A MANAGEMENT STRATEGY FOR THE EBRO DELTA IN THE CONTEXT OF FLOODING AND CLIMATE CHANGE

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INTRODUCTION

The Ebro delta is located on the Spanish Mediterranean coast about 200 km southward of Barcelona. It has an approximate subaerial surface of 325 km^2 with about the 50 % lying below the height +0.5 m above MWL. This deltaic plain is protected by a sandy coast with a coastline length of about 50 km, in figure 1 a location and situation map from Ebro delta is shown. Human action on the river basin (about the 97 % of the basin is regulated by dams) has led to a drastic decrease of solid river discharges and, as a consequence of this, the delta has become more influenced by wave action and it has been subjected to an intense reshaping process, especially since the 60's, Jiménez (1996). In practical terms, this has resulted in coastal areas with large erosion rates supplying sediment for the net longshore sediment transport to fed deposition areas such as the spits.

The combination of a very low-lying morphology and the long-term erosive behaviour of some coastal stretches has determined the delta to be highly sensitive to floods of marine origin. Coastal floods in the Ebro delta are originated by two main agents: RSLR and the impact of storms. The first one is a long-term process in which the difference between projected sea level and deltaic elevation will drive the inundation of low-lying areas in a permanent manner, whereas the second one is a transient process integrating the result of beach/dune erosion and overwash. Climate change effects have a very significant influence on both phenomena.

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The delta is an ecologically rich environment and at the same time, it is economically exploited by agriculture with about 66% of the total subaerial surface being dedicated to rice production. In consequence, potential "damages" associated to such flood events should be: (i) affectation of agriculture lands by inundation (local owners being the receptor) and (ii) affectation of natural values –wave exposure or inundation– (Natural Park being the receptor), (iii) aquiculture activities, and (iv) tourism.

The apparent increase in the frequency of storm-induced flood events on the Ebro delta during the last decade (or, at least, their consequences in terms of affected territory) together the projected increase in sea level (eustatic plus subsidence) has increased the awareness on the delta's future. Climate change phenomena, also, have influence in Ebro delta coastal area behaviour. As a consequence, different alternatives to design a long-term "solution" to the "problem" have been proposed, significantly differing among them depending on the target of the solution (sector affected).

Within this context, the main aim of this paper is to present the strategy selected to manage the area for the next decades taking into account processes and responses at present and under a scenario of rising sea levels, including climate change effects. The selected solution, in the strategy, is based on a combination of adaptation and defense proposals. In terms of adaptation, a change in the properties of the deltaic plain closest to the most vulnerable coastal areas has been designed. The objective is to change

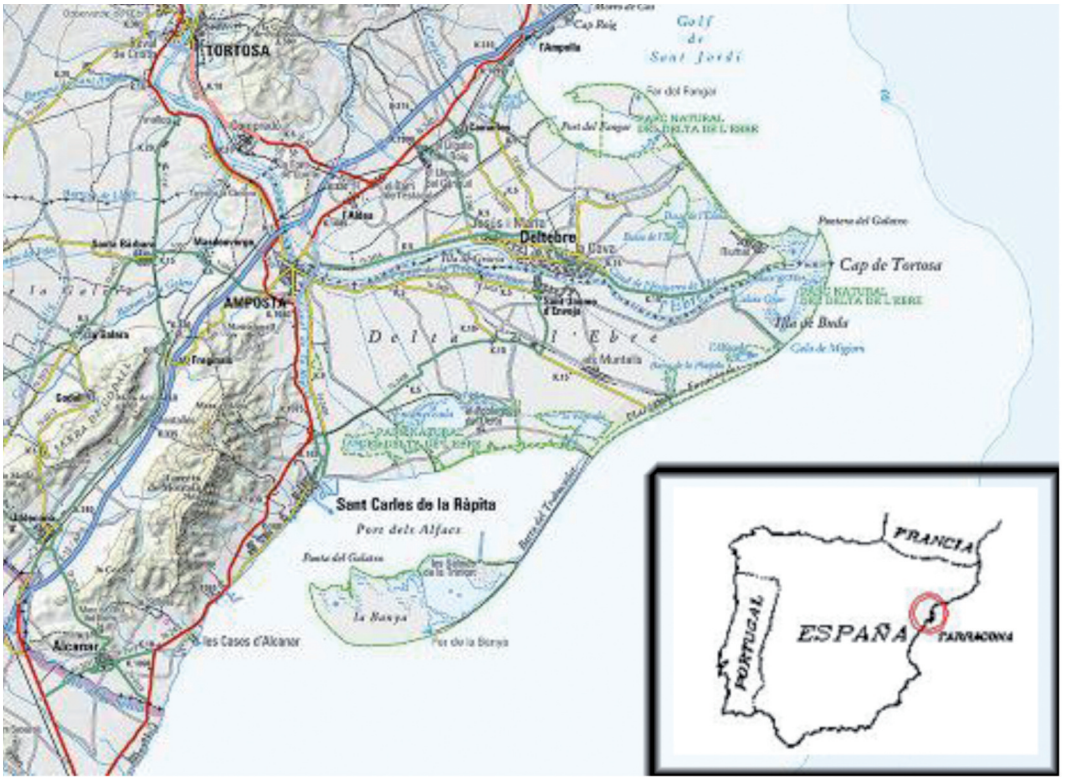

Figure 1. Site and location maps from Ebro delta.

agriculture lands -with some economic interest but very low (if any) resilience to floods- by originally low-lying coastal habitats -with high environmental values and very resilient to floods-. In the northern hemidelta, a 500 m wide fringe behind the beach is proposed to be recovered along the coast. In terms of protection, the landward limit of this recovered natural delta is reinforced by constructing a dune-sand dike which will serve to protect the hinterland from occasional flooding events. In the final paper, full details on the proposed solution and, how this solution behaves for different scenarios of storms, climate change effects and RSLR will be presented. In the bays, Els Alfacs and El Fangar, similar solutions will be taking account in the same way.

FLOODING AND CLIMATE CHANGE

Flooding consequences are the most important effects on the coast due to storms and climate change. A strategy of adaptation to climate change in coastal shores areas, such as deltas and estuaries, needs a very important effort. Integrated Coastal Zone Management allows working with several critical elements, such fragility, interface, demand, and scarcity affecting those areas so it's going to be one of the main tools for developing climate change adaptation strategies for flooding consequences.

Coastal zone significance is based on the values of the coast as a receiver and generator of goods and services as: agriculture, harbours, industries, cities, leisure, tourism, etc. According IPCC 50% of population is living on coastal zone. EUROSION program from European Union reached several interesting conclusions: 70 millions of European citizens are living on coastal municipalities and 1 billion of € in goods and services are located on the 500 m of coastal strip.

Coastal zone threats are basically: flooding and erosion. The cost of protection against erosion and flooding effects in Europe during 2001 was 3.200 millions € and induced cost on human activities due to the same phenomena was 5.400 € per year.

The climate change effects on coastal zones are the consequence of: sea level, wind, atmospheric pressure, wave height and wave direction. The analysis of instrumental and retro-analysis from atmospheric maps data during the period 1958-2001, GIOC (2004), applied to these consequences was developed by Spanish Ministry of Environment and applied to the Spanish coast. Several tendencies were found. From these tendencies the effects of climate change on the Spanish coast were analyzed taking account: flooding level, shoreline retreat, overtopping on maritime works and increasing of block weight on maritime works, GIOC (2004) and Ministerio de Medio Ambiente y Medio Rural y Marino (2008).

As a conclusion of this analysis several strategies were defined that can be summarized on: retreat, adaptation, and protection, all of these were considered on the Spanish coast. Retreat strategies, IPCC (1990) were applied in the Ebro delta as a case study.

EBRO DELTA CASE STUDY

One of most important challenges in climate change is adaptation and it is especially important in areas of fragile ecosystems and high population density. Coastal areas

have both of these conditions and in addition, they have a crucial importance in terms of economy. A strategy of adaptation to climate change in coastal shores areas, applied Ebro delta

The case studies are focused on:

- To expose the challenges, opportunities and adaptation strategies to the climate change and flooding effects in Ebro Delta.
- Start-up a debate about common problems in adaptation strategies to the climate change and flooding effects on Deltas.
- Gather any initiative in areas with similar problems, taking into account the way the problems are handled, not only at a technical level but as a national strategy as well.
- Idea-sharing of the topics more technically advanced, state of the art of the research throughout the world, and their main difficulties and uncertainties at a knowledge level in order to deal with the problems.

The adaptation to this specific coastal area to climate changes the main goal of this paper. Several alternatives must be taken account in order to consider climate change in coastal erosion and flooding phenomena. Dunes fields combined with buffer areas can be useful for this purpose. In figure 2 a scheme of sand dune system is shown. This solution is according with sea level rise estimate data, IPCC (2008)

Flooding and climate change effects on the coast are present on the low coast, where flooding effects can appear easily. Delta areas are the weak points in the Spanish coast. They are zones with high vulnerability sensitivity.

The case studies selected are located on the Ebro delta:

- Environmental adaptation in the Ebro left hemidelta, between Marquesa beach and Riomar. "Canal Vell" (finca "Bombita") lagoon is included.
- Environmental adaptation in "Els Alfacs" bay.
- Environmental adaptation in "El Fangar" bay.

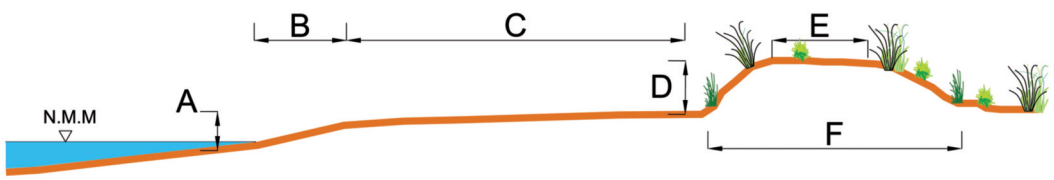

Figure 2. Sand dune system.

The Ebro left hemidelta project, Taller de Ingeniería Ambiental (2007), reaches a coast length of 4.5 km in the open beach. A 500 m strip back the coast is incorporate to the beach in order to create a buffer area against storm attacks. This is a retreat strategy taking account climate change effects and integrated coastal zone management (ICZM) tools, Cicin-Sain (1998), as: zonation; set back lines and exclusionary zones; special areas planning; acquisition, easements, and development rights; and mitigation and restoration. The scheme proposed is beach-dune-wetland. In the back of this scheme, 500 m from the public domain, a "rigid" dune is proposed. A promenade and a cycling way are located on the top of this dune. This

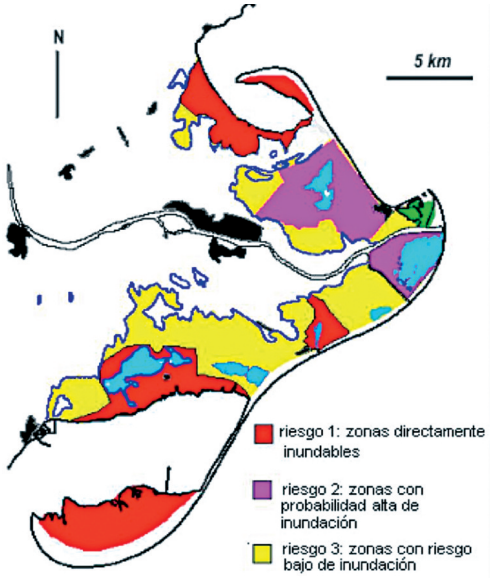

Figura 3. Flooding hazard map of the Ebro delta for a RSLR of +0.5 m, Valdemoro, H.I. (2005) y Sánchez-Arcilla, A. et al (2008).

Figura 4. Ebro left hemidelta project plan, between Marquesa beach and Riomar, "Canal Vell" lagoon is included.

dune is projected 1.5 m high in order to prevent floodind, as a consequence of se level rise (SLR), and climate change effects. In this proposal 515 Has are incorporate to public domain adjacent to this 500 m strip, it is included "Canal Vell" lagoon. In figures 2, 4, 5 and 6 project details are shown.

The environmental adaptation on "Els Alfacs" and "El Fangar" bays, Taller de Ingeniería Ambiental (2008, 2011), are actions taking account the improvement of the area and the coastal protection against flooding. Bays are, see figure 3, in flooding point of view area a coastal stretch with high vulnerability. There is not coastal dynamics with high

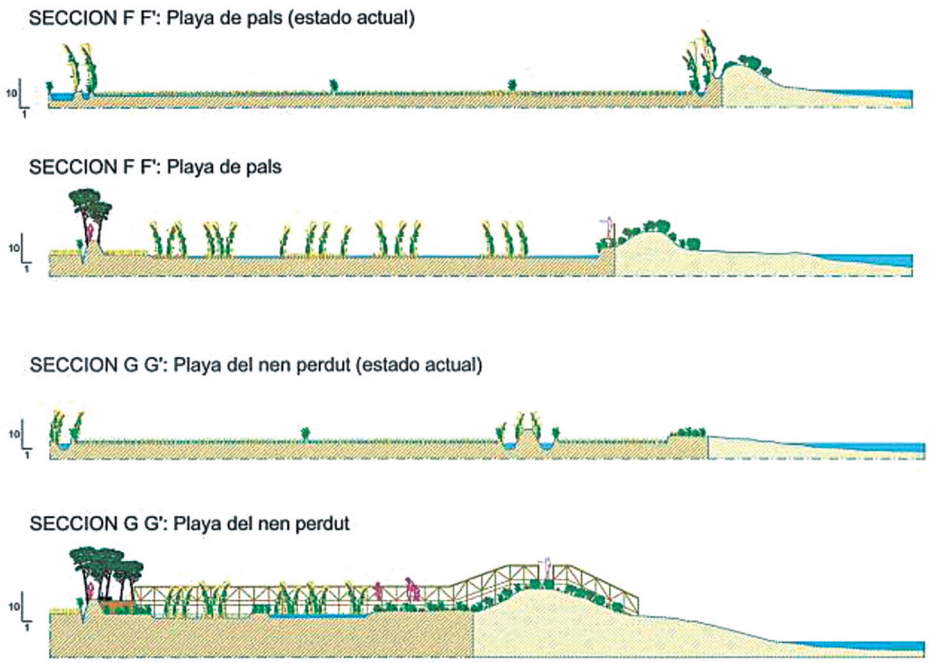

Figure 5.- Sections before and after Ebro delta left hemidelta project.

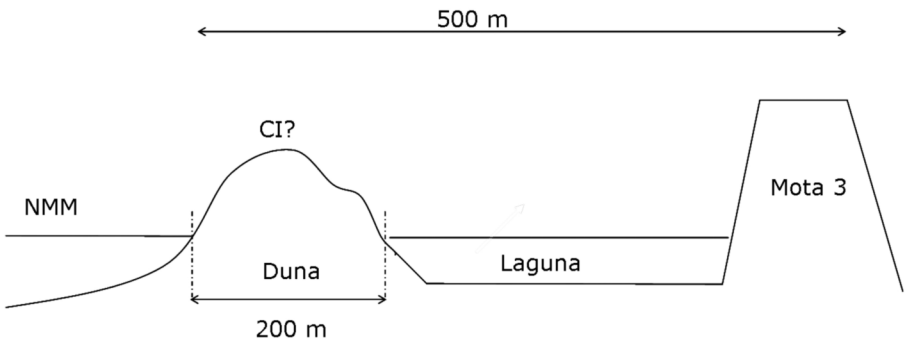

Figure 6.- Scheme of buffer area in the Ebro left hemidelta project.

energy spectrum inducing sediment transport to sand fill for beaches and dunes formation. All this stretch, where surroundings lands are less than 0.5 m over sea level, has high vulnerability against flooding, unless artificial elements will be built.

The solution adopted is a retreat strategy, 100 m from public domain, and in few areas adaptation strategy. A "rigid" dune, 1.5 m height, is proposed in the back of the stretch taking account sea level rise and climate change effects. In figures 7, 8, 9, and 10 project proposal are showed.

Figure 7. "Els Alfacs" bay project plant.

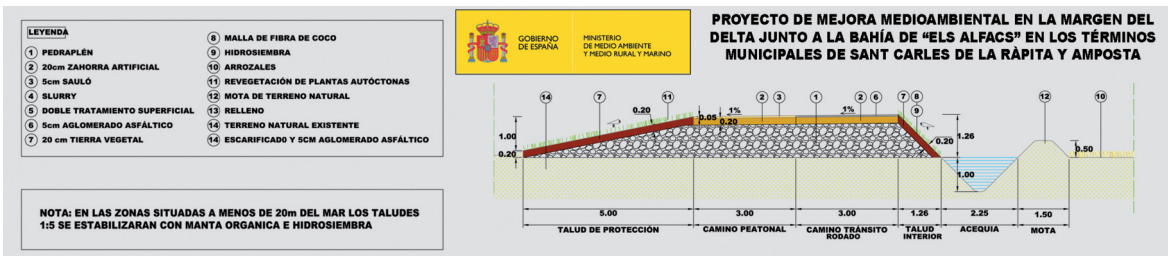

Figure 8. "Els Alfacs" bay detail, left, and "rigid" dune section, right.

Figura 9." El Fangar" bay project plant.

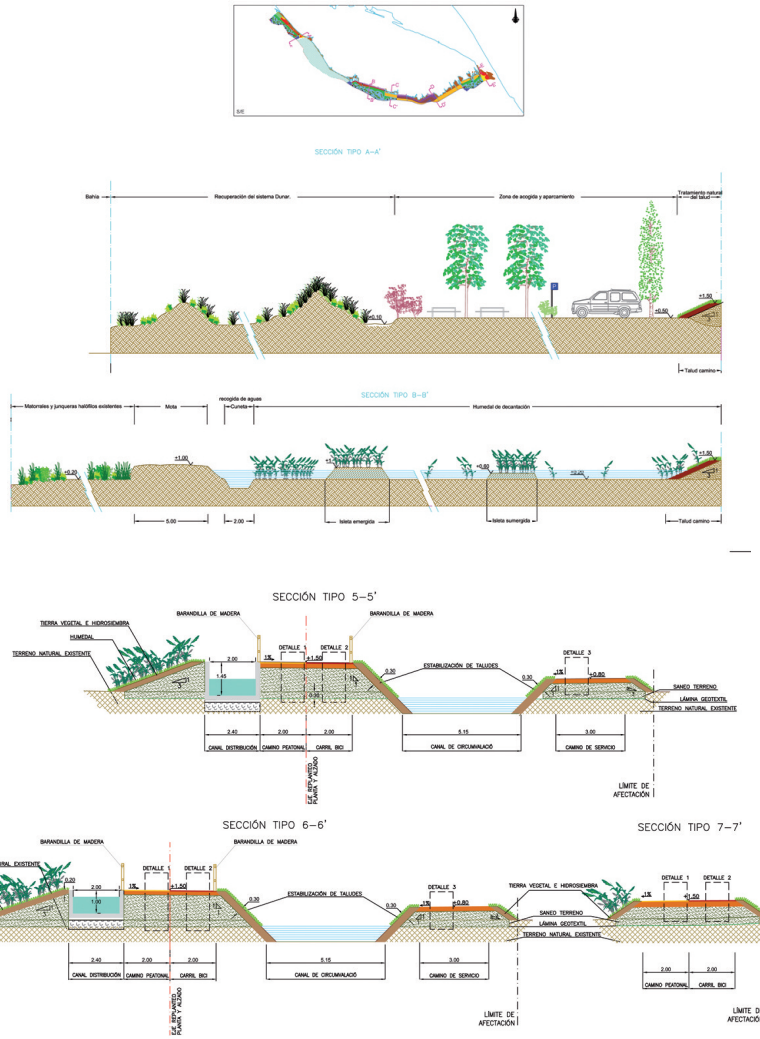

Figure 10. "El Fangal" bay Project sections.

CONCLUSIONS

A theoretical template is defined for flooding and climate change effects taking account ICZM. The most relevant conclusions are:

- Flooding and climate change effects are in the core of coastal management. It is important to be included on ICZM.
- Three case studies have been showed in Ebro delta, a high vulnerable area against sea level rise and flooding. Climate change effects are remarkable and it is necessary to introduce ICZM to coexist with them. It has an approximate subaerial surface of 325 km^2 with about the 50 % lying below the height +0.5 m above MWL.
- The case studies are:

  a) Environmental adaptation in the Ebro left hemidelta, between Marquesa beach and Riomar. "Canal Vell" (finca "Bombita") lagoon is included.
  b) Environmental adaptation in "Els Alfacs" bay.
  c) Environmental adaptation in "El Fangar" bay.

- The projects are focused on climate change retrait strategies and ICZM tools as: zonation; set back lines and exclusionary zones; special areas planning; acquisition, easements, and development rights; and mitigation and restoration.
- The projects represent the implementation of Spanish Shore Act in Ebro delta, and specifically the right of passage easement and access to the sea easement.

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