Portela, 2006). In 2007, of a total of 252 saltpans, only a few remained active (4%), a few others had been converted to fish farming (18%) and the large majority were abandoned (UNAVE, 2008). Saltpan walls are small rudimentary dikes, traditionally made of small blocks of hardened natural sediment and plant material. A recent survey showed that a large number of abandoned saltpan walls are in a deteriorated condition (Coelho *et al.*, 2008). The deterioration of saltpan walls and the ultimate loss of saltpans may have negative environmental, socio-economic and cultural impacts. Given the large number of abandoned saltpans, their destruction may also result in an increase of the flooded area as well as in changes in the hydrodynamics of the entire system (Picado *et al.*, 2009).

So far, however, there has been little information about the main mechanisms leading to the deterioration of saltpan walls. Thus, as part of a wider research project, a field study was undertaken to characterize the hydrodynamic and sediment transport conditions in an area of abandoned saltpans in the Ria de Aveiro. The study was undertaken both to gain a better understanding of the role of

the physical environment in the deterioration of the saltpan walls and to assist in the development of rehabilitation strategies. The provided data also contributes to the understanding of the local fine sediment transport mechanisms.

### STUDY AREA

The Ria de Aveiro is a shallow mesotidal lagoon located in NW Portugal, covering a total area of about 100 km<sup>2</sup>. The saltpans occupy about 15 km<sup>2</sup> (Picado *et al.*, 2009).

The study area is a small tidal channel (Esteiro dos Frades, Lat. 40°39'01"N, Long. 8°39'59"W), 15 m wide and 0.5 m deep (referred to ZH datum). This channel is confined between an abandoned saltpan and a fish farm. The saltpan wall is in an advanced state of deterioration, its crest being partly colonized by halophytic vegetation, partly bare and situated below high water spring tide level (Figure 1).

### METHODS

Three campaigns were conducted in the study area, on 11 March, 2 July and 9 July 2009. On 11 March, samples of surface sediment were collected in the saltpan wall manually and in the bottom of the channel with a Petit Ponar dredge. In the laboratory,

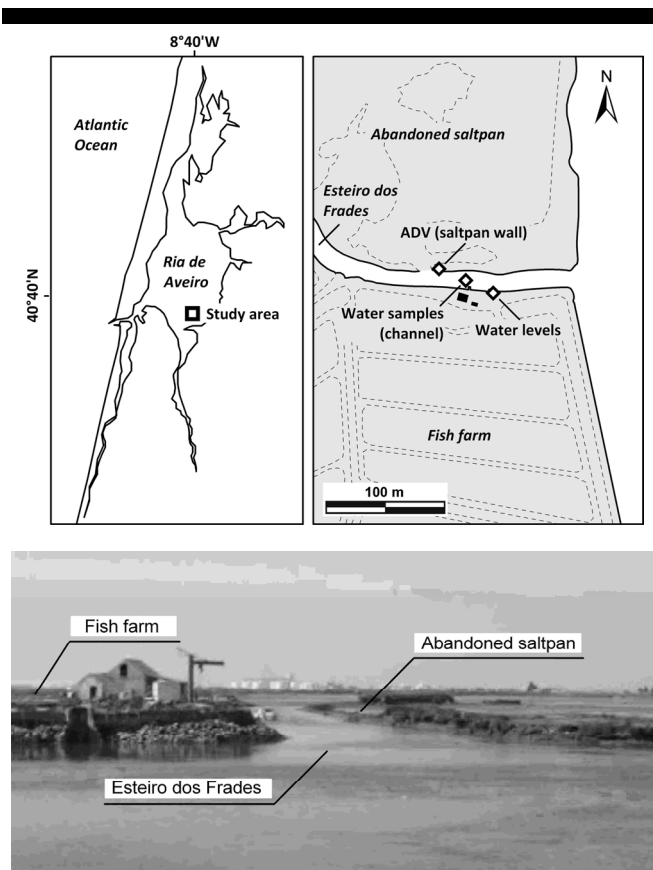


Figure 1. Location map of the Ria de Aveiro and the study area (top). View of the study area from the east (bottom).

the grain size distribution of the sediment samples was obtained by sieving and laser diffraction with a Malvern Mastersizer Micro (Portela and Freire, 2009).

On 2 July and 9 July, water column parameters (water level, velocity, salinity, water temperature and suspended sediment concentration) were determined over two tidal cycles (neap and spring tide conditions, respectively). The measurement of water level and water temperature was made with a Level Troll 500 instrument. Water samples were collected hourly at the surface and near the bottom with a Van Dorn horizontal bottle. Salinities were measured with a WTW LF-196 conductivity meter and suspended sediment concentrations were determined in the laboratory by the gravimetric method.

Velocity data was acquired using two instruments. A 3D Acoustic Doppler Velocimeter (ADV), Sontek 10 MHz, was deployed near the saltpan wall to measure velocities in the three directions, at 25 Hz in a  $0.25 \text{ cm}^3$  water volume situated above the channel bed. The ADV moved vertically in a metallic structure, installed at the slope base of the saltpan wall. The instrument recorded 5 min bursts, at different vertical levels, every hour along the tidal cycle. A separate current meter measured velocity at three levels in the water column in the channel axis.

## RESULTS AND DISCUSSION

The sediment from the saltpan wall consists predominantly (about 80% of the total sample) of fine-grained material (silt and clay), with median diameter of the order of 0.018 mm (Figure 2a).

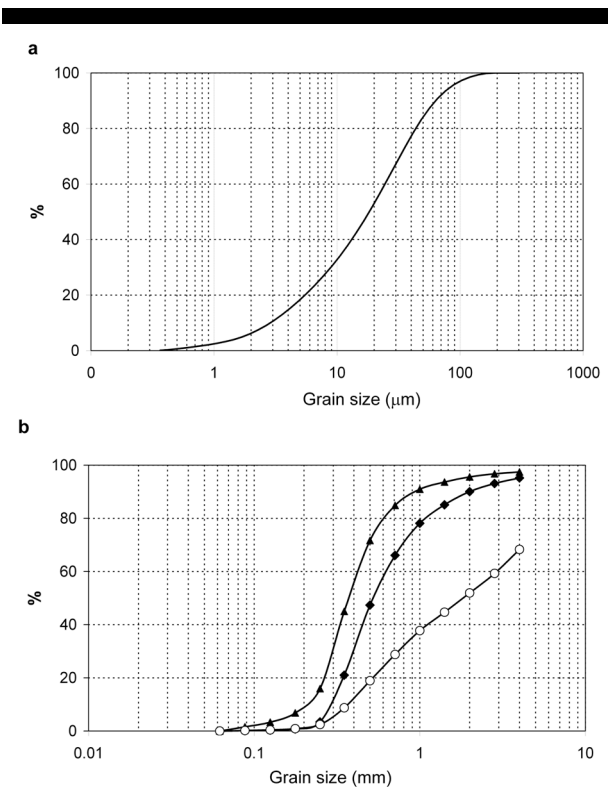


Figure 2. Examples of sediment grain size distributions. **a** Saltpan wall (sample A1); **b** Channel (samples B1, B2 and B3).

The sediment collected in the bottom of the channel is mainly composed of median to coarse-grained sand (only 2-15% of silt and clay), with median diameter of 0.3-0.5 mm. In addition to sand, the sediment in the channel may also contain a fraction of gravel-sized bioclasts (Figure 2b).

Figure 3 presents the depth-averaged values of the horizontal components of the velocity obtained by the ADV, in the direction of the channel ( $u$ ) and in the across direction ( $v$ ). The peak-values of the velocity in the channel direction ( $u$ ) were observed during the ebb and flood periods. The velocity was approximately zero at high and low tide. Velocities measured during ebb were slightly higher than during flood, with maximum values of 0.20 m/s. The component of velocity in the across direction of the channel ( $v$ ) was close to zero. However, a slight increase was observed during ebb, which could be explained by the water volume that, shortly after high tide levels, flowed out of the saltpan over the breached and eroded saltpan wall. This situation probably is one of the factors that are contributing to saltpan wall deterioration (Coelho *et al.*, 2008). In the channel axis, the local velocities showed maximum values of 0.40 m/s, that is, below the 1.0 m/s value typically assumed for the smaller tidal channels of the Ria de Aveiro (Coelho *et al.*, 2008).

The recorded water levels (Figure 4a) indicate that the tidal propagation in the lagoon, between the inlet and the study area, is not appreciably affected in terms of amplitude. The tidal range observed in the study area was actually greater than the range estimated from the tide tables issued by the Portuguese authorities for the inlet. On 2 July, the observed tidal range, 1.58 m, was larger than the predicted value by 0.14 m. On 9 July, the observed tidal range, approximately 2.35 m, was also larger than the predicted value. These results were not fully anticipated, given the

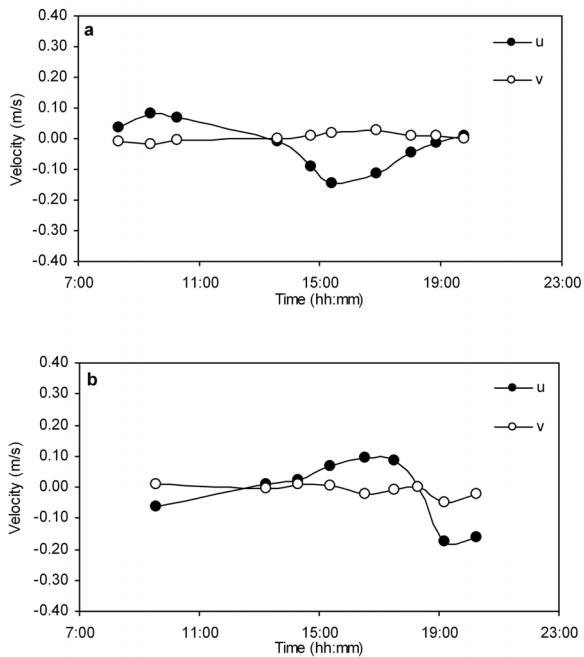


Figure 3. Depth-averaged flow velocity obtained by the ADV in the channel direction ( $u$ ) and in the perpendicular direction ( $v$ ). **a** 2 July 2009; **b** 9 July 2009.

fact that the tidal range at the tidal station closest to the study area (Lota) is estimated in the tide tables to be 87-94% of the tidal range at the inlet (Instituto Hidrográfico, 2009). Although the results of the present study should be interpreted with caution, a possible explanation may be related to the continuous deepening of the main navigation channel. In the past decades, a steady increase in the tidal range has occurred in the Ria de Aveiro in connection with dredging and port development (Silva and Duck, 2001; Araújo, 2005).

Water temperature values measured on 2 July varied between 23.5 and 27.9°C, with an average value of 25.6°C. On 9 July, water temperature varied between 17.1 and 22.1°C, with an average of 20.0°C (Figure 4b). Since the sensor was in a fixed position, the depth at which the measurements were made varied through each tidal cycle, which must be taken into account in the interpretation of the results. Nonetheless, the range of recorded water temperatures (17.1 to 27.9°C) reflects the shallow depth of the lagoon. Intertidal areas constitute the major part of the system (Silva and Duck, 2001). Only the frequently dredged navigation channels reach large depths (Lopes and Dias, 2007).

Salinity values observed on 2 July varied: at the surface, between 31.3 and 34.1‰, with an average value of 33.4‰; near the bottom, between 32.7 and 34.4‰, with an average of 33.8‰. On 9 July, salinity varied: at the surface, between 33.5 and 35.1‰, with an average value of 34.4‰; near the bottom, between 33.5 and 35.3‰, with an average of 34.5‰ (Figure 5). The obtained values indicate that the water mass of marine origin is clearly preponderant over the freshwater sources. This is consistent with the estimate that the total mean freshwater discharge into the lagoon during a tidal cycle is approximately equal to 1-5% of the spring and neap tidal prisms (Dias *et al.*, 2007).

Suspended sediment concentrations obtained from water samples collected on 2 July varied: at the surface, between 3.9 and 46.8 mg/l, with an average value of 13.5 mg/l; near the bottom, between 5.5 and 44.6 mg/l, with an average of 16.0 mg/l. On 9 July, suspended sediment varied: at the surface, between 12.5 and 78.5 mg/l, with an average value of 24.0 mg/l; near the bottom, between 14.3 and 66.1 mg/l, with an average of 31.1 mg/l (Figure 6). The concentrations near the bottom were slightly higher than at the surface and the concentrations with larger tidal range (9 July) were also higher than with smaller tidal range (2 July). The range of suspended sediment concentrations (3.9 to 78.5 mg/l) is in good agreement with the results of previous field studies in the Ria de Aveiro. In particular, the results of the present study are entirely consistent with those of Abrantes (2005), who reported minimum, average and maximum concentrations of 2.4, 16.7 and 75.0 mg/l, respectively.

## CONCLUSIONS

The purpose of the present study was to investigate the hydrodynamic and sedimentary characteristics of a small tidal channel in an area of abandoned salt pans in the Ria de Aveiro. The study has shown that, in the absence of maintenance, the nature of the sediment in the salt pan walls (fine-grained sediment, predominantly medium silt) makes them inherently vulnerable to wave- and tide-induced deterioration. The study has also found that the local tidal range is of the same magnitude as the tidal range at the inlet, which, combined with the steady increase in the tidal range that has occurred in the Ria de Aveiro in the past decades, further contributes to the vulnerability of salt pan walls to the erosive action of waves and tidal currents. Once breached, salt pan walls are expected to erode rapidly.

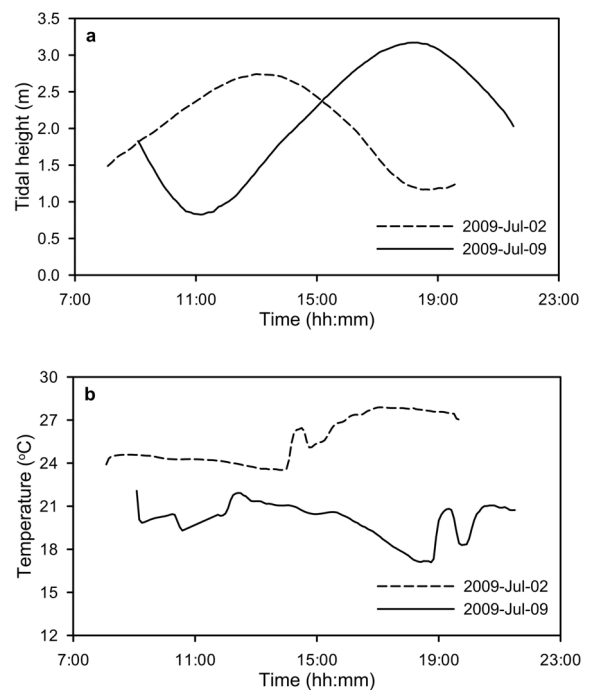


Figure 4. Data acquired by the pressure-temperature sensor on 2 and 9 July 2009. **a** Tidal height; **b** Water temperature.

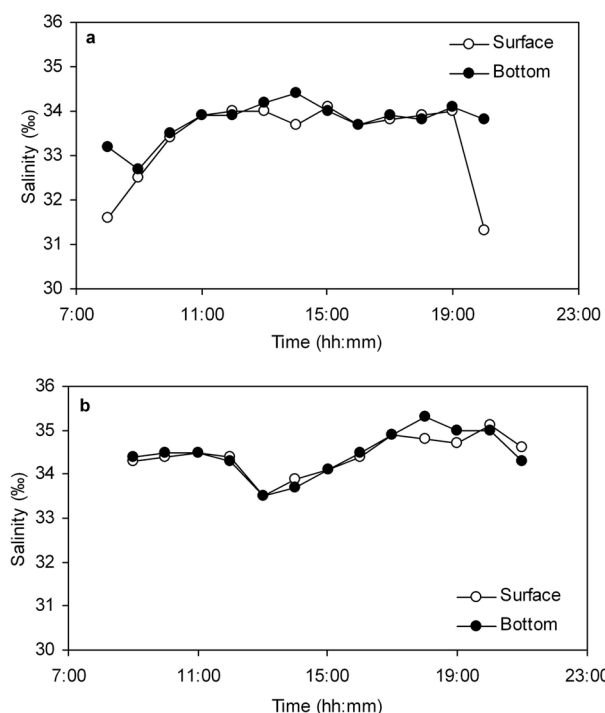


Figure 5. Near-surface and near-bottom salinity. **a** 2 July 2009; **b** 9 July 2009.

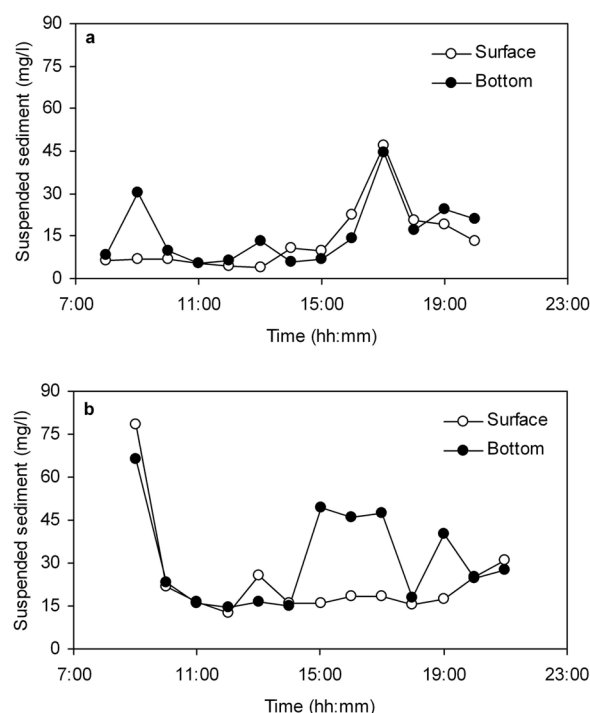


Figure 6. Near-surface and near-bottom suspended sediment concentrations. **a** 2 July 2009; **b** 9 July 2009.

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