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A Behaviour Oriented Model for the Evaluation of Long-Term Lagoon-Coastal Dynamic Interaction along the Po River Delta

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Abstract

We are further developing an aggregated-scale behaviour-model (Stive et al., 1996) describing the interaction between a tidal lagoon or basin and its adjacent coastal environment, including the ebb-tidal delta. While the model is based on general sediment transport equations, the behavioural aspect concerns the a priory assumption that the equilibrium state of each element of the system is known or at least can be defined. Here, we are able to rely on a vast body of reported experience for each of these system elements. The importance of the present work lies in the application of the model to the microtidal environment of the Po Delta, while the original model was validated for the mesotidal environment of the Wadden Sea.

Introduction

The sediment accommodation space that is provided by relative sea level rise in tidal basins and lagoons causes, in general, a net influx of sediments. It is generally assumed that this influx goes to the cost of the coastal stretches adjacent to the tidal entrance. Also, sediment may be delivered by the ebb tidal delta, which is, however, considered as a temporary source.

The idea behind these lines of thinking is strongly derived from the empirical findings (since O'Brien) that the morphological state of tidal basin elements (flats,

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channels, ebb-tidal deltas) seems to be in quasi-static equilibrium with the tidal prism. However, for some time now there has been the notion that morphological interactions take place between the adjacent coastal stretches, the tidal basins and their submerged deltas at different spatial and temporal scales, according to intrinsic dynamics and to external forcing factors. We are interested in developing approaches to account for these interactions on decadal and on centennial time-scales.

The ASMITA approach

A first modelling approach (ASMITA - Aggregated Scale Morphological Interaction between a Tidal basin and the Adjacent coast) has been developed, focusing on the "residual" interaction occurring on long term scales. Because of the time-scales of interest, the geophysical elements of the coastal fringe are considered at an aggregated scale, e.g. single-inlet lagoons are schematised into two or at most three spatial units such as channel area, and (high and low) flats area. The new element is that we introduce the nonlinear dynamic interaction between the lagoon elements, the submerged delta and the adjacent coastal sections.

These principal elements are morphodynamic systems themselves, consisting of interacting sand bodies and water masses. They can be considered as being mutually linked by sediment "conveyors", one of which goes through the tidal entrance.

The approach is an aggregation and an extension of a model formulation for tidal basins (Wang et al., 1996). The aggregation concerns the fact that we characterise the system elements by only one state variable (viz. a total wet or dry volume (V)). The extension concerns the incorporation of formulations for the ebb tidal delta and directly adjacent coast as well, without modifying the basic concepts.

We assume that the morphological state of each of these elements can be described by a small number of *aggregate state variables* (e.g. the total sand volume of the outer delta, or the total water volume below mean sea level and the area of the intertidal zone in the lagoon basin). The reason is that we want to use the model on very simple and representative variables for which we can "control" the accuracy on the long term. Conservation of sediment requires sediment exchange with other elements, or with the open sea, if these state variables change.

The most important hypothesis used in the model concept is that an equilibrium state can be defined for each element depending on the hydrodynamic condition, e.g., tidal volume (P) and tidal range (H). An empirical relation is required for each element to define the morphological equilibrium state. These relations are derived from literature (cf. Eysink, 1990).

A summary of the model equations is as follows. For the equilibrium volume we assume:

$$V_e = f(P, H) \tag{1}$$

A disturbance of these volumes causes changes in the local equilibrium concentration (c_e), which depends on the actual volume V. The equation determining the local equilibrium concentration is equal to:

$$c_e = c_E \cdot \left(\frac{V_e}{V}\right)^n \tag{2}$$

The overall concentration c_E, which is the long-term concentration of the system in equilibrium, also applies to the concentration at the boundaries and is assumed constant. The coefficient n equals 2, based on the usual assumption in sediment transport formulas that the sediment transport is proportional to the third power of the flow velocity. The difference between the actual concentration (c) and the local equilibrium concentration results in changes in the morphology. Morphological changes are governed by:

$$\frac{\partial V}{\partial t} = w_s \cdot A \cdot (c_e - c) \tag{3}$$

Here w_s equals the vertical exchange coefficient and A the horizontal area. As a result of the disturbance, sediment is exchanged between the various elements. Considering the neighbouring elements "a" and "b", the diffusion based sediment exchange yields:

$$\delta_{ab} \cdot (c_a - c_b) = w_s \cdot A_a \cdot (c_{ae} - c_a) \tag{4}$$

The exchange of sediment continues until the overall equilibrium concentration and the equilibrium volumes are reached again. Every element has a morphological time-scale, depending on the magnitude of the disturbance. For a single element the morphological time-scale τ equals:

$$\tau = \frac{1}{c_E \cdot n}\left(\frac{V_e}{w_s \cdot A} + \frac{V_e}{\delta}\right) \tag{5}$$

For a more complete description we refer to Stive et al. (1996).

Simplified "process-based" computation of the equilibrium concentration

The problem of definition of equilibria for the internal lagoon model can be translated into the definition of one "equilibrium concentration", one single empirical constant, with reference to the inlet. This is particularly important in microtidal environments like the Po Delta where both wave climate and tidal flux play a significant role, on the long term, in the determination of its values.

Similarly to the concept of equilibrium profile in longshore sediment transport modelling, in the modelling of the evolution of the internal lagoon we use the concept of "equilibrium concentration". Such a concept was also used extensively, even though still in a very experimental way, for the morphological evolution of the inlets in the Lagoon of Venice (Di Silvio, 1989). The equilibrium concentration represents the fundamental link between hydrodynamics, sediment transport and morphology at the entrance of the lagoon. Conceptually, c_E is the average annual concentration induced by waves and currents. In principle it would be possible to obtain a formulation for c_E by integrating over a long period of time any sediment transport formula, and obtaining something like:

$$c_E = c_E\,(\text{local wave climate, tidal currents, water depth, grain diameter}) \qquad (6)$$

Further it should be noted that if a constant c_E is used[5], than c_E by itself does not have any influence on the final equilibrium state of the system but it is an important parameter determining the time scale of the morphological development together with the dispersion coefficients and the fall velocity. Therefore c_E could be used as one of the calibration parameters in the model.

Model application results

The ASMITA model was applied to two lagoons of the Po River Delta (Italy): the Scardovari and Barbamarco lagoon. In the Po River Delta area a large number of tidally flushed lagoons is present (the tidal range is about 1.0m in this part of the Adriatic Sea) and there is an increasing need of predicting their evolution, focusing on the impact of management measures. The most important characteristics of the lagoon inlets are presented in Table 1.

Lagoon	*area at MLW (km^2)*	*fishery valley (km^2)*	*n. of inlets*	*inlet name*	*inlet section (m^2)*	*exchanged volume ($m^3 \cdot 10^6$)*	*Q_{max} in (m^3/s)*	*Q_{max} out (m^3/s)*
Caleri	10.5	30.0	2	Pozzatini	284	2.95	146	128
				P. Caleri	605	6.27	313	272
La Vallona	11.0	37.0	2	P. Levante	542	16.90	610	610
				Bocchetta	104	1.42	83	63
Barbamarco	6.9	18.0	2	Nord	330	totally	68	47
				Sud	203	7.4	250	150
Scardovari	29.0	0.0	1	---	3295	15.7	1625	1250

Tab. 1. *Main characteristics of the most important Po River Delta lagoons*

We present the details of the application to the lagoons Barbamarco and Scardovari for which the inner channel network and the recent morphological evolution of the inlets were derived from bathymetric information. In Table 2 we summarise the characteristics for the Scardovari and Barbamarco lagoon.

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[5] This is not a logical incongruence; simply, as we will further state in the following, the equilibrium concentration can be made dependent on variables that are subject to change.

	Scardovari	*Barbamarco*
BASIN DATA:		
lagoon area at MWL A_b (km^2)	29.0	6.74
exchanged volume V per tidal cycle (tidal prism or flood volume) (10^6 m^3)	15.7	7.4
tidal range R_t (m)	1.28	1.34
CHANNEL DATA:		
total length (km)	18.0	7.5
average depth (m)	1.75	3
mean width (m)	150	79
channel area A_{ch} (km^2)	2.7	0.59
channel volume V_{ch} (10^6 m^3)	4.7	1.78
FLAT DATA:		
lagoon area at HWL (km^2)	30.0	7
lagoon area at LWL (km^2)	28.0	6.5
tidal flat area (km^2)	27.3	6.38
tidal flat volume (above LWL) (10^6 m^3)	22.7	1.94
DELTA DATA:		
active base over a slope of 1:100 (m)	7.0	7.0
longshore extension (km)	2.0	0.6
delta volume V_d (10^6 m^3)	4.9	1.47
COAST DATA:		
active base over 500 m cross-shore (m)	5.0	5.0
longshore extension (km)	2.0	2.0
coast volume (10^6 m^3)	7.5	7.5

Tab. 2. *Characteristics of Scardovari and Barbamarco lagoon*

Applying the Wadden Sea relations for Barbamarco we acquire the following equilibrium data:

- for the equilibrium channel volume: $V_{ch} = 65 \cdot 10^{-6} \cdot V^{1.5} = 1.31 \cdot 10^6$ m^3;
- for the equilibrium delta volume: $V_d = 6.57 \cdot 10^{-3} \cdot V^{1.23} = 1.85 \cdot 10^6$ m^3.

Applying the Wadden Sea relations for Scardovari we acquire the following equilibrium data:

- for the equilibrium channel volume: $V_{ch} = 65*10^{-6}*V^{1.5} = 4.04*10^6\ m^3$;
- for the equilibrium delta volume: $V_d = 6.57*10^{-3}*V^{1.23} = 4.66*10^6\ m^3$.

We thus can conclude that the Wadden Sea relations may well be applicable to the Po Delta region.

A plan view of all the lagoons of the Po Delta is shown in Fig.1.

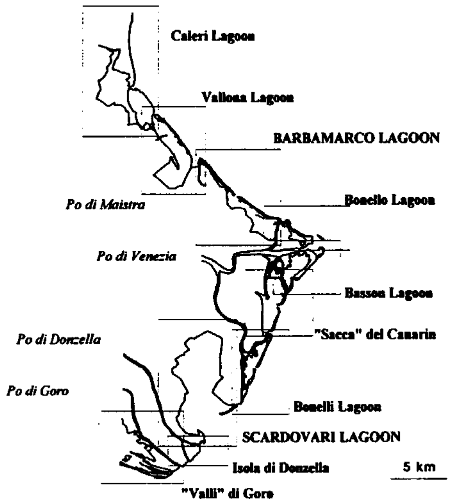

Fig.1. *Plan view of the Po River Delta*

Lacking validated information about the equilibrium flat volume we assume that the flats are in equilibrium in the case of the Barbamarco lagoon. Applying the equilibrium Wadden Sea relations we find the following model behaviour (Fig.2):

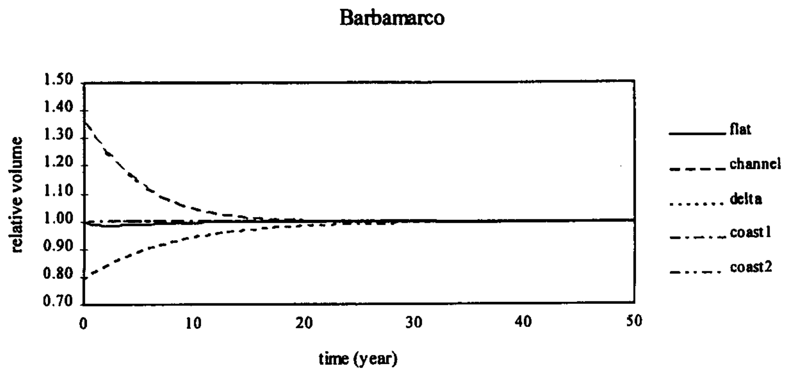

Fig.2. *Applying the Wadden Sea relations to the Barbamarco lagoon*

The volumes are taken relative to the proposed equilibrium volumes. Because the lagoon is small, the responses of the system are very rapid. The channel and the delta are subsequently too large and too small compared to their equilibrium states.

It is management practice to dredge the channels for navigation and flushing purpose. To maintain its initial volume we adapt a scenario in which the channel is dredged with an interval of about 4.1 years (Fig.3).

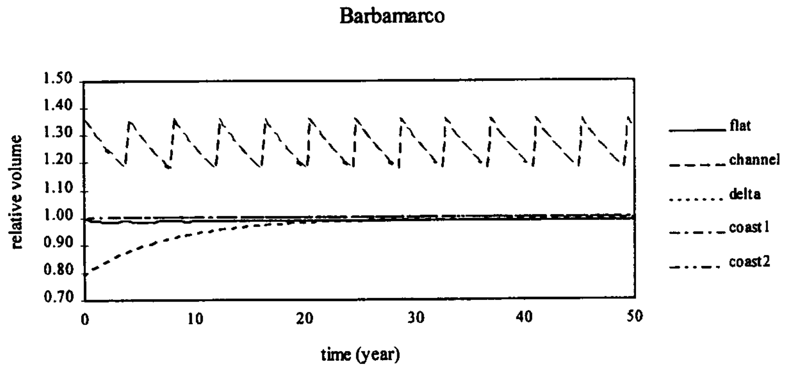

Fig.3. *Dredging the channel of the Barbamarco lagoon with an interval of 4.1 years*

Due to dredging much sand is withdrawn from the system. As can be seen all elements develop to a new equilibrium. Much sand is imported through the boundaries to compensate for the loss of sediment. The time response scales are relatively short, indicating the need for regular dredging.

A management scenario which is investigated concerns the creation of tidal flats with the material from the channel. In Fig.4 we see the effects of dredging sand from the channel, and dumping this volume of sand onto the flat. The system's responses are rapid, and much sand is directly transported back to the channel.

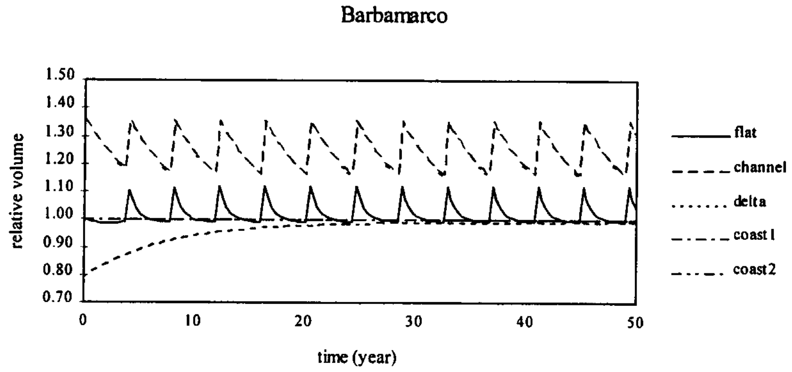

Fig.4. *Dredging and dumping of sediment in the Barbamarco lagoon*

A similar analysis was done for the Scardovari lagoon (Fig.5, Fig.6 and Fig.7). In this case we assumed also that the flats are in equilibrium. The channel and delta volumes in the initial states are a little larger than in their equilibrium states (Fig.5).

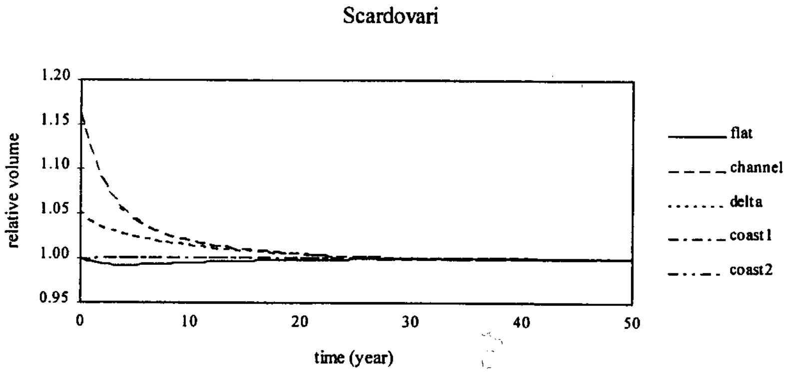

Fig.5. *Applying the Wadden Sea relations to the Scardovari lagoon*

In Fig 6 it can be seen that the flat suffers mostly from the dredging. Much sand is transported directly from the flat to the channel. Because of the import of sand across the boundaries the small ebb-tidal delta starts to grow. As can be seen all elements develop to a new equilibrium. The Scardovari lagoon is larger than the Barbamarco lagoon, resulting in larger morphological time-scales.

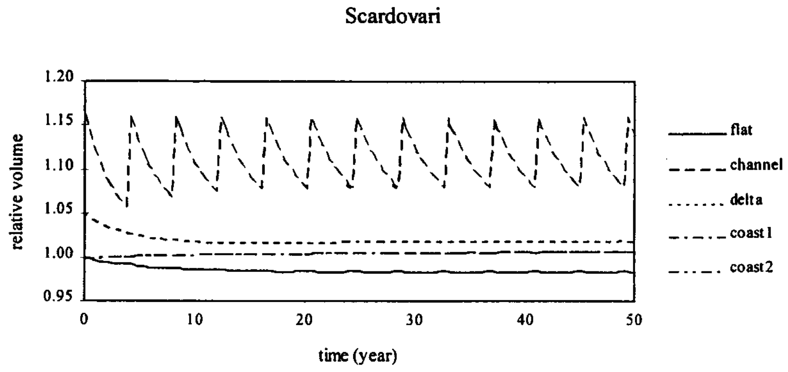

Fig.6. *Dredging the channel of the lagoon Scardovari with an interval of 4.1 years*

As we can see in Fig.7 the delta is negatively affected by the dumping of sediment onto the flats. Because the import of sediment equals zero the demand of sand of the channel affects also the delta.

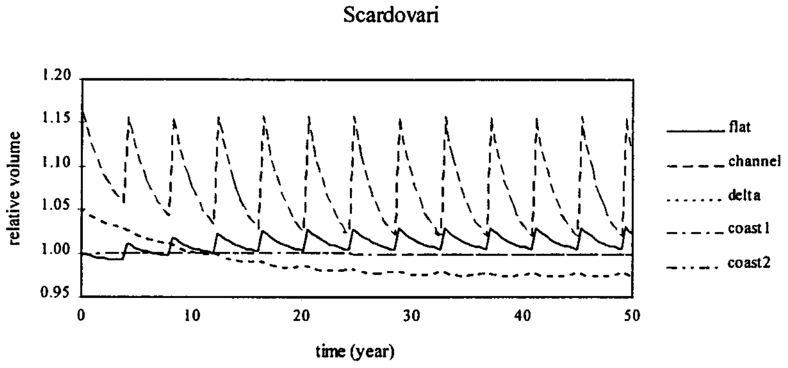

Fig.7. *Dredging and dumping of sediment in the Scardovari lagoon*

Conclusions

We have applied our mesotidal model ASMITA to microtidal lagoons of the Po Delta. ASMITA is a tool to evaluate with large scale intervention scenarios. There is a need for verifications concerning the evolution of the adjacent coastline and the extension of the flat area, however we can conclude that the first results look promising.

The adoption of ASMITA to the Po Delta lagoons is justified by the need to investigate the effects (on safety and on morphology) of possible accelerated sea-level rise, the effects of local subsidence and the effects of "reclamation" or "renaturalisation" interventions currently being planned.

Such questions need an integrated approach for a suitable answer and we recognise that we can integrate *if and only if* we proceed to a simplification of the available long term lagoon evolution and long term coastal evolution models.

Our analysis shows that the time-scales of the Barbamarco lagoon are shorter than the time-scales of the Scardovari lagoon. This indicates that dredging in the Barbamarco lagoon would have to be more frequent than in Scardovari lagoon.

A management scenario aimed at enlarging the tidal flat volume is more successful for the larger Scardovari lagoon.

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A conceptual model for barrier coasts behaviour at decadal scale. Application to the Trabucador Bar

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Abstract

A conceptual model for barrier coasts evolution a decadal scale is presented. The model considers all the dynamic processes acting on a barrier system, and in this sense, the RSLR is only considered as a passive factor. The model includes the concept of critical width for overwash contribution to backbarrier deposition. A first simplified version of the model has been used to simulate the landward rollover experienced by the Trabucador Bar during the last decades. The main identified agent driving such behaviour was the overwash transport and reasonable results were obtained. The effect of man actions (such as artificial dunes) preventing overwash on barrier evolution was also assessed.

Introduction

Traditionally, barrier coasts evolution has been largely related with mean sea level fluctuations. Although when long term evolution is studied, RSLR has to be considered as an element of the dynamic system, this is a relatively simplistic approach. In fact, when RSLR is used to explain some observed barrier type of evolution, e.g. landward rollover, most of the real dynamic processes controlling such behaviour are implicitely included in it but in a parametric and hidden way.

In order to solve this, and to explain and model the Ebro delta coast behaviour, where a relatively large barrier-spit complex (The Trabucador Bar-La Banya spit, Figure 1) does exist, a more comprehensive approach is presented.

This approach follows the large number of previous works done in

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