6 Santander case

6.1 Introduction

Port activity in Santander dates back more than 2,000 years ago. Throughout this period, the sea and the port have been the fundamental elements of a community which, through fishing, defence, shipbuilding and maritime trade has kept a constant presence on the world stage, acquiring invaluable experience with which to meet the challenges of the next century. Next, a figure of Santander bay is presented:

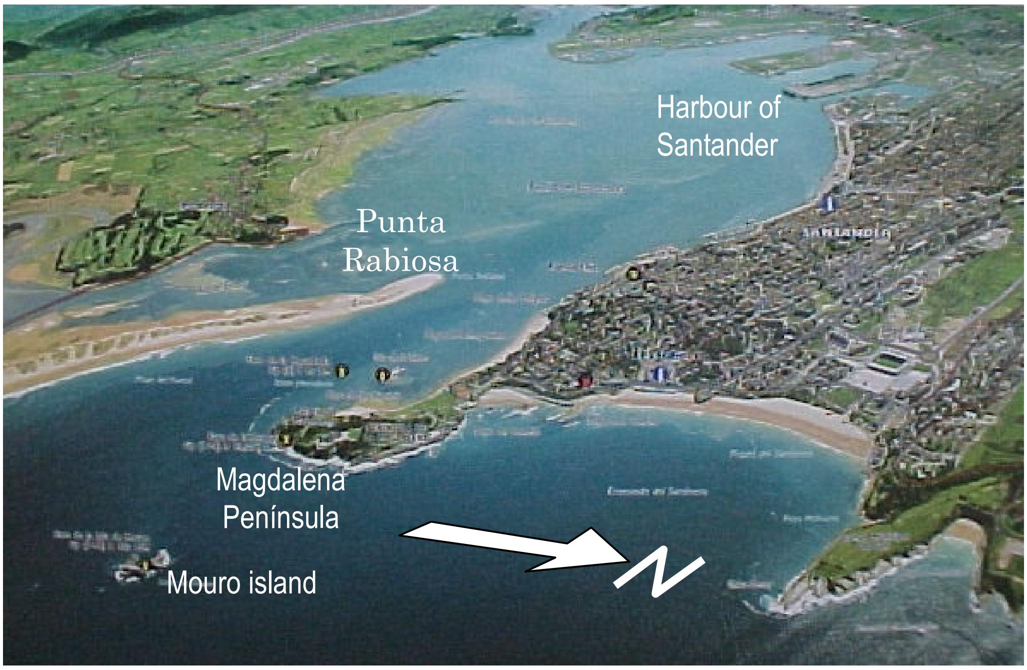

Figure 6-1 Santander Bay
After University of Cantabria (2002)

Port of Santander is placed in the Santander bay, in the north coast of Spain. This bay is constituted by a tidal inlet, with a channel, flat areas and a delta. There is also a small river that flows to the basin, which is called Ria de Astillero. We shall mention the presence of the Quebrantas shoal, since it divides the beach morphodynamics in two sections. Dynamics inside the basin are dominated by tides. That makes this area a good choice to site a harbour. However, since the channel might have a specific depth for the maritime traffic, continuous dredging works are needed, at least once a year, and especially after storm events.

Our aim is to understand how the system behaves, considering its own morphological and hydrodynamic characteristics. Furthermore, we will take into account the river discharge and see its influence to the system. For this purpose we will use the ASMITA model equations. The University of Cantabria made a study of this area in 1996. We will also include a summary of it. Together with the ASMITA model results, it will help us to obtain some conclusions.

6.2 Historical evolution of Santander bay

In 1833, the first large-scale dredging projects inside the bay, around 800.000m^3, are carried out. Then, the Quebrantas shoal decreases. Furthermore, the reduction of the tidal prism moves Punta Rabiosa to the North, reducing the area and depth of the navigation channel. As a consequence of the dredging activities, an important retreat of the beach in the area of Latas is detected. The exact amount of this recession is not clear due to the inaccuracies of the 1730 cartography, but estimation range between 200 and 500 m in the area of Latas, according to the University of Cantabria (2002).

Punta Rabiosa continues moving to the West. From 1870 to 1926 the displacement has been around 210 m, with an annual rate of about 3.7 m. Also, still the beach is retreating due mainly to the disappearance of the Quebrantas shoal.

From 1929 to 1960, the dredging activities over Punta Rabiosa causes the practical elimination of the Quebrantas shoal. As a consequence, a complete change of the beach morphology occurs. From the point of view of morphodynamics, the beach is in 1960 a continuous system from Loredo to Punta Rabiosa. The retreat of the beach in the Latas and Somo areas is about 100 m.

The permanent dredging causes a movement to the South and to the West of Punta Rabiosa. The movement to the West since 1926 has been around 100 m, with an annual rate of 3 m. With more accurate bathymetry, the loss of sand (mainly due to dredging) can be evaluated on $1.3 \cdot 10^6$ m^3 (around 50.000 m^3/year).

From 1960 to 1990, dredging activities increase, reaching annual rates of 300.000 m^3/year. The loss of sand in this period is about $8 \cdot 10^6$ m^3. The beach is still retreating (60 m from 1960 in Latas and 30 m in Somo) and Punta Rabiosa moves to the West 325 m, which means more than 10m per year.

Next, a figure is presented in order to see the retreat of the beach, and the movement of Punta Rabiosa to the West.

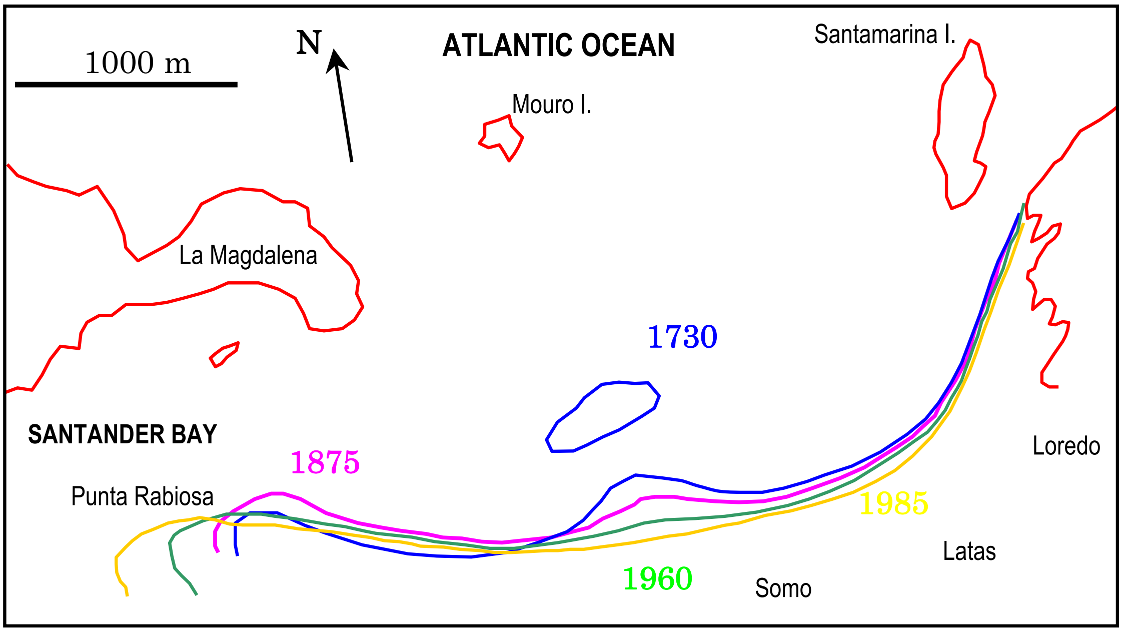

Figure 6-2 Historical displacement of the low tide line
After University of Cantabria (2002)

6.3 Results of the study carried out by the University of Cantabria (1996).

The final conclusions and recommendations from the University of Cantabria are:

The Puntal beach is a beach system in dynamical equilibrium between the actions of waves, tidal currents and human action. There has been a reduction of the flooded area, which is now 43% of the flooded area in 1730. The tidal prism and the equilibrium section of the navigation channel have reduced consequently.

Dredging on Punta Rabiosa and disposal of the dredged sand in deep water has produced a general retreat of the beach and the advance to the West of Punta Rabiosa. By 1990 the rate of retreat was 1.5 m/year in the area of Latas – Somo, threatening the village of Somo. The rate of advance of Punta Rabiosa to the West during the years of surveying was 13 m/year.

The increase of the dredging volumes in Punta Rabiosa to create a buffer of sand, increases the sand transport towards Punta Rabiosa, worsening the erosion of the beach and increasing the cost of maintenance of the channel. We can see the stability of the beach is important for the stability of the navigation channel, they are both related.

Without human action, the natural tendency of El Puntal to move to the North damps with time. During the 450 days that dredging was interrupted (to allow the University surveys), El Puntal moved 11 m to the North. The rate of sand deposition in El Puntal at the beginning of the survey was 101000 m^3 per year. By the end of the survey, with El Puntal 11 m to the North, the rate of sedimentation was 20000 m^3 per year. It is estimated that the natural equilibrium of El Puntal is somewhere 20 m North from its present position.

Over the equilibrium position, the coastline of El Puntal oscillates with the maritime weather and the alternating spring – neap tides. Storm events are what produce the biggest sand accumulations in El Puntal. Long shore transport over the surf zone due to periods of high waves is one order of magnitude higher than the cleaning capacity of the tides. As a consequence, there is a phase lag between the sand settled in El Puntal by the storms and the tide capacity for removing it. The amount of sand accumulated by a big storm can be up to 50.000 m^3, while the sand transport by tides removes around 1500 m^3/day. This means that around a month of good weather is necessary to recover the equilibrium position.

As the sand accumulation is not compatible with the channel operation, dredging might reduce the phase lag. This dredging should not go further South than the equilibrium line. This means that a continuous topo-bathymetric survey of Punta Rabiosa is needed.

The maintenance dredging depends on how much to the North will be allowed the Puntal to move. If the situation before the survey is maintained, the dredging rate will be around 100.000 m^3/year. If the situation after the survey (11m to the North) is maintained, the maintenance dredging could be reduced to around 20.000 m^3/year. Most of these maintenance dredging will take part on after-storm events.

All dredged sands should be dumped again on the beach, to avoid the loss of sediment and to stop beach retreat. Sand could be dumped in the Latas area, in the submerged profile of the beach.

Future increases of the width of the navigation channel should be done actuating on the North side of the channel. That means rock dredging.

Since 1996, the Port Authority has been following the recommendations of the University of Cantabria, dredging just the necessary to maintain the design line of the navigation channel and dumping the sand in the submerged profile in the area of Latas. No more general survey of the beach has been carried out, but from the last photographs a recovering of the beach in the area of Latas can be seen.

6.4 Input data for the Santander bay case

In 1986, the Port Authority asked the University of Cantabria for a solution for the channel problem. The University of Cantabria made a study that covers the historical evolution and morphodynamics of the bay system. It has been carried out thanks to monthly field surveys of bathymetry and topography during two years, measurements of tidal velocities at the entrance and measurements of hydrodynamics conditions in several sections of the beach.

Available data from this study is attached in the following table:

Total wet area (A_b)	Intertidal area (A_f)	Spring tide range (h_{max})	Average river discharge (Q)	Annual discharge of sand by rivers (S)	Annual loss of sand by wind (W)	Tidal prism at spring tides (P_{max})	Nominal depth navigation channel (d)
2.25e7m^2	1.45e7m^2	4.5m	13m^3/s	0.00032m^3/s	0.000254m^3/s	8.7e7m^3	12m

Table 15 Data from Santander bay
After University of Cantabria (2002)

These data are not enough to use the ASMITA equations. First of all, previous data are referred to the maximum tide range, the spring tide range, while we would like to work with the average tide range. Secondarily, there are some data missing which will have to be estimated.

From available geometric data and considering some hypotheses we will obtain all geometric parameters. The first step is to obtain areas and volumes corresponding to the maximum tide range. This will help us to know some coefficients of the empirical equations that relate volumes and areas. The second step is to obtain geometrical data for the average tide range.

There are two relations (explained in chapter 3) that will let us know the area of the channel and the volume of the flats:

$$A_b = A_f + A_c \tag{6.1}$$

Hence, $A_c = 8e6$ m^2

Then, from the tidal prism equation:

$$P_{max} = h_{max} A_b - V_f \tag{6.2}$$

we can obtain the volume of the flats. Thus: $V_f = 1.425e7$ m^3

We will use the depth of the navigate channel in order to know the volume of the channel, in the following form:

$$V_c = A_c \frac{d}{2} \tag{6.3}$$

In this way, $V_c = 4.8e7$ m^3

As it has been explained before, last parameters correspond to the maximum tidal range. We will assume certain empirical relations between the volume and the area of the channel and the flat, and also, we will assume that the area of the basin remain the same when we consider the average tide range instead of the maximum one. From the Port Authority data we obtain approximately the average tide range (h), which is equal to 3m. Thus:

$$\begin{aligned} V_c &= \alpha_c P^{1.5} \\ V_f &= \alpha_f V_b \end{aligned} \qquad \text{(6.4) and (6.5)}$$

In the case of h_{max}= 4.5m, we know the value of the tidal prism, the volume of the basin and the volume of the channel and the flat. Then, the constants α_c, α_f can be found:

$$\alpha_c = 5.91e\text{-}5 \tag{6.6}$$
$$\alpha_f = 0.14 \tag{6.7}$$

Now, these values will be used in order to find the volumes in the following way:

$$V_{bnew} = hA_{bnew} = hA_b \tag{6.8}$$

$$V_{fnew} = \alpha_f V_{bnew} \tag{6.9}$$

From here we obtain:

$V_{bnew} = 6.75e7$ m^3
$V_{fnew} = 9.45e6$ m^3

And we can calculate now the volume of the tidal prism:

$$P_{new} = V_{bnew} - V_{fnew} \tag{6.10}$$

Thus:

$P_{new} = 5.18e7\ m^3$

Then, from equation number 6.4 we obtain:

$V_{cnew} = 2.62e7\ m^3$

Finally, the only data missing are the volume and the area of the delta. We will consider the next hypotheses, based on empirical relations, already used in chapter 5:

$$V_d = 0.003P^{1.23} \tag{6.11}$$

$V_d = 9.24e6\ m^3$

For the area:

$A_d = 4e6\ m^2$

In the next table we summarise data obtained:

A_f	A_c	A_d	V_{fe}	V_{ce}	V_{de}
1.45e7 m^2	8.0e6 m^2	4.0e6 m^2	9.45e6 m^3	2.62e7 m^3	1.06e7 m^3

Table 16 Input data for the Santander bay
After University of Cantabria (2002)

We have assumed that our data correspond to the equilibrium situation, hence, we obtain the equilibrium volumes.

Transport parameters might be estimated. These are not coefficients that can be measured physically. We will consider that the vertical exchange parameter and the horizontal exchange parameter have the same value for the three elements. Also, as a first approximation, we will consider values close to the ones that correspond to the Amelander Zeegat case. Then, values for the exchange parameters will be the ones presented in the following table:

δ_i	w_i	c_E
1500 m^3/s	0.00001 m/s	0.0002

Table 17 Input parameter for the Santander bay
After University of Cantabria (2002)

We know that the initial volumes do not change the end situation of the system. They will vary depending on which kind of initial disturbance is in the system. Thus, we will consider them as a variable input data.

6.5 Applying ASMITA model to the Santander bay

6.5.1 Model application

In order to see which is the effect of the river in the system, we will consider a case where the initial (relative) volumes are zero, that means we start from a situation where volumes in each element are the equilibrium volumes without a river discharge. From previous explanations we know that the initial volumes do not affect to the end relative volumes, and we do not know the "initial" situation in the system. Therefore, it seems quite understandable to choose initial volumes equal to zero. Using the ASMITA linearised equations we obtain the next graph:

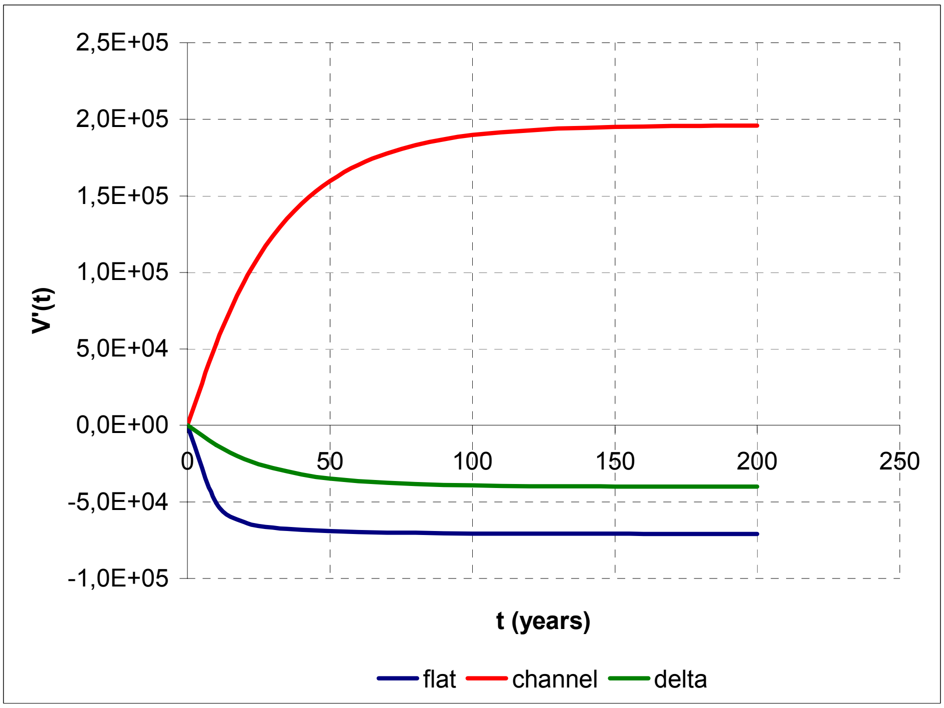

Figure 6-3 Evolution of relative volumes with time
After this report

As we can see, compared to the equilibrium volumes, the channel has an excess of water, and both channel and delta have a need of sediment. In comparison with the example considered to understand the model behaviour (in chapter 4), the sign of the end relative volumes has changed, so it could seem these results are wrong. Usually, we think that the river means a sediment input, and then, the channel response is a need of water, and the delta and flat responses are an excess of sediment. However, we should consider not only input and outputs of sediment but concentrations. We might remember that the sediment tend to be transported from elements with higher concentrations to elements with lower concentrations; and that elements tend to evolve to an equilibrium situation where the concentration is equal to the concentration in the outside world.

In our case, the outside world concentration is equal to 0.0002; for the river, the concentration is equal to the sediment input divided by the river discharge. This concentration is 1e-5. From this, we see the river has lower concentration than the outside world. Compared to the equilibrium situation, the river means a decreasing concentration for the channel. How will the system react: in order to reach the global equilibrium concentration, the channel will try to import sediment. Since the channel demands sediment constantly, it needs to be in an "out of equilibrium" situation where there is an excess of water, so the system will tend to import sediment. Delta, flats and boundary will provide the needed sediment for the channel. It becomes clear now why end relative volumes for the flat and the delta are negative: they are supplying sediment to the channel.

Concluding previous explanations we see that, contrary to what it can be expected, not always a river in a system make the channel volume decrease, it depends on the difference between concentrations, hence, between river and outside world concentration. We might keep in mind that sediment exchange occur when concentrations between elements or within an element differ. Therefore, at the steady state, $c_{ce} = c_c$ in the channel, but c_{ce} is not equal to c_E due to the river discharge.

6.5.2 Validity of the linearised ASMITA equations

We will also obtain the end volumes for each element from the full equations in order to be sure the end volumes from the linearised equations do not differ too much from the non linearised equations. In the following table we can compare the values:

Full ASMITA equations			Linearised ASMITA equations		
V_{fend}	V_{cend}	V_{dend}	V_{fend}	V_{cend}	V_{dend}
9.379e6 m^3	2.640e7 m^3	1.056e7 m^3	9.379e6 m^3	2.633e7 m^3	1.059e7 m^3

Table 18 Linearised equations vs full ASMITA equations
After this report

We will also calculate a relative error for each element as it follows:

$$\varepsilon_{ir} = \frac{\left| V_{ifulleq} - V_{ilineq} \right|}{V_{ifulleq}} \times 100 \qquad (6.12)$$

Thus:

ε_{flat}	$\varepsilon_{channel}$	ε_{delta}
0%	0.26%	0.28%

Table 19 Relative error for each element
After this report

We will consider the linearised equations are a good approximation. This seems quite understandable, as the river discharge is not big enough to make the system be moved too much far away from the equilibrium situation without river, and then, linearisation around equilibrium volumes gives a reasonable approximation to the solution with the full ASMITA equations.

6.5.3 Considering annual loss of sand by wind

Comparing the discharge of sand coming from the river, and the loss of sand by wind, the last one represents an 80% of the first one. Therefore, we will include the loss of sediment by wind in the linearised equations in order to see how previous results change.

The loss of sand by wind only affects the flat areas, a wet volume defines the channel and the delta is a submerged area. The mass balance equation for the flat in this case is presented next:

$$\delta_{cf}(c_f - c_c) + W = w_{sf} A_f (c_{fe} - c_f) \qquad (6.13)$$

The new parameter, W, is not related to concentrations, then, it will be considered in the independent term, as the term S. Then, equations can be solved in the same way as in the three elements case. We present next the new equations:

$$\begin{pmatrix} 1-\dfrac{\delta_{12}}{a_1} & \dfrac{\delta_{12}}{a_2} & 0 \\ \dfrac{\delta_{21}}{a_1} & -\dfrac{1}{a_2}(\delta_{23}+\delta_{21}+Q)-1 & \dfrac{\delta_{23}}{a_3} \\ 0 & \dfrac{1}{a_2}(\delta_{32}+Q) & -\dfrac{1}{a_3}(\delta_{34}+\delta_{32}+Q)+1 \end{pmatrix} \begin{pmatrix} \dfrac{dV_1}{dt} \\ \dfrac{dV_2}{dt} \\ \dfrac{dV_3}{dt} \end{pmatrix} =$$

$$= \begin{pmatrix} -c_E\delta_{12} & c_E\delta_{12} & 0 \\ c_E\delta_{21} & -c_E\left(\delta_{23}+\delta_{21}+Q\right) & c_E\delta_{23} \\ 0 & c_E\left(\delta_{32}+Q\right) & -c_E\left(\delta_{34}+\delta_{32}+Q\right) \end{pmatrix} \begin{pmatrix} \left(\dfrac{V_{1e}}{V_1}\right)^{r_1} \\ \left(\dfrac{V_{2e}}{V_2}\right)^{r_2} \\ \left(\dfrac{V_{3e}}{V_3}\right)^{r_3} \end{pmatrix} + \begin{pmatrix} -W \\ S \\ \delta_{34}c_E \end{pmatrix} \tag{6.14}$$

It is clear now that only the independent vector has changed. The following graph shows the results from the linearised equations:

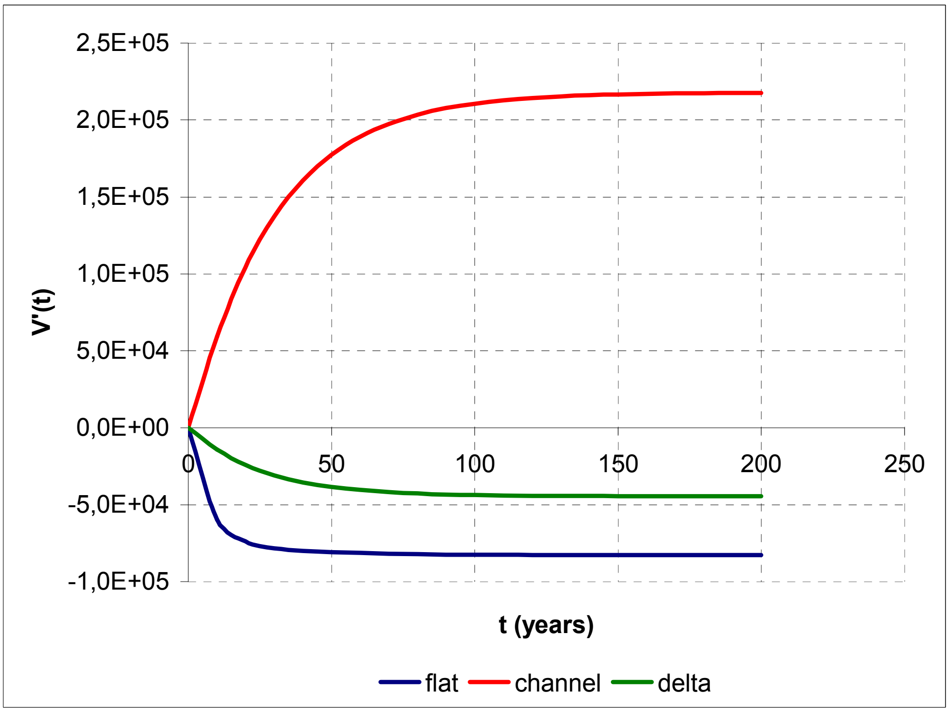

Figure 6-4 Volumes evolution in case of loss of sand by wind
After this report

Almost no difference can be seen compared to the previous graph. Numerical values are presented in the following table in order to compare better both situations (with and without loss of sand by wind):

Without loss of sand by wind			With loss of sand by wind		
V'_{fend}	V'_{cend}	V'_{dend}	V'_{fend}	V'_{cend}	V'_{dend}
-7.0897e4 m^3	1.9610e5 m^3	-4.0053e4 m^3	-8.2796e4 m^3	2.1795e5 m^3	-4.4515e4 m^3

Table 20 Results considering loss of sand by wind
After this report

From these results, we see we can omit the effect of the wind to the system, as it does not change end relative volumes considerably.

6.5.4 Relating results to the reality in Santander bay

So far we have been talking about needs and excess of sediment in each element, about validity of the linearised equations and about the influence of the loss of sand due to the wind. Now, we will try to understand the behaviour of the system keeping in mind that there are dredging activities continuously because of the channel operation.

t is easy to understand that dredging activities create a need of sediment in the channel (let's keep with the consideration that our initial condition is the equilibrium situation without river discharge, so this will be our case to compare to). How does the river influence to these dredging activities? First of all, let's think about how the channel reacts to the dredging activities, without the river discharge. The dredging is an annual rate of loss of sediment, it is also comparable to the sediment input (in order of magnitude). The aim of the dredging is to reach a certain depth in the channel, which can be also understood as a minimum amount of excess of water in the channel. The system reacts moving to an out of equilibrium situation with a need of sediment in the channel.

It is quite simple to introduce the loss of sediment by dredging works in the ASMITA equations as it represents an annual rate, hence, dV/dt=D (where D is the annual sediment dredged). Just like it has been done in the case of loss of sand due to the wind, we can consider the dredging activities in the linearised ASMITA equations. Only the equation referred to the channel will change, and it will do it as it follows:

$$\delta_{cf}\left(c_c - c_f\right) + \delta_{dc}\left(c_c - c_d\right) + Qc_c - S + D = w_{sc}A_c\left(c_{ce} - c_c\right) = \frac{dV_c'}{dt} \qquad (6.15)$$

We will consider now how the channel changes in case of a river discharge, and in case of a river discharge plus dredging works. A figure from the results obtained is presented next:

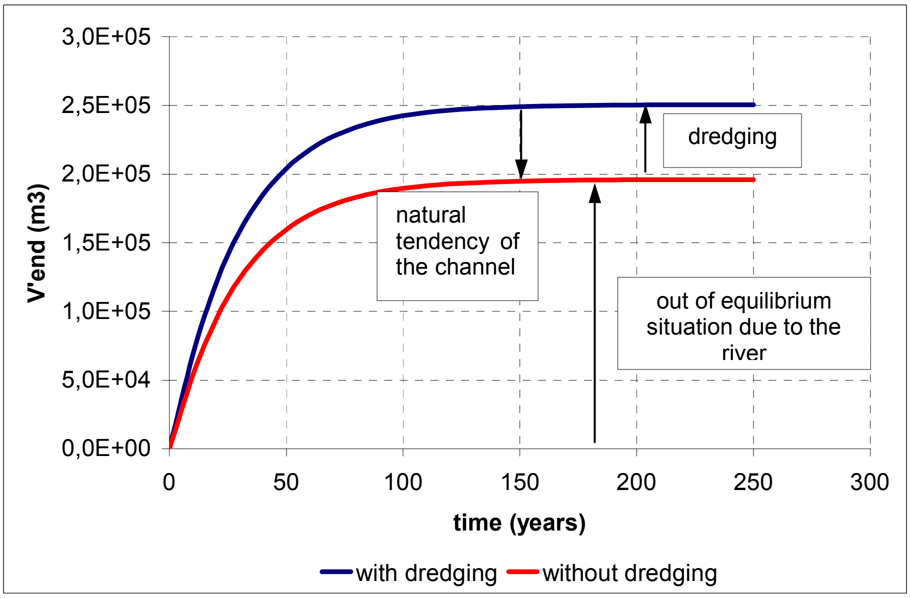

Figure 6-5 Effect of dredging works
After this report

What determines how much "out of equilibrium " the channel might be are the channel operation conditions. We need a certain "amount of water" in the channel. The river helps to achieve this condition in the channel, since it makes the channel be in a situation with a constant demand of sediment. Then, having a river in the bay reduces the dredging activities, compared to a situation without river.

6.6 Concluding remarks

Continuous dredging in the navigation channel mean a disturbance for the system. During the 450 days that the dredging was interrupted, the channel evolved freely to its own equilibrium state, thus it moved to the North. The rate of deposition sand decreased with time, because the element was approaching to an equilibrium situation. However, after storm events, because of the channel operation, sand might be removed fast: dredging is needed after strong storm events.

As much as El Puntal moves to the North, less sedimentation there will be in the channel because the system is closer to its equilibrium state. It seems a good choice to let the system evolve to the North as much as it is allowed, which means it has to be compatible with the channel operation, because dredging can be reduced then. Furthermore, despite there is no bathymetric survey, a recovering of the beach can be seen (from pictures) after the dredging reduction.

It is clear that dredging produce a need of sediment in the channel. The sand will come from the adjacent elements: the flat and the delta, and from the outside world (the beach). Retreating of the beach is related to the need of sediment in the channel. When this tendency to import in the channel is reduced, the beach starts recovering, and this is what it has been happening since the dredging activities were reduced strictly to maintain the design line of the navigation channel.

From the results after using ASMITA equations we can see the influence of the river in the system. Compared to a situation without a river, it is clear that the channel, in the new equilibrium state (new steady state), tends to import sediment, hence, there is an excess of water in the channel. This is due to the difference in concentrations between the river and the outside world (the global equilibrium concentration).

What about if a need of sediment is created somewhere in the system so that the channel has to provide sediment? Then, a "natural dredging" tendency will be created in the channel, and the dredging activities might be reduced, which also means that the beach will be recovering. Reducing dredging activities in the channel helps also to improve the port operation (traffic activities do not have to be stopped).