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SPAIN'S EBRO DELTA

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ABSTRACT

The Ebro river is one of the most important rivers in the western Mediterranean Sea, flowing into a delta. It is 910 km long, with a drainage basin of 85,000 km^2. The Delta has an emerged surface of approximately 330 km^2 and a coastline length of about 45 km. The population is of approximately 50,000 inhabitants.

The mean annual discharge at the Delta is 11,700 hm^3/year. For the next 20 years, the National Hydrological Plan proposes to increase the water demands upstream of the Delta and water transfers to other basins of 1,050 hm^3/year are planned too. All of this implies that the mean water discharge into the Delta will be decreased to 7,375 hm^3/year. At the Delta, a minimum river flow of 100 m^3/s is guaranteed. Discharge regime in the Delta has strongly been modified by the reservoir system of Mequinenza-Ribarroja-Flix located 80 km upstream.

The salinity of river water is very high at the entrance to the Delta because of mineral supply coming from gypsum formations (22% of the drainage basin). In the period 1980-2000 the mean conductivity was 1000 μs/cm. Concentrations of organic material in the period between 1980-2000 were 4.5-5.5 mg/l of DBO_5.Concerning nutrients, since 1995 there is a concentration decrease to 0.25 mg/l, due to the operation of new wastewater treatment plants. The values obtained for nitrates are 10 to 12 mg/l since 1995.

A salt wedge can usually be found in the deltaic reach of the Ebro river and can create an anoxic situation, very frequent during the summer season.

Throughout the last century, several upstream dams have strongly decreased the solid contributions from the Ebro to the Delta. At the beginning of the XX century, the solid discharge at the Delta was from 15 to 30 millions of tones per year, according to the estimations of different authors. Nowadays, the solid discharge amounts to about 0,15 millions of tones per year of suspended load and an insignificant volume of bed load.

The Delta is subsiding due to compaction of sediments. Depending on the area, subsidence rates range from 0 to 5 mm/year. Due to the no flooding conditions of the Delta, the subsidence is not compensated by solid discharge from the Ebro river as it was in the past. The sediment deficit and subsidence have caused a clear backward movement of the coastline position.

The Delta has a big number of habitats and species: 18 habitats, about 600 vegetal species and 428 animal species, 330 of those are birds. There are 50 species of aquatic birds. In the last century 6 species became extinct, 3 of those were birds. Nowadays 30 vertebrate species and 22 vegetal species are in risk of extinction. The Catalonian Government created in 1983 the Natural Park of Ebre Delta, with a total area of 7,736 ha.

Water management in the Delta is closely related to the 22,000 ha of rice fields, which represents the 66% of the total area in the Delta and the 88% of the irrigation area. A significant part of the rice fields are less than 0,5 m above sea level. Water supplies to rice fields guarantee the evapotranspiration demands and also should be able to control the salinity induced by groundwater, which is strongly salted and has a watertable near the surface. To satisfy these requests, high water supplies are running continuously across the fields. The annual supply is about 24,200 m^3/ha, 4,900 m^3/ha for evapotranspiration demands and 19,300 m^3/ha for the salinity control.

1. THE EBRO RIVER

The Ebro river is one of the most important rivers in the western Mediterranean Sea, flowing into a wide delta (figure 1). It is 910 km long, with a drainage basin of 85,000 km^2 (84,000 km^2 in Spain) and 2.8 millions of inhabitants living there. The 11% of this population are farmers, Barrera (1999). The irrigation area is approximately of 800,000 ha and has strongly been increased in the last 40 years (in 1960 the irrigation area was 500,000 ha), PHN (2000).

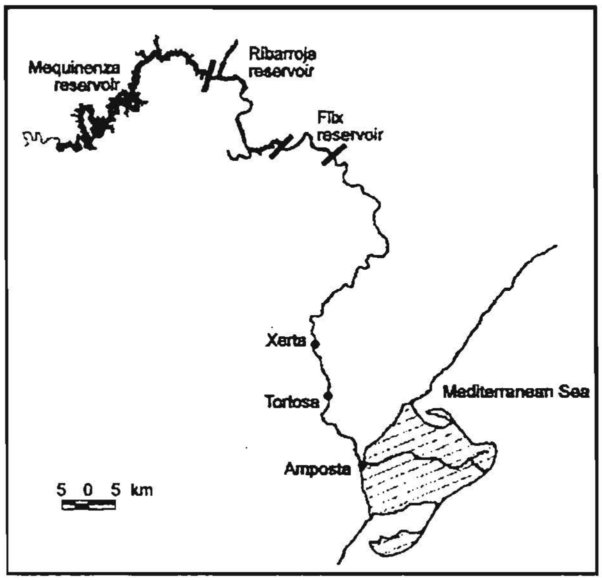

Figure 1. The final reach of the Ebro river

1.1 <u>Water discharge</u>

The mean annual discharge at the Delta is 11,700 hm^3/year and the water demands upstream of the Delta is about 5,500 hm^3/year. So, the mean natural discharge into the Delta was 17,200 hm^3/year, PHN (2000).

For the next 20 years, the National Hydrological Plan, PHN (2000), proposes to increase the irrigation area by approximately 500,000 ha. That means that the water demands would be increased by 3,300 hm^3/year. Water transfers to other basins of 1,050 hm^3/year are planned too. All of this implies that the mean water discharge into the Delta will be decreased to 7,375 hm^3/year. At the Delta, a minimum river flow of 100 m^3/s is guaranteed by the Plan, PHN (2000).

Temporal distribution of the Ebro river discharge is very irregular (figure 2).

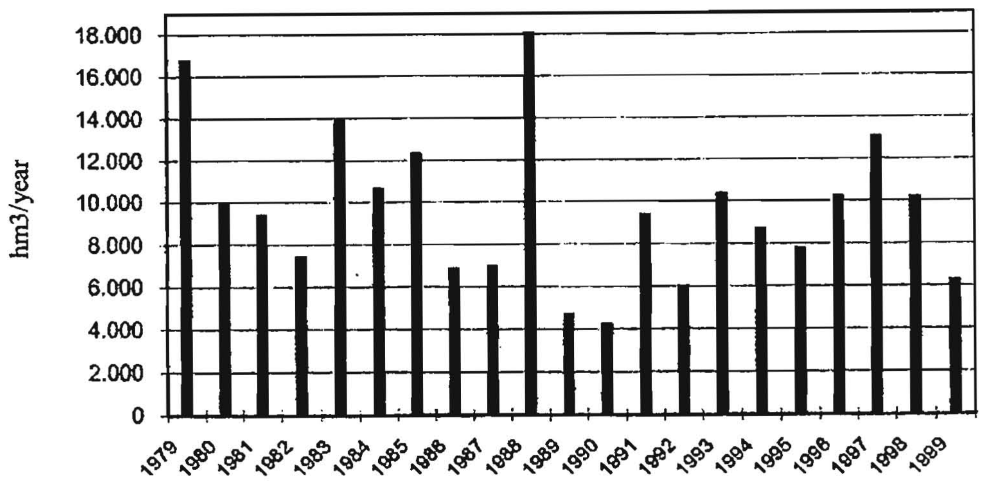

Figure 2. Annual discharge of Ebro river at the Delta, Universidad de Cantabria (2001)

In the Ebro basin there are 151 reservoirs with a total storage capacity of 6,761 hm^3. The reservoirs under construction will increase by 941 hm^3 the total volume, Libro Blanco del Agua (2000).

Figure 3 shows the mean monthly discharges for two different periods: 1951-1959 and 1975-1999. The regulating effect of the reservoirs can be observed as well as the irregularity of monthly values: for the period 1975-1999 the 70% of discharges accumulate within 6 months, from December to May.

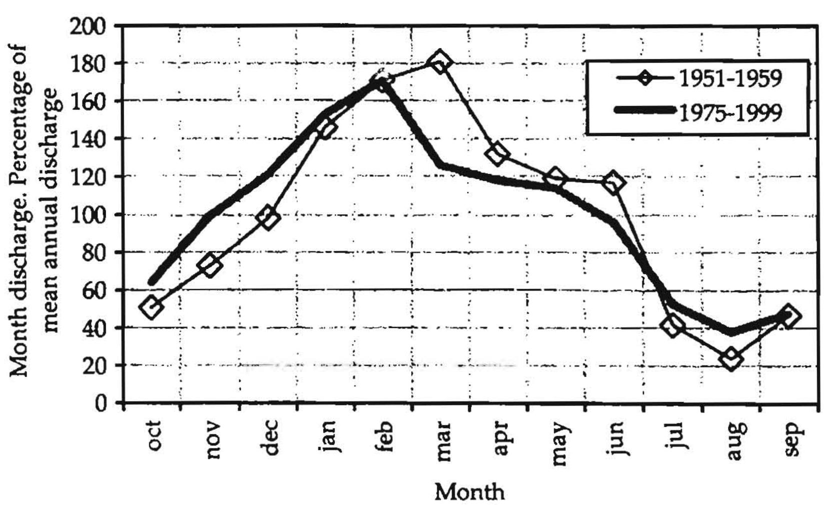

Figure 3. Mean monthly discharge (in percentage of the mean annual discharge) of Ebro river in the Delta, CEDEX (2002)

Discharge regime in the Delta has strongly been modified by the reservoir system of Mequinenza-Ribarroja-Flix located 80 km upstream (figure 1). The total volume of the system, associated to hydroelectric power plants, amounts to 1,750 hm^3. Downstream, the Ebro river does not receive significant water supplies. Xerta, situated between the dams and the Delta, is the origin for two irrigation canals (one on each side of the river) with a total water discharge of approximately 50 m^3/s.

The discharge regime in the Delta has a great variability during a day because of the upstream hydroelectric power plants (figure 4). This affects the river fauna and flora, and also the stability of riverbanks.

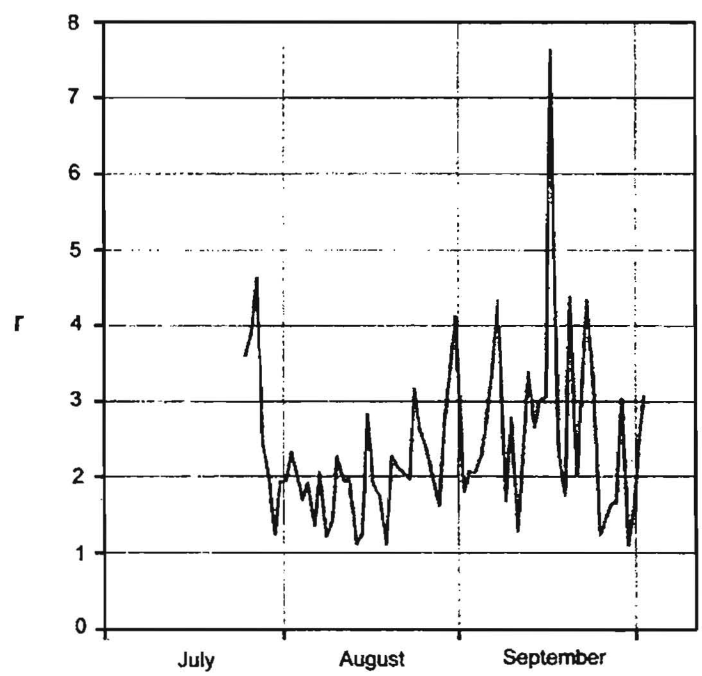

Figure 4. Discharge regime irregularity downstream of Flix hydroelectric power plant in summer 1974. For a day, maximum and minimum mean hourly discharge ratio (r), Dolz et al. (1997).

1.2 Water quality

The salinity of water is very high at Tortosa (the entrance to the Delta) because of mineral supply coming from gypsum formations (22% of the drainage basin). Minerals are added by the runoff and irrigation land drainage. Salinity has increased as irrigation area does. In 1970 conductivity was about 800 µs/cm and in the period 1980-2000 the mean conductivity was 1000 µs/cm. In the same period, for the last three months of the year the mean monthly conductivity was about 1200 μs/cm, CEDEX (2002). Figure 5 illustrates the mean monthly concentration of different salts.

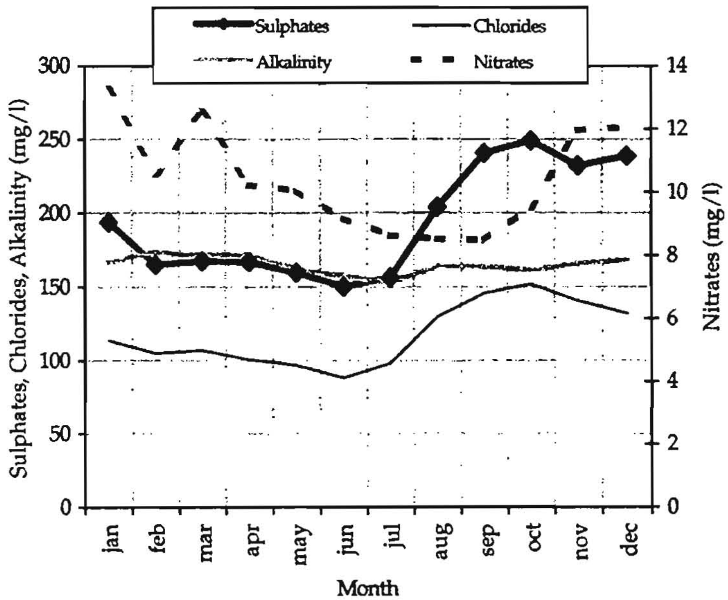

Figure 5. Mean monthly salts concentration in the Ebro river at the entrance of the Delta, 1980-2000 period, CEDEX (2002).

Concentrations of organic material are not very high. In the period between 1980-2000 the values were 4.5-5.5 mg/l of DBO_5, CEDEX (2002).

Concerning nutrients, mean monthly phosphates concentration for different time periods are showed in figure 6. Since 1995 there is a concentration decrease due to the operation of new wastewater treatment plants. The values obtained for nitrates are 10 to 12 mg/l since 1995, CEDEX (2002).

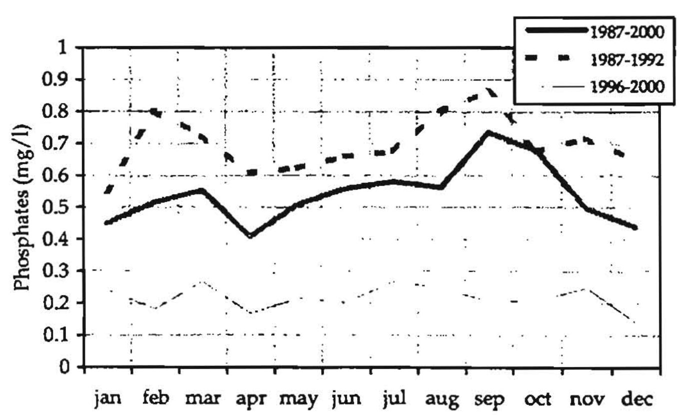

Figure 6. Mean monthly phosphates concentration at the entrance of Delta, CEDEX (2002).

1.3 The salt wedge

A salt wedge can usually be found in the estuarine reach of the Ebro river: upper freshwater layer (riverine origin) and lower saltwater layer (marine origin). Between upper and lower layers, an interface of low thickness and high salinity and density gradients reduces the reaereation of the lower layer. This is the origin of an anoxic situation, a very frequent phenomenon during the summer season because of the high nutrient concentrations, Universidad de Cantabria (2001).

Due to low variations of sea level caused by tides (the astronomical tide is about 0.25 m) the river length affected by salt wedge just depends on water discharge and channel geometry (especially the appearance of sills on the bed river).

Figure 7 shows the relationship between interface depth and water discharge for a section located 13 km upstream of the mouth. There is a clear linear relation between both.

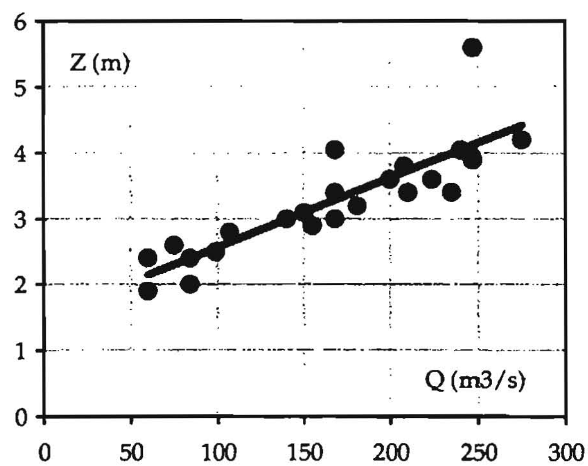

Figure 7. Freshwater-saltwater interface depth (z) vs. water discharge. Section 13 km upstream of the mouth. CEDEX (2002) from data of Ibáñez (1993).

With regard to the presence of salt wedge, according to CEDEX (2002) we can say:

- Water discharges up to 300 m^3/s normally don't lead to the formation of salt wedges, but if they occur they affect just a small river length
- For water discharges from 100 to 300 m^3/s, the salt wedge arrives 18 km upstream of the mouth, in the Gracia Island, where a sill on the bed river can be found

- For water discharges less than approximately 100 m^3/s, the salt wedge arrives 32 km upstream of the mouth where another sill is located on the bed river

Nowadays, during 12% of the year there is no salt wedge and during 20% it is located upstream of the Gracia Island, Universidad de Cantabria (2001).

1.4 Sediment transport

Throughout the last century, several upstream dams have strongly decreased the solid contributions from the Ebro to the Delta. In the last years, flood frequency and magnitude, main factors for the solid discharge at the Delta, have also been decreased due to reservoirs. Mequinenza and Ribaroja dams, constructed at the end of the sixties, are the most important dams causing the reduction of sediment transport because of their big storage volumes and their proximity to the Delta.

At the beginning of the XX century, the solid discharge at the Delta was from 15 to 30 millions of tones per year, according to the estimations of different authors, Bayerri (1935), Palanques and Guillén (1992), Ibáñez et al. (1996). Nowadays, the solid discharge amounts to about 0,15 millions of tones per year of suspended load and an insignificant volume of bed load, Palanques (1987), Palanques and Guillén et al. (1992).

Figure 8 shows the evolutions of the reservoir volume, flood flows up to 3,500 m^3/s and the transport of sediments of the Ebro at the Delta. It can be observed that solid transport has practically disappeared and the flood flows have strongly been reduced due to reservoir capacity increase.

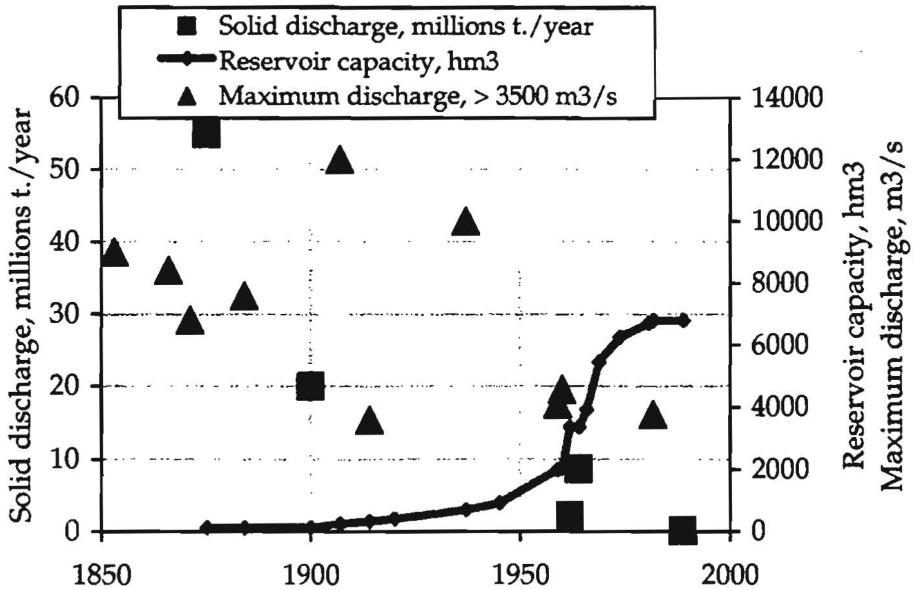

Figure 8. The evolutions of the reservoir capacity, flood flows up to 3,500 m^3/s and the transport of sediments of the Ebro at the Delta. CEDEX (2002) from data of different authors.

Solid retention in dams of the Ebro basin has been analysed in CEDEX (2002). In Mequinenza and Ribaroja reservoirs it has been evaluated in 7 and 1,35 millions of tones per year respectively.

The Delta is subsiding due to compaction of sediments. Depending on the area, subsidence rates range from 0 to 5 mm/year, ITGE (1996), Jiménez et al. (2000), MEDDELT (1996). Nowadays, due to the no flooding conditions of the Delta, the subsidence is not compensated by solid discharge from the Ebro river as it was in the past.

The sediment deficit and subsidence have caused a clear backward movement of the coastline position. Figure 9 illustrates the coastline near the mouth in 1957 and 1994. It is worth mentioning that the present mouth was opened in 1937 northward of the previous one. Today a tendency to the stabilisation of the coastline can be observed, CEDEX (2002).

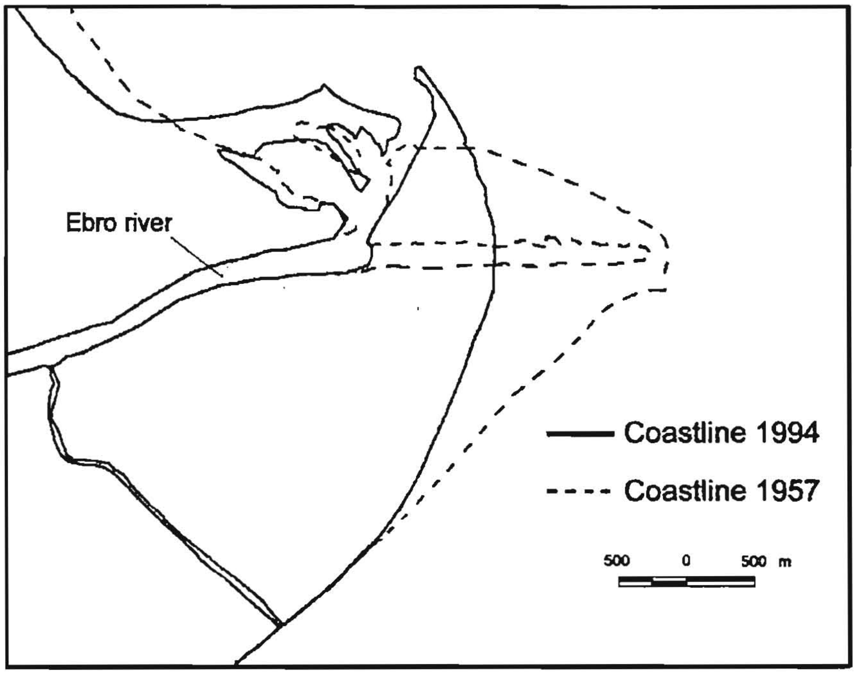

Figure 9. Coastline evolution around the mouth, CEDEX (2002)

2. DESCRIPTION OF THE EBRO DELTA

The Delta has an emerged surface of approximately 330 km^2 and a coastline length of about 45 km. The deltaic river reach is 29 km long, with depths about 2-12 m and widths of about 160-380 m.

In the Delta there are 9 lagoons with a total surface of 32.9 km^2. Surface spits cover areas of 4.6 km^2 (El Fangar) and 28.3 km^2 (La Banya), Ibáñez et al. (1977). Figure 12.

Cartographic information starting from the XVI century allows to study with some accuracy the evolution of emerged lands of the Delta. In 1580 the surface was only 75% of today's surface (figure 10). In the last century the main morphological variations were caused by the change at the river mouth. The present mouth was opened in October 1937 during a flood and is located 3 km northward of the previous one.

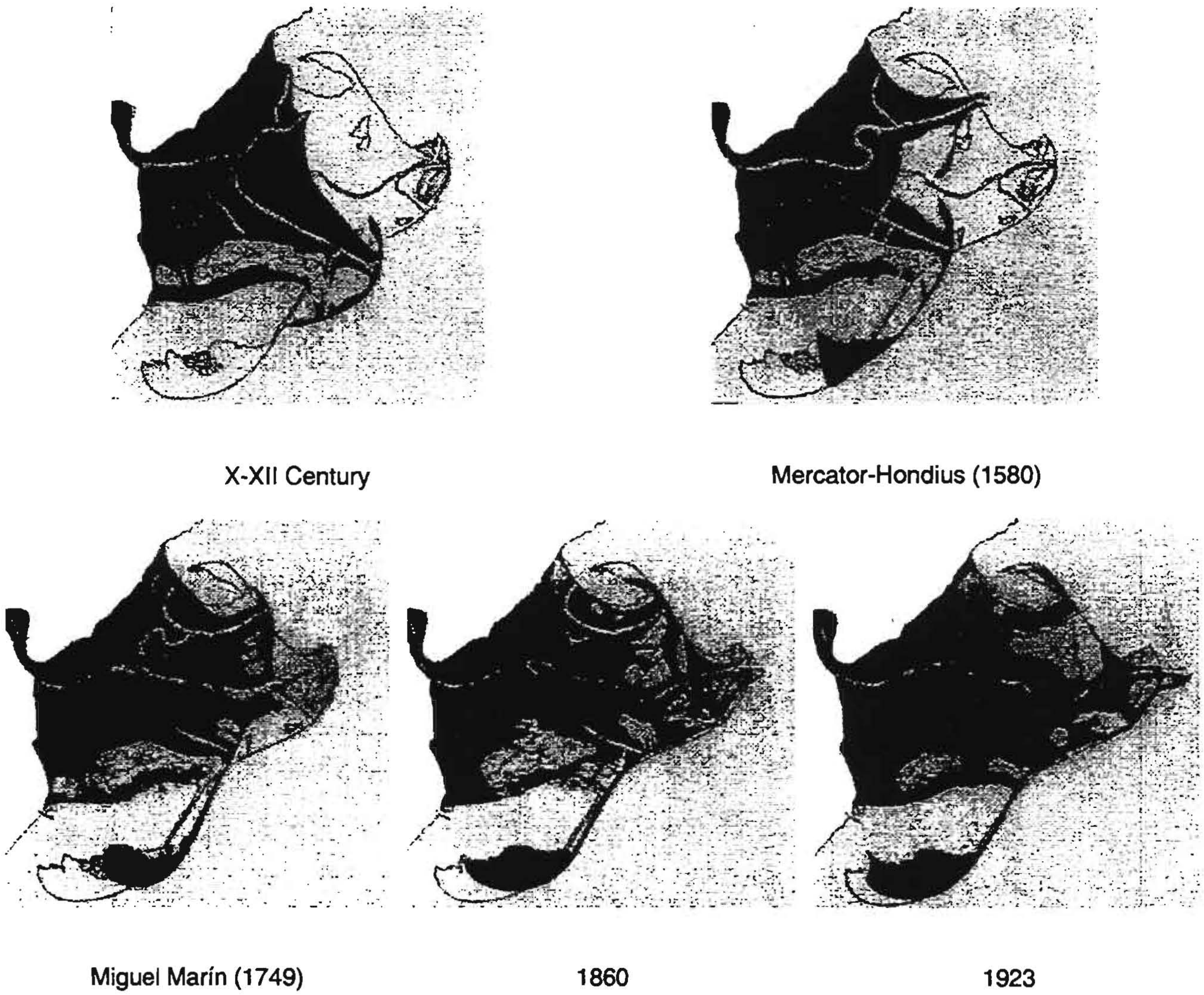

Figure 10. Morphological development of the Ebro Delta, Ibáñez et al. (1997)

2.1 Climate

The mean annual temperature in the Ebro Delta is 18°C, with 27°C as the maximum (in August) and 10°C as the minimum (in January) mean monthly temperatures.

Precipitations are very irregular. The mean annual precipitation is 550 mm, with two periods of rainstorms: April-June and September-November.

2.2 Topography

The Delta has its maximum height in the fluvial levees. Table 1 is a summary of the Delta topography. About 45% of the deltaic plain (excluding the river, lagoons and spits) is less than 0.5

m above mean sea level. The astronomical tide is about 0.25 m. The meteorological tide for 10 years of return period is of approximately 1 m, Sanchez Arcilla et al. (1997). It can be observed that a big area of the Delta has to be artificially protected from tidal floods.

5 - 4 m	0.1 %
4 - 3 m	2.3 %
3 - 2 m	8.3 %
2 - 1 m	20.9 %
1 – 0.5 m	14.5 %
< 0.5	37.3 %
spits	9.9 %
lagoons	4.3 %
river	2.4 %

Table 1. Heights distribution in emerged deltaic plain, Ibáñez et al (1997)

2.3 Population

The population is of approximately 50,000 inhabitants, including people living in the Delta itself (14,000) and in the villages at the Delta limits (36,000).

2.4 Agriculture

In 1860 the right bank canal was inaugurated. This allowed the beginning of agricultural activity in the Delta. In 1913 the left bank canal was put in operation. The irrigation area is about 25,000 ha, 91% of the deltaic plain (excluding spits, lagoons and the river). The farms are of very different sizes. The 15,000 ha irrigated by the right bank canal are distributed in 7818 properties with 4420 land owners, according to information from the “Comunidad General de Regantes del Canal de la Derecha del Ebro”.

An evolution of the cultivated area in the Delta is shown in figure 11. Figure 12 shows land use.

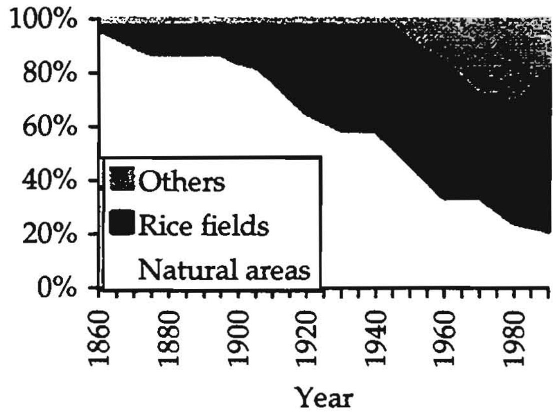

Figure 11. Evolution of the cultivated area in the Ebro Delta, Ibáñez et al (1999)

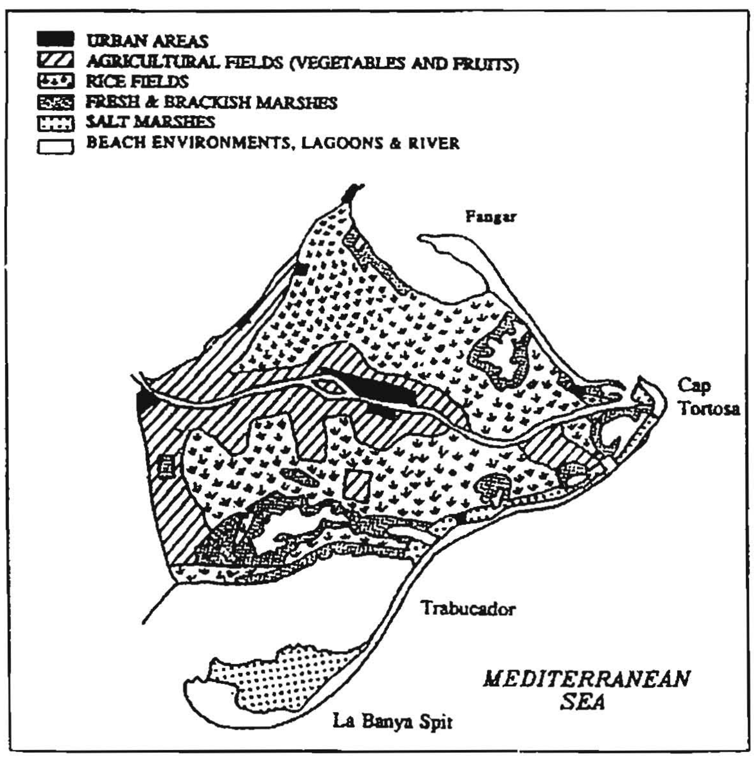

Figure 12. Land use in the Ebro Delta, Prat and Ibáñez. (1995)

The most important economic activity is the rice production, with 22,000 ha, Fábregues (2002). This represents 88% of the agricultural area in the Delta and the 66% of the total area. The mean production is 6,000 kg/ha. and the gross-profit is 430 €/ha., Ibáñez et al. (1999). The rice cultivation is subsidised by the European Union (E.U.). The total rice production area in Spain is about 100,000 ha.

2.5 Fishing

Fishing is an important activity in marine waters around the Delta, which produces about 6,000 t/year. In the lagoons, the catches have notably decreased in the last 30 years and today they have been stabilised in 50 t/year, Museu del Montsià (1996).

River fishing has not a commercial interest.

Mussel production started in the Fangar and Alfacs bays in 1978. The production has reached 8,000 t in 1988. It was not sustainable and nowadays it amounts to 3,000 t/year, Ibáñez et al. (1999). Over the last 10 years aquaculture installations for another species, mainly sea bream, have become more important.

2.6 Hunting

Waterfowl hunting is a traditional activity in the Delta, which has become more important as an economic activity over the last years. Local hunting associations have 4,000 members, Balada et al (1997).

2.7 Tourist industry

This is another economic sector with a very promising future and closely related to the natural values of the Delta. The number of tourists is about 1 million per year, Ibáñez et al (1999).

2.8 Delta heritage

The Delta has a big number of habitats and species: 18 habitats, about 600 vegetal species and 428 animal species, 330 of those are birds. There are 50 species of aquatic birds with about 40,000 breeding pairs and a mean population of 180,000 individuals in January. In the last century 6 species became extinct, 3 of those were birds. Nowadays 30 vertebrate species and 22 vegetal species are in risk of extinction, SEO-Birdlife (1997).

The Catalonian Government created in 1983 the Natural Park of Ebre Delta, with a total area of 7,736 ha and in 1993 the Natural Spaces of Interest Plan (PEIN), with 11,710 ha. The PEIN includes the Natural Park and other protected areas. The E.U. declared the PEIN a Place of Community Interest which belongs to the Nature 2000 Net.

Nowadays there are 2,000 ha of marshes. This is 20% of the initial area, Ibáñez et al. (1999). The transformation of marshes in rice fields decreased considerably the natural habitats. However many species were preserved until the sixties thanks to traditional agricultural techniques and the non-use of pesticides. Since then, agriculture mechanisation and the use of pesticides have essentially changed this situation.

2.9 Irrigation infrastructures in the Delta

Water management in the Delta is closely related to the 22,000 ha of rice fields, which represents the 66% of the total area in the Delta. A significant part of the rice fields are less than 0,5 m above sea level. Water supplies to rice fields guarantee the evapotranspiration demands and also should be able to control the salinity induced by groundwater, which is strongly salted and has a watertable near the surface. To satisfy these requests, high water supplies are running continuously across the fields.

Figure 13 illustrates the water level on rice fields. In the last years it is observed an extension of the flooding cycles, especially in the left side of the Delta. This phenomenon is associated to hunting purposes.

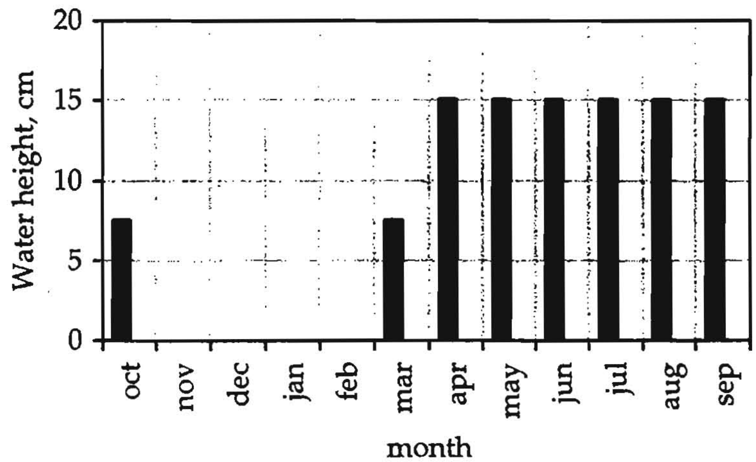

Figure 13. Flooding cycles of rice cultivations, CEDEX (2002)

Figure 14 shows the requests for evapotranspiration and the salinity control. The total supply is about 24,200 m^3/ha, 4,900 m^3/ha for evapotranspiration demands and 19,300 m^3/ha for the salinity control. It means that 80% of water supply is for salinity control, CEDEX (2002).

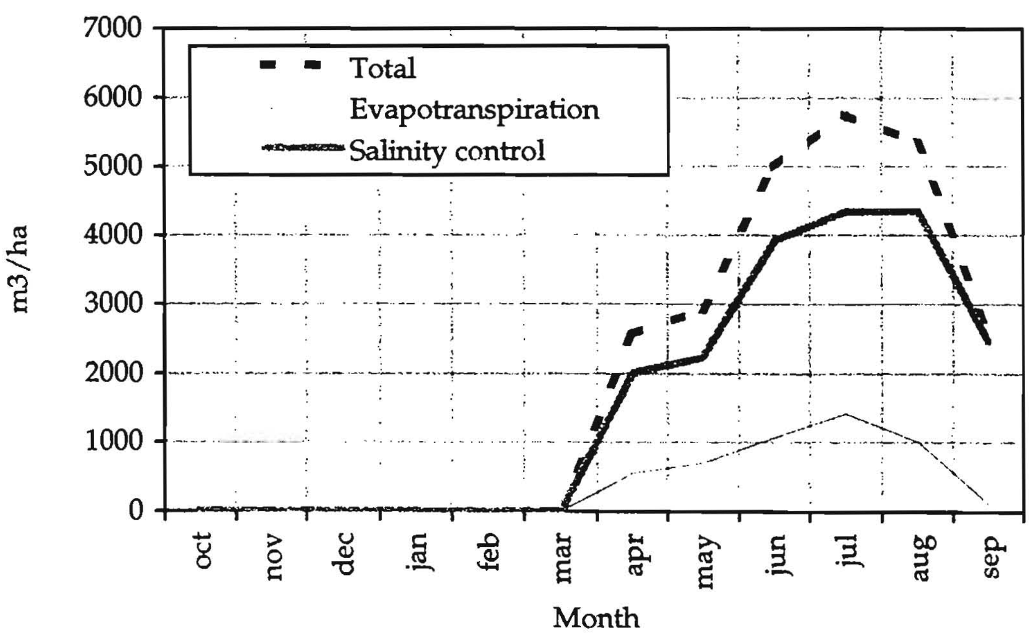

Figure 14. Water requests for the rice cultivation, CEDEX (2002)

Water supply arrives to the delta through two main canals, one at each side of the river. Water discharge in the right bank canal is 25,56 m^3/s and in the left bank canal is 25 m^3/s.

Figure 15 illustrates the diagram of the Delta supply canals.

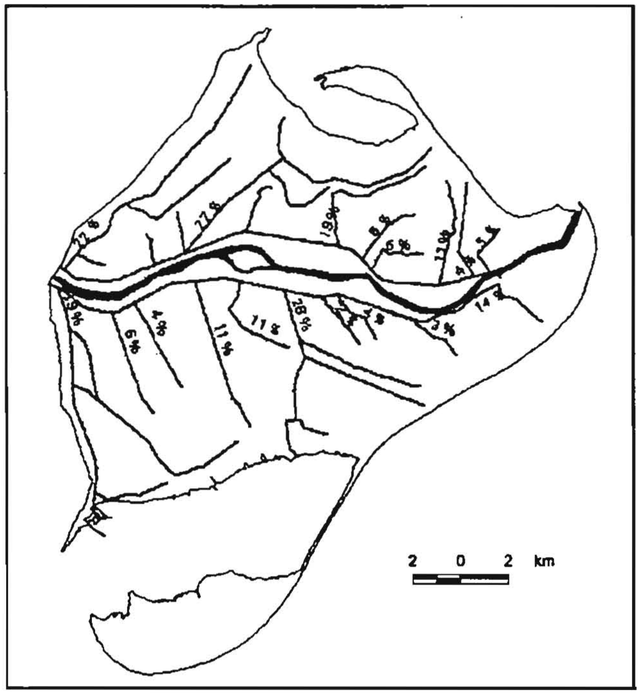

Figure 15. Canal network for water supply distribution in the Delta and the percentage of the total water discharge, CEDEX (2002)

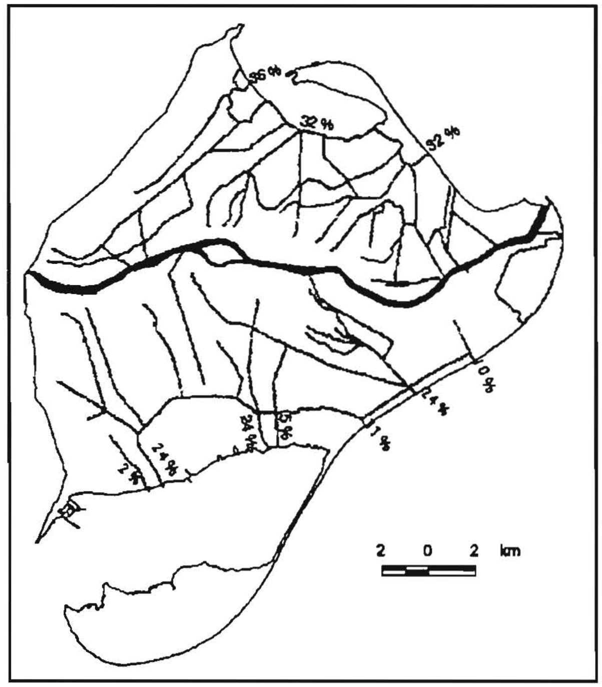

Figure 16. Land drainage canal network and percentage of water discharge through each channel, CEDEX (2002)

Figure 16 shows the land drainage canal network. A high proportion of this water is directed to the bays. This clearly affects the water quality.

Pumping stations are needed to drain water into the sea. Their total capacity is 33 m^3/s in the left side of the Delta and 47 m^3/s in the right side. With this capacity it is possible to drain a precipitation of 125 mm in 72 hours. Rainstorms with these characteristics are typical of autumn, coinciding with the rice harvest.

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