CHAPTER 142

Effects of non-uniform sediment grainsize in the long-term evolution of tidal lagoons

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1. INTRODUCTION

Long-term coastal processes [9, 10] usually consist in slight net morphological changes that result from large positive and negative oscillations occuring to a much shorter time-scale. As soon as one is not interested in these short-term variations, one may perform a preliminary time averaging of the basic waterflow and sediment transport equations in order to obtain a much simpler and manageable model for long-term simulations [6].

Long-term mathematical models, in fact, not only require much less computer time, but can run without knowing the detailed time - history of all the boundary conditions (which on the contrary is absolutely needed by short-term mathematical models).

Averaging of non-linear equations, on the other hand, produce residual terms that either may be neglected or should be expressed, in some convenient way, as a function of the averaged quantities. The procedure, indeed, is analogous to the averaging of the Navier-Stokes equations in order to eliminate turbulence pulsations, where the Reynolds stresses should be conveniently expressed in terms of averaged velocity.

In the case of long-term morphological models of tidal lagoons, semi-empirical expressions of the residual terms can be found. The relative calibration coefficients may be then identified by comparison with field data and/or with a limited number of simulations carried out on short-term models.

In some previous papers, long-term morphological models of a tidal lagoon have been developed with different space-resolution (zero-dimensional [4] and two-dimensional [5] approach) by considering only one equivalent (uniform) sediment grainsize. The zero-dimensional procedure, in particular, has been applied to the Lagoon of Venice [8].

In the present paper the two-dimensional model is re-considered and extended to the case of particles with different grainsize, ranging from sand to silt.

2. TWO DIMENSIONAL LONG-TERM MODEL

The n two-dimensional balance equations for the sediments belonging to the i-th grainsize class (i = 1, 2,..., n) are written as:

$$\frac{\partial Tx_i}{\partial x} + \frac{\partial Ty_i}{\partial y} = E_i \qquad (1)$$

where Tx_i and Ty_i are the long-term sediment transport (averaged over a long period of time) in the direction x and y respectively and E_i is the long-term rate of removal from the lagoonal surface.

The following expression for the "net" sediment transport are obtained by integrating the suspended transport equations over a long period of time:

$$Tx_i = h\left(C_i U - Dx\,\frac{\partial C_i}{\partial x}\right) \qquad (2)$$

$$Ty_i = h\left(C_i V - Dy\,\frac{\partial C_i}{\partial y}\right) \qquad (3)$$

where h is the average water depth and C_i the average sediment concentration of the i-th class over the water column. The components of the residual currents, U and V, are mainly due to the inland water input but also to the (eulerian) net circulation produced by the asymmetry of tidal flow. Even with a symmetrical tidal flow, however, a large amount of net transport is due to the intertidal dispersion produced by the irregular morphology of the lagoon; dispersion coefficients Dx and Dy result in fact being quite large (hundreds of m^2/s), as recently confirmed by experiments in the lagoon of Venice [7]. The quantities U, V, Dx and Dy may be provided by a tidal model.

The long-term evolution of the water depth, h, is given by adding up the bottom erosion rate ΣE_i (removal of all the grainsize classes), the eustatism rate α_e (rise of mean sea level) and the subsidence rate α_s (settlement of ground surface):

$$\frac{dh}{dt} = \Sigma E_i + \alpha_e + \alpha_s \qquad (4)$$

A first-order reaction equation is assumed for the bottom erosion rate:

$$E_i = w_i\,(\beta_i C_{ji} - C_i) \qquad (5)$$

where C_{ji} is the equilibrium concentration of the i-th grainsize class, β_i is the percentage of the same class present in the bottom and w_i a parameter that, for fine particles, coincides with the fall velocity of the particle with a diameter d_i. Eq. (5) shows that the equilibrium concentration of the i-th class in a certain place is the average sediment concentration over the water column which would yield neither erosion or deposition, should the bottom be composed by that grainsize ($\beta_i = 1$). Equilibrium concentration C_{ji} depends on the grainsize diameter d_i, on the local hydrodynamics (waves and currents) and on the local depth, as it will be discussed in the subsequent section.

The mathematical model should also include the balance equation of the i-th class in the bottom:

$$\frac{d\,(\beta_i\,\delta)}{dt} = -\,E_i + \beta_i^*\,\Sigma E_i \qquad (6)$$

where δ is the thickness of the "mixing layer" (i.e. the amplitude of the bottom variation during the annual cycle) and

β_i^* is the grainsize percentage in the mixing layer (if $E_i < 0$) or below it (if $E_i > 0$).

The numerical integration of eqs. (1) to (6) provide the evolution of water depth, sediment transport and grainsize composition all over the lagoon, provided that initial and boundary conditions are duly prescribed.

3. EQUILIBRIUM CONCENTRATION

The expressions of the equilibrium concentration, C_{ij}, constitute the crucial link coupling hydrodynamics, sediment transport and morphology of a lagoon. These expressions are obtained by integrating over a long period of time (say, one year) any transport formula of sediments by currents and waves. By assuming a plausible statistical distribution for wave climate and tidal flow and by treating residual terms with necessary simplifications, one comes to a formulation of this type:

$$C_{ji} = C_{ji}\,(W,\, Q,\, d_i,\, h) \qquad (7)$$

which is in principle different for channels ($C_{ji} \equiv C_{ci}$), shoals ($C_{ji} \equiv C_{si}$), and tidal flats ($C_{ji} \equiv C_{fi}$), where w and Q, respectively, are quantities related to the local wave climate and tidal flow; coefficients in eq. 7 are to be determined <u>via</u> calibration against morphological and sedimentological data.

An approximate form of eq. (7) is a simple monomial expression; however, if one considers a threshold-value for the waves and currents capable of picking-up the sediment from the bottom (incipient motion), one comes to more complicated expressions that can explain various interesting features of the lagoon's morphology and sedimentology.

4. CONCLUSIONS.

Grainsize distribution in estuaries and tidal lagoons is generally far from being uniform. In the Lagoon of Venice, for example, a systematic survey [1, 2, 3] shows that sediments tend to be sandy near the inlet sand to decrease towards the periphery, especially in the northern-eastern part, where silt and clay definitely prevail (Fig. 1). Another distinction, although less clear, exists between a channel and the adjacent shoals where sediments are generally finer.

In a lagoon with negligible sediment input by rivers and moderate eustatism and soil subsidence, this typical pattern is essentially due to the "threshold effect" of the pick-up function by currents and waves. Indeed, as the net transport through the lagoon should be practically zero, the average concentration of each grainsize class in the water column should be almost the same all over the lagoon. Consequently, shoals that are less subject to wave action result to have a smaller depth and a finer bottom composition; in this way all the particles here are put in suspension less frequently but with a higher concentration with respect to the particles in more exposed shoals.

In general, however, grainsize distribution is also controlled by the sediment net fluxes towards the sea (by river input) or towards the periphery (by eustatism and soil subsidence), as well as by any long-term evolutionary process. The relative importance of the various mechanisms in the transport of non-uniform grainsize particles in estuaries and tidal lagoons can be assessed and discussed by the mathematical model described above.

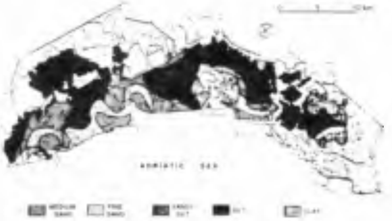

Fig. 1: Grainsize distribution of the bottom in the Lagoon of Venice.

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