APPENDIX 9, ANNEX V FROM THE EBRO RIVER BASIN MANAGEMENT PLAN 2010-2015

(TRANSLATED INTO ENGLISH)

ENVIRONMENTAL FLOW REGIME AT THE MOUTH OF THE EBRO RIVER

CONTENTS

1.- INTRODUCTION

The Spanish legislative development in recent years has included a major advance in determining environmental flow regimes of rivers. The main milestones to note are:

- Law 11/2005 amending Law 10/2001 of the National Hydrological Plan (Government of Spain, 2005). Article 42.1.b.c of the Consolidated Water Law is amended by including the definition of environmental flows as those that "*maintain at least fish life that naturally inhabits, or could inhabit the river and its riparian vegetation*".

- Hydrological Planning Instruction (Government of Spain, 2007), where:

  + Environmental flow is defined as that "*which helps to achieve good status or good ecological potential in rivers or in transitional waters and maintains at least fish life that naturally inhabits, or could inhabit the river and its riparian vegetation*" and states that the establishment of environmental flows will take place in the framework of the River Basin mManagement Plans (RBMPs).

  + "*Environmental flows or environmental demands will not be regarded as another use, but as a **general restriction imposed to operating systems**. In any case, it will also apply to environmental flows the rule of the supremacy of supply to populations as stated in Article 60.3 of the Consolidated Water Law*"(Article 17).

  + In the case of prolonged drought, a less demanding flow regime may be applied. However, this exception does not apply in areas included in the Natura 2000 Network nor in the wetlands of international importance under the RAMSAR Convention of February 2, 1971. In these areas, the maintenance of environmental flows is considered a priority, although the rule of supremacy of human supply still applies (Article 18).

  As discussed below and in accordance with this standard, **it is not possible to define a less demanding environmental flow for situations of prolonged droughts in the lower Ebro because there are Natura 2000 sites and Ramsar wetlands related to the dynamics of the water environment**.

- Hydrological Planning Instruction (Government of Spain, 2008) details, in section 3.4, the methodology to be applied for the determination of environmental flow regimes.

From the time the Planning Instruction was adopted, water administration began developing specific studies aimed at defining environmental flow regimes in Spanish rivers. This process will finish with the approval of management plans.

The objective of this report is to present the analysis and discussion of all the information relating to environmental flows in the final stretch of the river Ebro, exposing the technical justification of the proposed environmental flow regime according with the requirements of the regulations in force.

2. - COLLECTION OF ENVIRONMENTAL FLOWS AT THE MOUTH OF OTHER RIVERS

Before analyzing the detailed information on the final stretch of the Ebro, it has been made a first collection of environmental flows established in other current Spanish regulations and in other major rivers in the world that can be a reference for the case of the Ebro River Basin.

2.1. - Spanish Rivers

The first item of interest is obtained from the analysis of the rules of the Autonomous Community of Catalonia, which in 2005 conducted a study on the so-called “maintenance flows” (ACA, 2005). The results of this study were included in the Sector Plan for Environmental Flows in the Inland Basins of Catalonia, adopted in 2006 (Generalitat de Catalunya, 2006).

The comparison of environmental flows established in this Plan for the mouth of each one of the rivers belonging to the Internal Basins of Catalonia with the average flow in natural regime (Table I) indicates that the average flow allocated for environmental requirements in these rivers is 20% of the resources in natural regime estimated for each basin. This percentage ranges from 8.6% in the Daró river basin and 28.9% in the Foix river basin. The Llobregat River basin, which is the largest oen of the District, has an environmental requirement of 20% of the natural resources.

Table I: environmental flows at the mouths of the Internal Basins of Catalonia

Basin	catchment area km^2 (a)	Contribution natural regime 1940-2008 (hm3/year) (a)	Provision for environmental flows (hm3/year) (b)	Percentage contribution regarding ecological natural regime (%)	Minimum flow in the lowest flow month (m3/s) (b)	Percentage of the minimum flow compared to the natural system (%)
La Muga	758	147	33	22,4	0,800	17,2
Fluvià	974	268	66	24,6	1,68	19,8
Ter	2.955	816	173	21,2	4,40	17,0
Daró	321	43	3,7	8,6	0,089	6,5
Tordera	876	170	15	8,8	0,361	6,7
Besòs	1.020	126	23	18,3	0,567	14,2
Llobregat	4.957	676	139	20,6	3,52	16,4
Foix	310	9	2,6	28,9	0,064	22,4
Gaiá	423	24	5,1	21,2	0,126	16,6
Francolí	853	45	6,5	14,4	0,163	11,4
Riudecanyes	72	5	1,2	24,0	0,030	18,9
TOTAL	13.519	2329	468,1	20,1	11,80	16,0

(a) Data taken from ACA (2010)

(b) Data drawn from ACA (2005)

The implementation of environmental flow regimes in Internal Basins of Catalonia is not finished and its future deployment still faces some problems.

The comparison of mean ecological flows with those of the month with the lowest average flow in natural regime is an indicator of the requirements in low waters. As an average, at the mouths of the rievers in the in Internal Basins of Catalonia the flow in low waters is around 16% of the mean flow, with a variation ranging from 6.5% in the river Daró and 22.4% in the river Foix.

In the framework of the 2010-2015 Water Planning process a proposal of environmental flow regimes has been included in major Spanish rivers. Table II summarizes environmental flows at differente river mouths taken from the Spanish River Basin Management Plans (RBMPs). It can be concluded that the allocation of environmental water is highly variable, ranging from 1.9% in the Júcar river and 23.3% in the Minho river. Regarding low waters, the lowest monthly flow ranges from 1.9% and 13.7% of the mean annual flow.

Table II: Environmental flows at the mouth of the main Spanish rivers included in the draft River Basin Management Plans 2010-2015

Basin	Catchment area km^2	Discharge in natural regime 1940-2008 (hm^3/year)	Provision for environmental flows (hm^3/year)	Percentage contribution regarding ecological natural regime (%)	Lowest monthly flow (m^3/s)	Percentage of the minimum flow compared to the natural (%)
River Miño at the mouth [(a)]	16.275	12.216	2.852	**23,3**	53,1	**13,7**
River Júcar at Marquesa Weir [(b)]	21.578	1.698	31,5	**1,9**	1,0	**1,9**
River Guadalquivir in Alcalá Dam[(c)]	44.951	5.387	235	**4,4**	6,87	**4,0**

(a) Data from the Minho River Basin (2011)

(b) Data from Júcar River Basin Authorit (Confederación Hidrogáfica del Júcar, 2009)

(c) Taken from Guadalquivir River Basin (2010). The average discharge in natural regime for the entire basin of the Guadalquivir river (56,952 km^2) is 7.043 hm^3/year. This table has been referred to the Alcalá site, since it is the last point of the Guadalquivir river where a normative value of environmental flow is given.

2.2. - Rivers in the world

Collections of information has been made on water flow reserves in other deltas and estuaries worldwide which have a certain similarity with the Ebro River hydrology (Table III). Between other sources, it has been collected the information contained on the website of the International Union for Conservation of Nature and websites of government agencies responsible for water management in selected basins.

The analysis has been extended to the Garonne River (France), Po River (Italy), the San Joaquin and Sacramento deltas (California), Murray-Darling River (Australia) and the Colorado River (USA-Mexico). The comparison of requirement level for environmental flows between countries and in different hydrological circumstances is always a complex issue. However from the analysis it can be concluded that:

- The proposals may establish a single minimum flow for the entire year, regardless of it being wet, or dry, as in the case of the Garonne and Po rivers (and also the indicative proposal of the 1998 Ebro Plan), or may take into account monthly values, the type of year or even the type of period as in the casde of the San Joaquin river (California).

- The magnitude of the established minimum environmental flows in dry years ranges from 2.3% of the average flow in natural regime for the Colorado River in critical years to 14.5% for the minimum environmental and management flow in the Garonne River. In the case of the river Po, although environmental flows are set at 30.2%, there are uncertainties of their actual degree of compliance.

Table III: Environmental flow reserves at the mouth of some rivers of the world with hydrological similarities to the Ebro

Basin	Catchment area km^2	Discharge in natural regime 1940-2008 (hm^3/year)	Provision for environmental flows (hm^3/year)	Percentage contribution regarding ecological natural regime (%)	Lowest monthly flow (m^3/s)	Percentage of the minimum flow compared to the natural (%)
River Garonne (France)	51.500[a]	21.700	3.154[b][c]	**14,5**	100	**14,5**
			1.325[b][d]	**5,4**	42	**5,4**
River Po Delta (Italy)	70.000[e]	47.000[e]	14.191[f]	**30,2***	450[f]	**30,2***
River Sacramento[g] Delta of California Bay	70.567	27.616	--	--	85-127[h,i] 85-99[i,j]	**9,7-14,5** **9,7-11,3**
River San Joaquín[g] Delta of California Bay	82.880	2.220	--	--	20[k]	**28,4**
River Murray Darling (Australia)[l]	1.060.000	31.600	1.000[m]	**3,1**	--	--
Estuary of Colorado River[n]	637.000	22.075	826[ñ,o]	**3,7**	15	**2,1**
			507[o,p]	**2,3**	9	**1,3**

* There are concerns about compliance

(a) Taken from Garonne River Basin Management Plan: http://www.eau-adour-garonne.fr/fr/quelle-politique-de-l-eau-en-adour-garonne/un-cadre-le-sdage.html

(b) Flows are assigned to the gauging station of Tonneins taken from http://www.hautes-pyrenees.pref.gouv.fr/atlas_eau_web/sirs_atlas-eau_ressource_eau.htm

(c) Relates to the objective of low water flow ("debit Objectiv d'Étiage"), which are those that allow the coexistence of all uses and the proper functioning of the aquatic environment.

(d) corresponds to the flow of crisis ("debit of Crise") that enable the delivery of drinking water and the survival of the species present in the aquatic environment.

(e) Taken from Rusconi (2008)

(f) Taken from Veneto (2012)

(g) For details of the sources see Annex I.

(h) These are the minimum flows for gauging station D-24 (RSAC101) Sacramento River in Rio Vista for the months of September to December are not critical. The remaining months of the year there is no defined environmental flows.

(i) Holding Water Rights Decision 1461:
http://www.waterboards.ca.gov/waterrights/board_decisions/adopted_orders/decisions/d1600_d1649/wrd1641_1999dec29.pdf

(j) These are the minimum flows for gauging station D-24 (RSAC101) Sacramento River in Rio Vista for the months of September to December in critical years. The average daily minimum flows circulating in this gauging station in the period 1955-2010 are:

Data in m^3/s

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
perc 10	214	218	281	298	340	374	297	250	262	289	297	289
perc 5	199	203	220	262	267	318	253	215	229	262	273	264
min	113	155	156	187	172	157	124	133	164	201	200	153

(k) are the minimum flows for gauging station C-10 (RSAN112) San Joaquin River at Airport Way Bridge, Vernalis. This flow is defined in terms of the type of year (wet, above normal, below normal, dry and critical) and in the months of February to June (inclusive) and for the month of September. The variability is very high and it was decided to put the minimum flow in critical condition. For more details refer to Annex I. The average daily minimum flows circulating in this gauging station in the period 1955-2010 are:

Data in m^3/s

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
perc 10	24,97	30,29	28,86	33,43	36,37	35,43	24,11	21,26	15,05	12,32	13,49	17,91
perc 5	16,85	26,16	24,75	27,49	28,40	22,22	15,54	16,10	9,58	6,89	8,05	12,17
min	6,23	7,34	2,83	16,40	13,74	6,09	1,94	5,17	1,91	1,03	0,86	3,17

(l) For details of the sources see Annex II.

(m) The condition is that in three consecutive years the average annual flow is greater than 1,000 hm3/year. In current situation the average flow for the period 1895-2009 is 5,100 hm3/year. The years with minor contributions have been 2008/09 with 0 hm3, 2007/08 with 50 hm3, 1902-1903 with 60 hm3, 1914-1915 with 80 hm3 and 1944-1945 with 240 hm3. In the Basin Plan has set a target to recover water from the application of various management measures.

(n) For details of the sources see Annex III.

(n) It corresponds to the minimum flow regime established for the middle years

(o) The actual minimum daily flow measured at gauging station 08162000 Colorado River at Wharton, near the mouth of the estuary, in the period 1938-2011 are:

Data in m^3/s

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
perc 10	12,06	10,23	9,83	10,20	11,26	10,97	16,17	19,57	23,39	21,20	15,72	15,80
perc 5	10,06	8,76	8,60	7,97	8,80	9,29	12,40	15,58	20,00	18,06	12,40	12,80
min	3,06	3,51	2,43	4,94	6,11	4,20	3,46	3,00	2,34	2,69	1,20	4,54

(p) It corresponds to the minimum flow regime established for dry years

3. - STUDIES OF ENVIRONMENTAL FLOWS IN THE RIVER MOUTH EBRO

3.1. - The Water Plan in force

The 1998 Hydrological Plan of the Ebro Basin currently in force (Government of Spain, 1998 and 1999) provides in its Article 33.3 **provisional** minimum ecological flows which apply to future water concessions that "***for the mouth area*** *is set indicatively a minimum ecological flow of 100 m^3/s* ".

3.2. - Historical Data Collection

3.2.1. - Bibliographic information

The collection of historical data of Ebro flows at Tortosa provides a good reference on the minimum flows that the river has endured. The main studies that provide information on this aspect are:

1) "Hydrological Survey of the Ebro Valley" (De Mesa, 1865) in which, for a rather wet summer, there is a flow of 136 m^3/s. This study points out that the minimum flow in driest summers downstream of the mouth of the Segre River is 50 m^3/s.

2) In the Ebro Reservoir Project (Lorenzo Pardo, 1918) low flows were studied, especially that of 1912, which was considered as the driest until that moment. The flows at Fayón were about 40-60 m^3/s. The same author, in a conference held in 1920 (Lorenzo Pardo, 1931, page 120) refers to the project for the navigability of the River Ebro and indicates that low flows are 75 m^3/s in Xerta and 20-25 m^3/s in Tortosa and Amposta.

3) Heraldo de Aragon, a local newspaper; (1935) refers to a minimum flow in Tortosa 40 m^3/s.

These references show that the minimum flow records at the mouth in the late nineteenth and early twentieth centuries could drop to values around 20-50 m^3/s. This fact is confirmed by the information of Tortosa gauging station, which, as discussed in the next section, in some periods has come to be less than 10 m^3/s.

Taking into account the estimated consumption at that time and other information, summer flows in a hypothetical natural regime could be of the order of 50-100 m^3/s (CHE, 2008d).

3.2.2. - Data from the gauging station nº 27 River Ebro at Tortosa

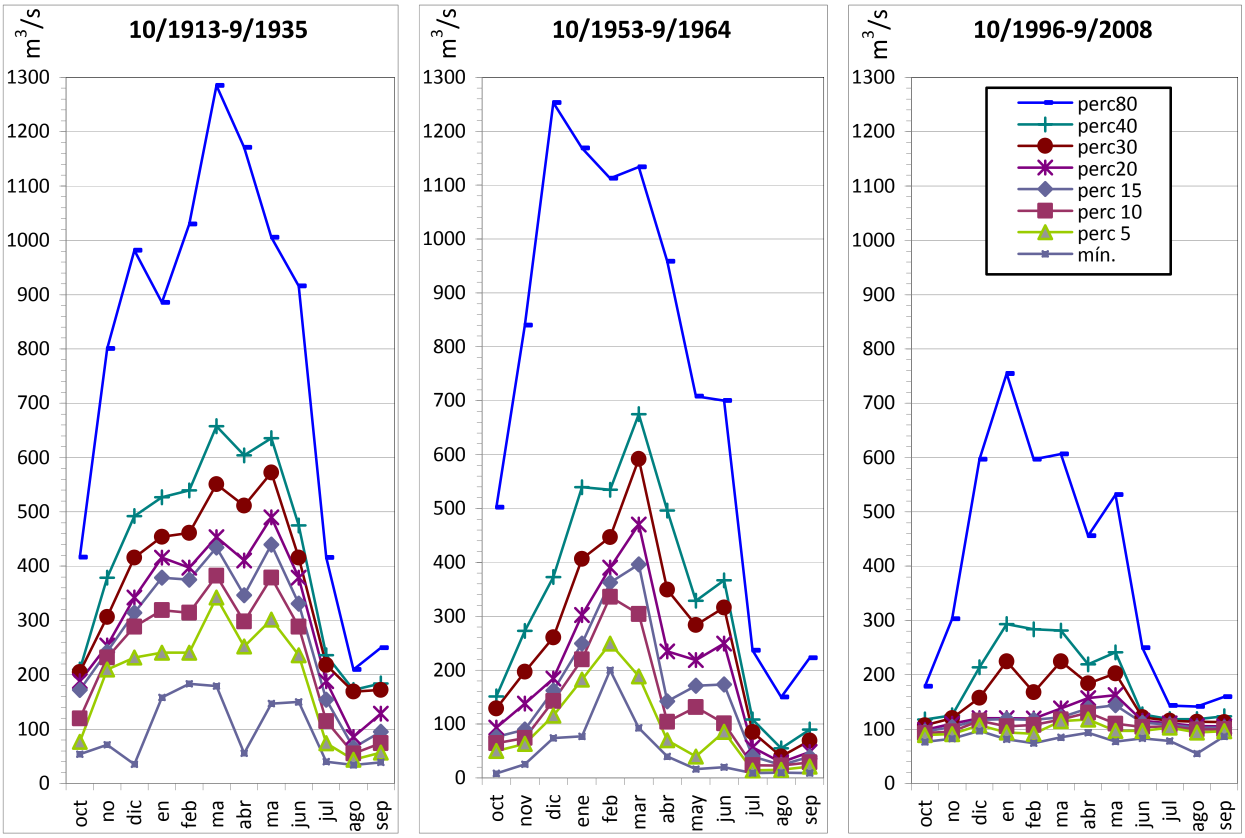
The Official Gauging Stations Network of the Ministry of Agriculture, Food and Environment has the gauging station number 27 in the Ebro River at Tortosa, which presents data from January 1912 to the present. These data are available on http://hercules.cedex.es/anuarioaforos/. The study of the evolution of the series allows identifying different periods in relation to the impact of human activities on the river. These periods are (CHE, 2002):

- From the beginning (1912) until September 1953, regime altered by traditional irrigation existing at that time.
- From October 1953 to August 1964, with a more altered hydrograph than in the previous period by increased irrigation and river regulation and also by increased hydropower activity.
- From September 1965 to the present, very altered regime due to the construction of the Mequinenza dam in 1966 with a reservoir storage capacity of 1.534 hm^3 and the subsequent construction of the Ribarroja dam in 1969 with 210 hm^3.

Focusing on the average daily minimum flows in the two periods prior to the construction of the Mequinenza dam different behaviors can be observed (Table IV).

Table IV: Minimum daily mean flows at gauging station nº 27 of the Ebro River at Tortosa in different periods

	oct	nov	dic	ene	feb	mar	abr	may	jun	jul	ago	sep	Anual
	m³/s												hm³/año
Periodo 10/1913-9/1935													
nº días	682	659	680	682	618	682	660	678	660	682	682	659	8024
Media	333	571	727	668	758	950	815	839	672	326	174	215	18482
perc 15	172	243	314	379	375	435	347	440	331	154	66	95	
perc 10	120	232	289	319	314	383	298	379	289	115	55	74	
perc 5	76	209	232	241	241	342	252	302	236	74	44	57	
mín.	54	71	35	158	183	179	55	147	150	40	34	39	
Periodo 10/1953-9/1964													
nº días	341	330	341	341	311	341	330	341	330	341	341	330	4018
Media	362	536	748	848	819	831	622	481	489	163	115	171	16199
perc 15	76	90	162	249	363	396	142	171	174	40	24	39	
perc 10	64	74	143	220	336	304	104	131	101	24	23	29	
perc 5	50	63	115	183	249	188	70	40	86	14	15	21	
mín.	9	25	74	77	200	93	40	17	20	9	9	9	
Periodo 10/1996-9/2008													
nº días	372	360	372	372	339	372	360	372	360	372	372	360	4383
Media	150	211	403	468	411	429	346	377	215	129	128	139	8937
perc 15	96	104	117	118	117	122	138	144	112	108	103	103	
perc 10	93	96	115	105	107	118	130	110	104	105	99	100	
perc 5	89	91	107	94	91	114	117	97	97	103	94	96	
mín.	76	83	97	81	74	85	93	77	83	78	55	87	



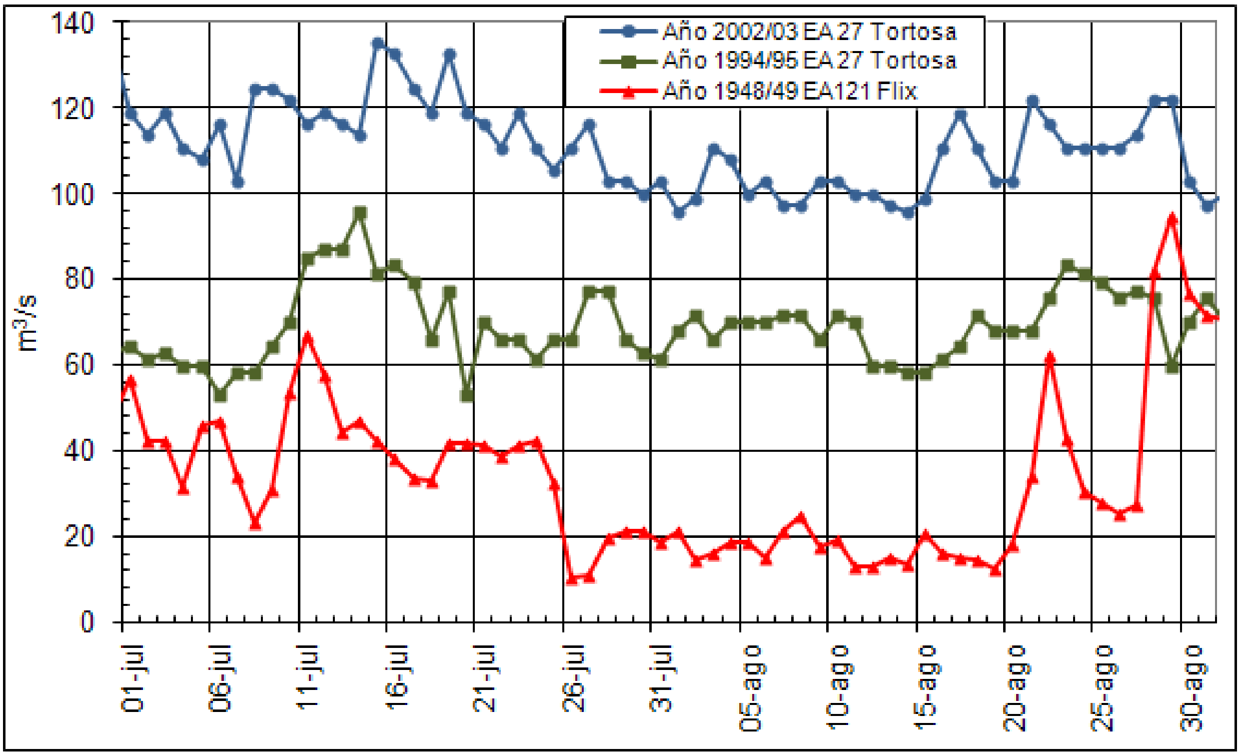
In the period oct/1913 - sep/1935 the absolute minimum flows ranged from 34 m³/s (August) and 183 m³/s (February). In the period oct/1953-sep/1964 minimum flows were substantially lower because it is a period with more consumption and growing water regulation in the basin, and absolute minimum flows recorded in Tortosa varied between 9 m^3/s (from July to October) and 200 m^3/s (February).

The oct/1996-sept/2008 period is indicative of the flow in the current situation, with the large dams in operation and with the current uses of water scheme in the basin. It may be observed that since 1996, the minimum flow is maintained around 100 m^3/s, which means that minimum flows have been substantially regulated in the lower Ebro River.

As an example of the evolution of summer minimum flows in the lower Ebro during the last Century, Figure 1 shows the flows in dry years in the period July - August. It can be seen that in the hydrological year 1948/49 and for over a month flows in Flix (before inflows from the water channels in the left and right margin of the Ebro) were below 25 m3/s. In 1994/95, before the adoption of the current RBMP, the flows in Tortosa were below 75 m3/s in most of the days. In 2002/03, after RBMP was approved, the minimum flows in July and August remained around 100 m^3/s.

This characterization suggests that achieving more naturalized regimes in the lower Ebro River should move towards greater variability in minimum flows including the effects of potential low waters potential (significantly lower than the 100 m^3/s which remain today) as has happened historically without adverse environmental effects.

Figure 1: Evolution of daily minimum flows in dry years at gauging stations nº 27 in the lower Ebro



3.3. - The National Water Plan 2001

3.3.1. – Previous Documentation (MIMAM, 2000)

In the technical documentation for the National Hydrological Plan, the minimum flow was estimated by the the basic flow method (MIMAM, 2000), applied to the data series of the gauging station 27 of the river Ebro at Tortosa in the period between October 1986 and September 1998, being the last 10 hydrological years whith available measured data.

The maintenance flows hydrograph represents an annual discharge of 3.788 hm^3/year (121 m^3/s mean flow) with the following modulation.

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
104	125	147	166	152	132	140	128	110	90	80	84

The data series are affected by the regulation in the reservoirs, so that it can be deduced that the environmental flow regime obtained by the application of the method to this series is overestimated.

3.3.2. – Study by the Hydrological Planning Office

In 1999 the Hydrological Planning Office of the Ebro River Basin Authority (Confederación Hidrográfica del Ebro) conducted a study applying the basic flow methodology taken from CEDEX (1998) at the gauging stations of the Ebro basin (OPH-CHE, 1999). For the gauging station of the river Ebro at Tortosa during the data period between October 1953 and September 1964, it was obtained an annual volume required to meet the environmental flows of 2.793 hm^3 with the following seasonal distribution:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
76,7	97,7	114,0	118,6	114,0	116,0	98,6	86,5	88,6	53,7	45,3	55,1

The results from this study are lower than those calculated by MIMAM (2000) since the series analyzed are those recorded at the gauging station before the commissioning of Mequinenza reservoir. It could be considered to be a low estimate because the series is not reconstructed to natural regime and consequently data are affected by the water consumption in the basin.

3.3.3. - Proposal by the Ministry at the technical meeting held in Brussels, 2003

On 16 and 17 October 2003, a technical meeting was held in Brussels to discuss the proposal of transferring 1.050 hm^3 of water from the River Ebro to other Mediterranean basins. At this meeting, the Ministry of Environment showed a proposal for the determination of ecological flows in the lower Ebro based on the application of the basic flow method with actual daily data from the gauging station of the river Ebro at Tortosa in the period 1956 - 1969 (Sánchez, 2004). This determination resulted in a base flow of 71.5 m^3/s. Two hypotheses were considered for the definition of Temporal Variability Factor, corresponding with two environmental flow regimes with an annual volume required to maintain minimum environmental needs:

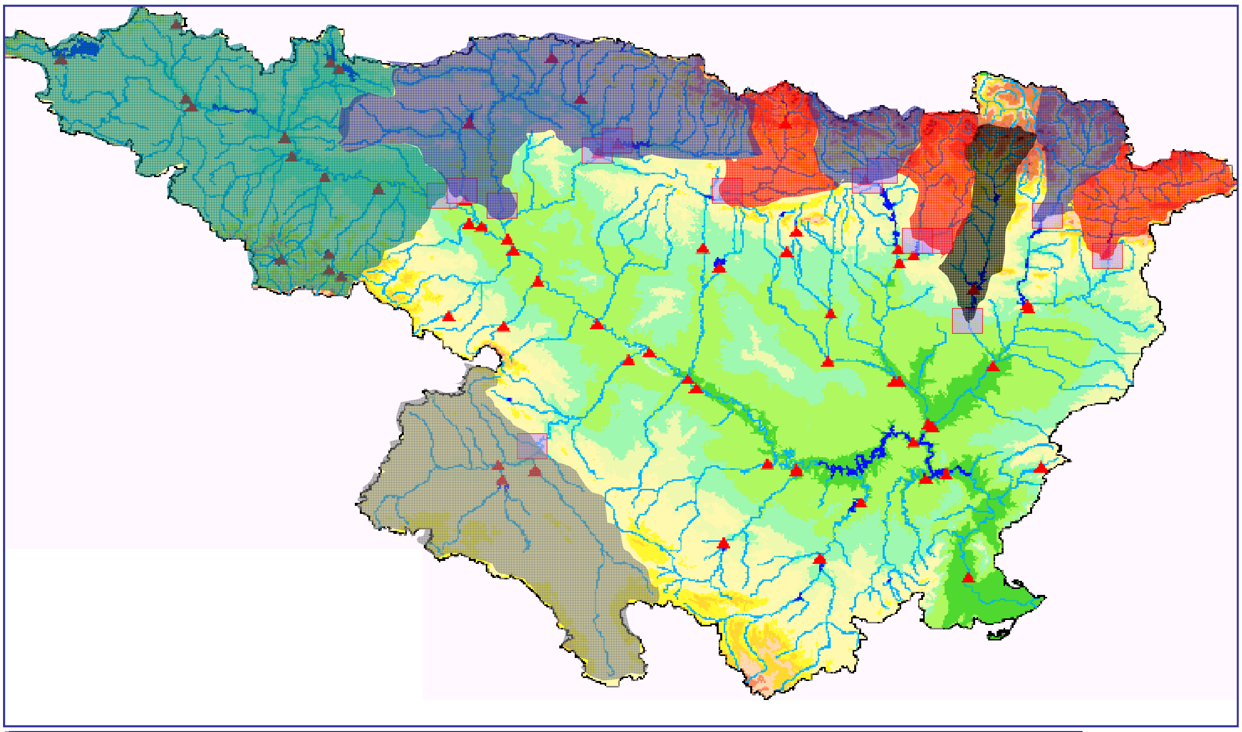
- 3.522 hm^3/year with the variability factor obtained from the series of actual records.
- 4.581 hm^3/year with he variability factor obtained from the monthly series in natural regime.

with the addition of two controlled flood events in May and October.

This proposal was discussed in Sánchez (2004), which concludes that the basic flow method has major limitations for such complex cases as the lower Ebro. Even more, the application of the basic flow is qualified as inadequate since the series used is greatly affected by the water use whitin the basin. As a consequence, flow rates in the proposal of the Ministry are sunstantially lower than ctose orresponding to the natural regime.

To demonstrate the effects of these diversions, Sánchez (2004) constructed a series called β from data recorded in 13 main gauging stations and 33 auxiliary ones used to complete the series of the former (Figure 2). These stations covered 60% of the basin area and 80% of its water discharge. By adding the daily flows of the 13 main stations with a retardment varying from 1 to 4 days which represents the delay of their discharges in getting to the mouth of the Ebro River, a series of daily flows in the period 1950-1960 was obtained. The main conclusion is that in this hypothetical natural regime the average annual absolute minimum flow is 97 m^3/s.

Figure 2: Gauging stations used for the construction of the β series in Sánchez (2004)



RIO	TIPO	ESTACION
EBRO	E. de referencia	EA 120
	E. auxiliares	EA 1; EA74; EA 50; EA 38; EA 36; EA 149; EA 26
EGA	E. de referencia	EA 3
	E. auxiliares	EA 71
ARGA	E. de referencia	EA 4
	E. auxiliares	EA 69
IRATI	E. de referencia	EA 65
	E. auxiliares	EA 64; EA 79; EA 66
ARAGON	E. de referencia	EA 101
	E. auxiliares	EA 62; EA 61; EA 63; EA 18; EA 170
JALON	E. de referencia	EA 9
	E. auxiliares	EA 55; EA 126
GALLEGO	E. de referencia	EA 123
	E. auxiliares	EA 12; EA 89; EA 59
CINCA	E. de referencia	EA 16
	E. auxiliares	EA 51; EA 40; EA 17
ESERA	E. de referencia	EA 13
	E. auxiliares	EA 128
ISABENA	E. de referencia	EA 47
	E. auxiliares	
N. PALLARESA	E. de referencia	EA 102
	E. auxiliares	EA 146
N. RIBAGORZANA	E. de referencia	EA 115
	E. auxiliares	EA 137; EA 119; EA 133; EA 97
SEGRE	E. de referencia	EA 111
	E. auxiliares	EA 114; EA 83

However, even though Sánchez (2004) considers the basic flow method is not suitable for the determination of environmental minimum flows for the Ebro delta, an exercise of application with β series (period 1950/1960) is carried out obtaining the following results:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
148,2	190,1	232,0	241,6	255,1	271,1	249,9	255,4	248,4	170,3	130,6	139,4

resulting in an annual volume of 6.644 hm^3/year for environmental allocation.

The main objection to the work of Sánchez (2004) is that it has no actual data to calibrate the minimum flowsof the β series, which are the determining element when applying the base flow method. Validation of β series is made with series obtained from hydrological models (natural regime series taken from CHE 1998, 1993) and series reconstructed to natural regime from CHE (2003). Both series are the result of estimates made with many previous hypotheses and therefore not valid to calibrate a proposal of daily series in natural regime. Furthermore, the hydrologic period of the β series contains no dry years, so that their statistical values are much overestimated.

3.3.4. - Proposal on allegation to the National Hydrological Plan (Prat, 2001)

During the discussion process on the National Hydrological Plan, Prat (2001) makes a proposal based on the environmental functions of the flow resulting in an annual volume of 10.654 hm^3/year disaggregated as reflected in Table V.

No further technical justification of the proposed flows is included in Prat (2001), so that it is not possible to discuss the methods used to obtain them.

Table V: Proposed ecological flow Prat (2001)

Month	Nº days	Flow to control the salt wedge	Basic flow	Flood Flow	Flow to prevent anoxia	Agro-environmental flow[(a)]	**TOTAL**
		m^3/s					
oct	31	147				71	**218**
nov	30	147					**147**
dec	31	147					**147**
jan	31	147					**147**
feb	28		403				**403**
mar	31		403	569			**972**
apr	30		403	569			**972**
may	31	147					**147**
jun	30	147					**147**
jul	11	147					**147**
	20	147			250		**397**
aug	31	147					**147**
Sep	10	147					**147**
	20	147			250		**397**

Month	Nº days	Flow to control the salt wedge	Basic flow	Flood Flow	Flow to prevent anoxia	Agro-environmental flow[(a)]	TOTAL
		m^3/s					
ANNUAL	**365 días**	**3.500 hm^3**	**3,100 hm^3**	**3,000 hm^3**	**864 hm^3**	**190 hm^3**	**338 m^3/s 10,654 hm^3/year**

(a) This flow rate is specified in Prat's approach (2001) as a reserve of 190 hm^3/year for floods in autumn and for the purposes of this table, this reserve has distributed every day of October.

3.4. - Environmental flows studied under the Integral Plan for the Protection of the Ebro Delta (*Plan Integral para la Protección del Delta del Ebro, PIPDE*)

3.4.1. - Preliminary study of 2003

In 2003 a draft document of the Integral Plan for the Protection of the Ebro Delta (CPIDE, 2003) was released as provisioned in Law 11/2001 of the National Hydrological Plan (Government of Spain, 2001). This document contains an analysis and a proposal for environmental flow in the Ebro, assuming that, as stated in CPIDE (2003), the series of daily flow from the gauging station nº 27 (Ebro at Tortosa) during the period 1956/1969 is sufficiently representative for the application of hydrological methods for assessing environmental flows.

Different hydrologica methods are applied to this series (Table VI) with the conclusion that results range from 51.2 m^3/s with the French approach to 174.6 m^3/s with the "high" Italian approach. It is concluded that the flow rate of 100 m^3/s established in the RBMP is on the side of safety.

The application of the basic flow method to different periods (1956-1963, 1956-1966, 1956-1969) results in basic flows of 70, 68 and 71 m^3/s, that with a variety of seasonal distributions render a set of possible proposals (Table VII).

With all this information, it is concluded that the flow rate of 100 m^3/s of the RBMP is on the side of safety but it would be interesting to consider a more pronounced minimum in low flows. The Integral Plan was presented to the Commission in July 2003 PIDE with a proposal of environmental flow regimes for the Delta ranging between 103 and 143 m^3/s (Table VII) with two flood events, one in spring (with a maximum flow of 600 m^3/s for 36 hours) and one in the fall (with two peaks of 1.200 and 1.000 m^3/s for 48 hours). This Plan was not approved at the meeting because, among other reasons, the proposed environmental flow was not considered sufficient (Alcácer-Santos, 2004).

3.4.2. - Proposal by IRTA

In ACA (2007) IRTA (Institut de Recerca i Tecnologia Agroalimentàries of the Generalitat of Catalonia, Institute for Research ans Agri-Food Technology) conducted a study to determine environmental flows in the final stretch of the river Ebro This study was commissioned by the Catalan Water Agency and the technical staff of the PIPDE for the Commission for the Sustainability of the Ebro Region. This study applied a variety of hydrological methods obtaining monthly regimes with the results listed in Table VIII.

Table VI: Maintenance flows (m^3/s) obtained by applying different calculation methods (CPIDE, 2003)

<table>
<tr><th></th><th>oct</th><th>nov</th><th>dec</th><th>jan</th><th>feb</th><th>mar</th><th>apr</th><th>may</th><th>jun</th><th>jul</th><th>aug</th><th>sep</th><th>year</th></tr>
<tr><td>Montana</td><td colspan="6">102</td><td colspan="6">205</td><td>153</td></tr>
<tr><td>Arkansas</td><td>105</td><td colspan="5">443</td><td colspan="3">381</td><td colspan="3">105</td><td>315</td></tr>
<tr><td>Utah</td><td colspan="6">202</td><td colspan="6">105</td><td>153</td></tr>
<tr><td>NEFM</td><td colspan="12">110</td><td>110</td></tr>
<tr><td>NGPRP</td><td colspan="12">97</td><td>97</td></tr>
<tr><td>0,25 QMA</td><td colspan="12">128</td><td>128</td></tr>
<tr><td>7Q2</td><td colspan="12">54</td><td>54</td></tr>
<tr><td>France</td><td colspan="12">51</td><td>51</td></tr>
<tr><td>Auverge Limousin</td><td colspan="6">165</td><td colspan="6">127</td><td>146</td></tr>
<tr><td>La Vaudoise (Switzerland)</td><td colspan="12">70</td><td>70</td></tr>
<tr><td>Austria</td><td colspan="12">175</td><td>175</td></tr>
<tr><td>Italy</td><td colspan="12">168</td><td>168</td></tr>
<tr><td>Italy. 10.</td><td colspan="12">51</td><td>51</td></tr>
<tr><td>England & Scotland</td><td colspan="12">102</td><td>102</td></tr>
</table>

The methods applied are (CPIDE, 2003):

- Montana method, where flow is equivalent to 20% of average flow between October and March, and 40% between April and September.

- Arkansas method, a derivation of Montana method, which proposes that between November and March the environmental flow is 60% mean monthly flow; between April and June, 70%; and between July and October and 50%.

- Utah method proposes to divide the year into two periods (Oct-Mar and Apr-Sep) and uses the average of the lowest values of monthly mean flows for each month in each of the periods.

- NEF, New England Flow Method also known as ABF (Aquatic Flow Basis) calculates the average of the median values for the daily discharges of August, for each year of the series.

- NGPRP method, Northern Great Plains Resource Program, determines the flow which is equaled or exceeded 90% of the time on the basis of the flow classification curve, once dry and wet periods are discarded.

- 0.25 QMA is a derivation of the Montana method: 25% of the annual average.

- 7Q2 is one of the oldest methods applied in the southern United States; it is the average minimum flow through seven consecutive days, and for a return period of two years.

- France. The French law establishes the same criterion adopted as indicative in the Ebro RBMP of 1998. The maintenance flow is 10% of the annual average flow while above 80 m^3/s the percentage may be 5%. In the table the more conservative valu3 (10%) has been adopted

- Auverge Limousin. The French regulations in this region establish 1.3 x Q_{355} between April and September and 1.7 x Q_{355} between October and March.

- The Vaudois (Switzerland), criterion from the cantonal legislation are applied, following an algorithm based on the Q_{347} known as "Mathey formula".

- Austria, Austrian regulations criteria: Q_{300}.

- Italy. Italian regulations: equivalent to 2 $l/s/km^2$.

- Italy 10: equivalent to 10% of annual average.

- England and Scotland: equivalent to Q_{347}

Tabla VII: Application of the basic flow calculation with different assumptions, made in CPIDE, 2003.

Data in m^3/s

FVT	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep	year
Period: 1956-63 Qmin= 44 m^3/s Qb= 70 m^3/s													
RN 1940-86	90	109	118	126	126	125	128	138	124	85	70	75	109
CN 1956-63	119	147	168	182	168	168	154	126	133	84	70	84	134
Mx 1950-00	101	126	140	151	156	147	140	130	124	85	70	82	121
R 1969-00	91	109	120	135	147	130	126	125	117	84	70	80	111
R 1986-98	91	110	128	145	133	116	123	112	96	79	70	74	106
Period: 1956-66 Qmin= 46 m^3/s Qb= 68 m^3/s													
RN 1940-86	87	105	115	122	122	121	124	134	120	82	68	73	106
CN 1956-66	122	156	177	183	170	183	163	136	136	81	68	81	138
Mx 1950-00	98	122	136	147	151	143	136	126	120	82	68	79	117
R 1969-00	88	106	116	131	142	126	122	121	113	81	68	77	108
R 1986-98	88	107	124	141	129	112	119	109	93	77	68	71	103
Period: 1956-69 Qmin= 52 m^3/s Qb= 71 m^3/s													
RN 1940-86	91	111	120	128	129	127	130	141	127	86	71	76	112
CN 1956-69	122	164	186	186	172	186	172	143	143	86	71	86	143
Mx 1950-00	103	129	143	154	159	150	143	132	127	86	71	84	123
R 1969-00	93	112	122	134	149	132	129	127	119	86	71	81	113
R 1986-98	93	112	131	148	136	118	125	114	98	81	71	75	109

FVT = Temporal Variability Factor

Qmin = Minimum Average Daily Flow

Qb = Basic Flow

To calculate temporal variability factors (FVT) the following reference series has been used:

- RN 1940-1986: series taken from CHE natural regime (1993) in the period 1940/1986
- 1956-1963 CN: almost natural series gauging station 27 at Tortosa in the period 1956/1963
- 1956-1966 CN: almost natural series gauging station 27 at Tortosa in the period 1956/1966
- 1956-1969 CN: almost natural series gauging station 27 at Tortosa in the period 1956/1969
- Mx 1950-1900: mixed series taken from the gauging station 27 at Tortosa in the period 1956/2000
- R 1969-00: regulated series taken from the gauging station 27 at Tortosa in the period 1969/2000
- R 1986-98: regulated series taken from the gauging station 27 at Tortosa in the period 1986/1998

Tabla VIII: Hydrological methods applied in ACA (2007).

	RVA_{NGPRP} (a)	RVA_{p25} (b)	Hoppe	Tessman	Montana	$QBM_{serie\ \beta}$ (c)	QBM_m (d)
Data type	Monthly	Monthly	Monthly	Monthly	Annual	Daily	Monthly
Series used	Sacra. (e)	Sacra. (e)	Sacra. (e)	Sacra. (e)	Sacra. (e)	Serie β (f)	Sacra. (e)
Period	1940-1985	1940-1985	1940-1985	1940-1985	1940-1985	1950-1959	1940-1985
Minimum monthly Q (m^3/s)	**119**	**164**	**158**	**227**	**173**	**150**	**241**
Environmental needs (hm^3/year)	**9.509**	**12.624**	**16.361**	**8.474**	**7.728**	**7.419**	**11.903**

(a) RVA_{NGPRP}: Range of Variability Approach with the 10th percentile citeria from Northern Great Plains Resources Program

(b) RVA_{p25}: Range of Variability Approach with the criteria of 25^{th} percentile range

(c) QBMserie β: Basic maintenance flow with β series

(d) QBM_m: Basic maintenance flow with monthly series

(e) Sacra: Flow series obtained from the application of the Sacrament model in CHE (1993)

(f) β Series: Daily natural flows in the final stretch of the river Ebro (Sanchez, 2004) obtained from the reconstruction of data in gauging stations not affected in their natural regime

This paper proposes as the best method for the lower Ebro the RVA_{NGPRP} using the 10^{th} percentile range. This method has been used in the Northern Great Plains Resource Program (USA) and is calculated as the 10% percentile of estimated discharges in natural regime for each month of the year. These values are assigned to an average (normal) year while for dry and wet years it is applied a factor based on the deviation from the 50^{th} percentile to the 25^{th} and 75^{th} percentiles for each month, respectively. Thus the following proposal is obtained:

Data in m^3/s

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
Dry	87	135	248	285	327	276	336	396	252	167	116	103
Medium	119	202	359	388	436	360	428	500	342	198	150	135
Wet	207	317	449	468	511	526	569	623	453	254	187	210

In terms of annual volumes, this regime represents an allocation of 7.149 hm^3 in dry years, 9.482 hm^3 in normal years and 12.517 hm^3 in wet years. This proposal was also included in the study CHE (2007a) and by the New Water Culture Foundation (*Fundación Nueva Cultura del Agua*, FNCA, 2006).

The main objections for this method are: that the methodology applied has not been considered a reference in Spanish rivers; that selected hydrological methods are those that result in higher minimum flows; and that the series used cover the period 1940-1985, while the Hydrological Planning Instruction recommends using the period 1980/2006, substantially drier.

3.4.3. - Biological validation of the proposal and discussion

In ACA (2008a) a validation of environmental flow regimes proposed in ACA (2007) is carried out. To perform this validation habitat simulation methods are used as provisioned in the Planning Instruction. The features of the simulation performed as representative of lower Ebro are the following:

+ Reference Section: stretch of 2,4 km downstream of the Cherta weir

+ Reference Species: Twait shad (*Alosa fallax*). This species inhabits the lower Ebro in their spawning season (mid-March to late June). During the twentieth century, populations were declining, especially from the year 1950 to 1955 (still without reservoirs), being the 40s the decade with highest number of captures (when summer flows were below 100 m^3/s for many days). The main causes of declining sabogas were the woersening of the water quality, the proliferation of non-native species and the over-exploitation of the natural environment (Boquera and Quiroga, 2001). Over the past decade the population of twait shad is having a significant recovery.

+ Preference curves: were developed specifically for the section under study from acoustic and visual observations taken by boat ride in the only time when twait shad enters the River Ebro (April to June). In these curves it may be observed that preferential spawning speeds are high (1 to 1.5 m^3/s) while preferred depths are greater than 2 m.

With the habitat simulation model, different flow rates are simulated to determined the area effectively used by the twait shad (Table IX).

Table IX: Percentage of weighted usable area with different flows in the section downstream of the Cherta weir (ACA, 2008a).

	Year type	April		May		June	
		m^3/s	%	m^3/s	%	m^3/s	%
Natural	medium	660	*100*	609	*100*	400	*100*
	dry	463	*83*	424	*80*	263	*66*
Real	wet	273	*51*	469	*86*	317	*80*
	medium	254	*47*	381	*73*	243	*61*
	dry	191	*34*	239	*45*	235	*58*
PHCE[(a)]		100	*15*	100	*15*	100	*20*
Proposal CSTE[(b)]	wet	569	*94*	623	*101*	453	*111*
	medium	428	*78*	500	*90*	342	*81*
	dry	336	*63*	396	*75*	252	*63*

(white)	Meets the 50% habitat limit established in the Hydrological Planning Instruction
(grey)	Does not Meet the 50% habitat limit established in the Hydrological Planning Instruction

(a) PHCE= Hydrological Plan of the Ebro Basin 1998

(b) CSTE= Commission for the Sustainability of the Ebro Region (ACA, 2007)

According to ACA (2008a) from these simulations it may be concluded that the environmental flow currently in force for the lower Ebro (100 m^3/s under the RBMP of 1998) is not advisable in terms of twait shad protection since ir represents an 80% reduction of the usable are for spawning in relation to natural conditions. It is also concluded that the environmental flows proposed in ACA (2007) represents a 15% reduction compared to natural conditions, supporting a satisfactory scenario from the point of view of the conservation of the species.

Regarding the methodology applied in ACA (2008a) the following issues can be pointed out:

a) Maximum weighted usable area is defined as that corresponding to half year. This interpretation is a clear underestimation of the percentage of weighted usable area for each flow. The Planning Instruction provides guidance to define this maximum as that which corresponds to the flow defined by the range of 10-25% percentiles of the daily discharges in natural regime of a representative series of at least 20 years (Section 3.4 .1.4.1.1.3 Government of Spain, 2008).

b) The selection of the twait shad as indicative species for the habitat simulation is also a matter of debate, since its only temporary use of the river and also the limited use of space make it not advisable to select it as a reference. This has been discussed in detail in CHE (2009a) from reference information about the presence of fish fauna in the lower Ebro (Lopez and Sostoa, 2001; CHE, 2005a; Lopez et al., 2007; Ibáñez, 2009; CHE, 2010a). Recent new studies on fish population in the lower Ebro (CHE, 2011a) and across the Ebro basin (CHE, 2012th) have been carried out. The conclusion is that twait shad is not a good indicator for the lower reaches of the Ebro, being more appropriate the selection of three species whose preference curves are commonly used in the Spanish rivers for habitat simulation studies. These species are the common barbel (*Barbus bocagei*) the Iberian nase (*Pseudochondrostoma polylepis*) and the Iberian chub (*Squalius pyrenaicus*).

c) The preference curve definition in an area as the Cherta reach results in a use curve more than a proper preference curve. The Cherta weir is an insurmountable barrier for twait shad and its localization spots are highly conditioned.

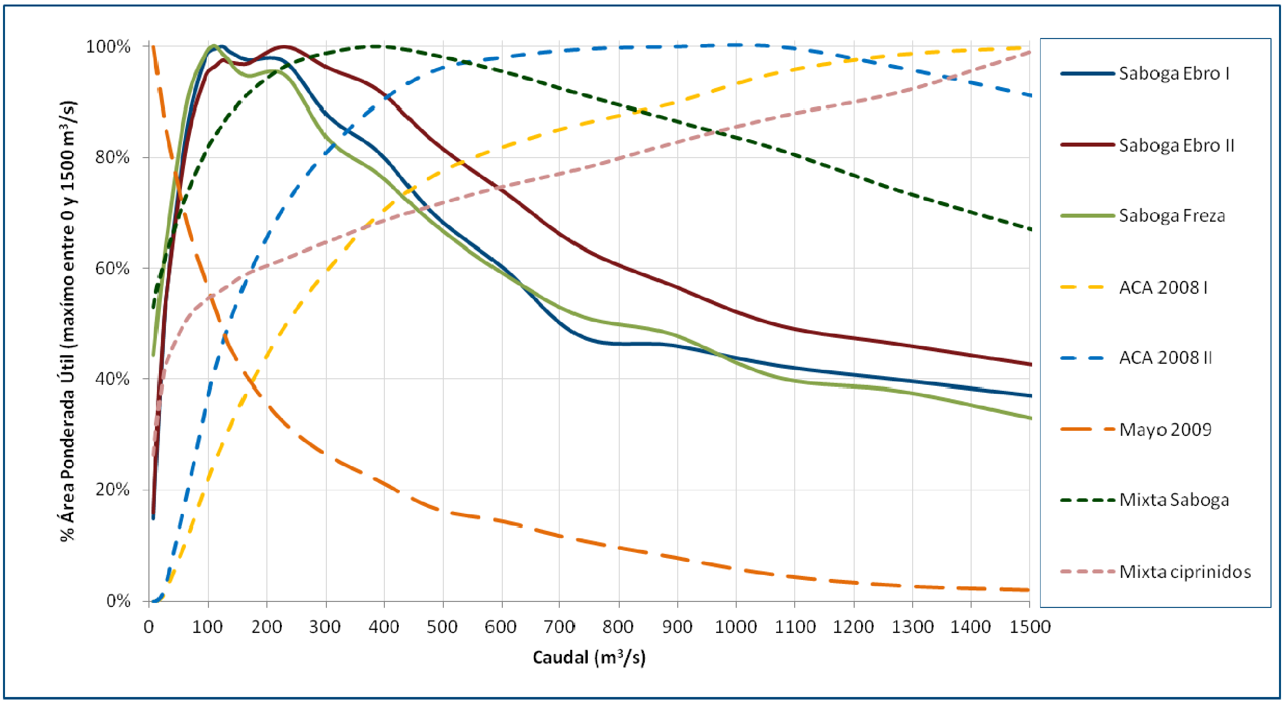
d) In ACA (2008a) there is a brief description of the methodology used to obtain the preference curves for speed, depth and substrate. There is no detailed information on how this curve was drawn. The fact that optimum speeds for twait shad are assessed around of 1.0 - 1.5 m^3/s is the key factor that determines the preference of twait shad for high flow rates, as concluded by ACA (2008a). These twait shad preference curves defined in ACA (2008a) are very different from others ellaborated in the Ulla River (Minho basin), which were obtained in the framework of the environmental flows determination made by the Ministry of Environment (MARM, 2009), with on field studies based on electric fishing techniques, direct surface observation and diving. The curves for the Ulla River provide suitability values around 0.3 m/s and 0.4 m optimal depth.

To analyze in detail the preferences of the twait shad in the lower Ebro specific studies were conducted during 2010 and 2011 (CHE, 2010b; CHE, 2010c; CHE, 2011b) by marking and controlling individuals during the period in which they are in the Ebro, allowing locating the position of each of the tagged fishes. This methodology was based on the most advanced techniques and facilitated, together with a characterization of the speed, depth and substrate, the interpretation of preferences in the reach, which is the same that was simulated by ACA (2008a).

Tagging works support the proposal of a twait shad preference curve for the lower Ebro, based on the best techniques, resulting in the best preference for 5 m deep and velocities characterised by a bimodal distribution with two peaks at 0, 25 and 0.75 m/s.

Habitat simulation for the twait shad considering different preference curves (OPH-CHE, 2011; CHE, 2011b) allow to assess great differences in habitat values obtained with the application of a variety of preference curves. Those curves obtained from specific field studies (CHE, 2011b) clearly supports that flows significantly lower than 100 m^3/s ensures habitat criteria established in the Planning Instruction are met (Figure 3).

Figure 3: Curves of weighted usable area from different sources (CHE, 2011b)



Description of preference curves used:

- **Saboga Ebro I**, **Saboga Ebro II** and **Saboga Ebro III** curves are obtained by CHE (2011b) with different corrections of the positioning probability.

- **ACA 2008 I** and **ACA 2008 II** curves are proposed in ACA (2008a) with different behavioral assumptions regarding the substrate.

- **May 2009** are the curves obtained in MARM (2009)

- **Mixed saboga** considers depth curve by ACA (2008a) and substrate and speed curves by MARM (2009)

- **Mixed cyprinid** considers the combined cyprinid curve used in CHE 2009th from the curves originally proposed by Capel (2000 and 2009).

3.4.4. - Other studies related to the proposal by ACA

3.4.4.1. - Iszkowski and Principality of Asturias Methods

In Franquet (2004) a proposal fro environmental flows at the Ebro Delta is made, with a minimum flow of 239 m^3/s.

A few years later the same author published a monograph (Franquet, 2009) in which his original proposal is reviewed concluding with the following environmental flow for the Ebro River downstream of Cherta weir:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
182	286	349	367	414	431	379	353	307	153	118	125

which represents an annual volume to meet the environmental needs up to 9.075 hm^3. These flows are derived from the application of the environmental flows assessment method developed by ISZKOWSKI (its applicability to Mediterranean streams is unknown) and also by applying the method used in the

Principality of Asturias (based on the Swiss Law). These values are similar to those obtained in ACA (2007), what the author interprets as a validation of his method.

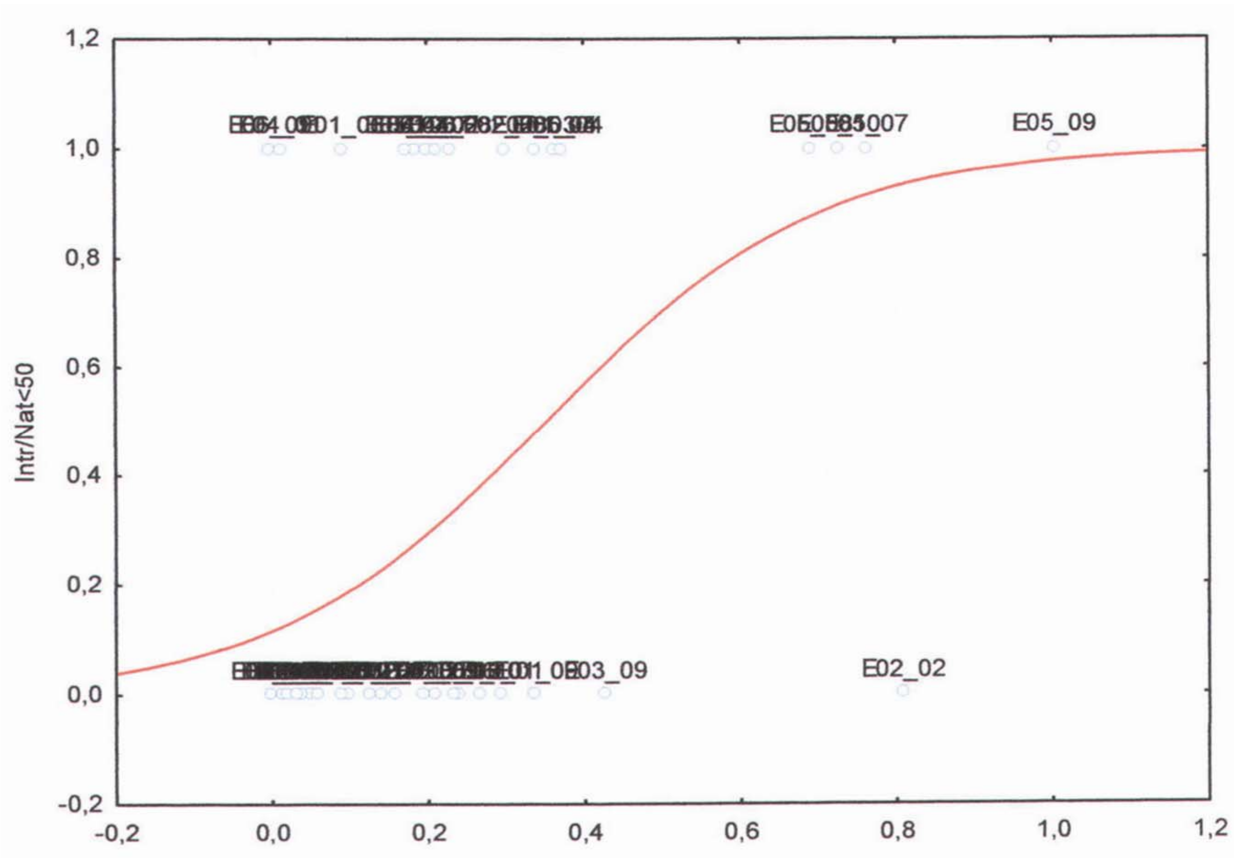
The main criticism that can be made of the work to Franquet is that his argument does not address the new criteria incorporated in the Planning Instruction of 2008 and the use of not contrasted methodologies and general formulations from experiencies in other countries with hydrologic conditions that have little to do with the Mediterranean environment.

3.4.4.2. - Statistical analysis of flow - native species dominance

In order to have different criteria for environmental flows in the lower Ebro, CHE awarded a study to the Platform in Defence of the Ebro, which in turn looked for technical support from IRTA (CHE, 2008a). In this study the biological validity of the various proposals for environmental flows in the lower Ebro was analysed: 100 m^3/s from RBMP 1998, 121 m^3/s from MIMAM (2000); 88.6 m^3/s from OPH-CHE (1999), and 227 m^3/s, 301 m^3 397 m3/s in dry, normal and wet years proposed by ACA (2007). Fish community in the lower Ebro is characterized from fishings conducted in five stations (Flix, Vinebre, Mòra, Ginestar and Xerta).

Since the completion of 50 samples with electrofishing conducted in August 2007 and 2008 the discrete indicator of the dominance of native or alien species is determined: 0 if introduced species outweigh the native and 1 otherwise. An adjustment is made with the flow velocity at every sampling according to a regression function (Fig. 4). The conclusion was that from a speed of 0.4 m/s the adjusted regression curve gives a ratio of introduced/native species greater than 0.5, indicating that management to be pursued in the lower Ebro should look for average speed greater than 0.4 m/s. From hydraulic modeling of flows it is concluded that the flows proposed by ACA (2007) are the only ones that meet the ecological function of providing habitat conditions that does not favor alien species.

Figure 4: Correlation between flow velocity and the discrete indicator: increased presence of native species (1) or alien (0) in 50 samples of electrofishing in five sections of the lower Ebro and adjustment curve (CHE, 2008a).



regarding the methodology used in CHE (2008a) it should be stated that:

- The greater or lesser presence of native species in rivers is an indicator that depends on many factors. The analysis of the distribution of the fish fauna in the Ebro basin made from the collection of fish stocks performed (CHE, 2012a) shows that, overall, in the upper basin there is a dominance native species and as the rivers progress in their journey downstream the number of alien species increases, especially in the axis where population is higher as is the case of the Ebro. It is under discussion which are the appropriate measures to reduce non-native species, but it seems that measures such as the selective extraction of these species are the most effective. In any case, in view of the information available, the relation of the dominance of introduced species with the water velocity in the Ebro basin is not obvious. Historical experience shows that at low flow rates as those produced in the first half of the twentieth century, the fish fauna of the river Ebro was native. So it questions the correlation shown by this study.

- In CHE (2008a) data are taken from electrical catches made on the banks of the river, not taking information from the central regions of the channel due to limitations of the sampling methodology itself. This lack of information can cause a bias to be evaluated. To perform a detailed analysis of the fish population in a representative reach of the lower Ebro a detailed quantitative survey was conducted on fish and habitat in the river stretch between Asco and Cherta (CHE, 2011a). Applied techniques include boat electrofishing, scientific benthic and pelagic networks. With them a digital bathymetric model was obtained, the three-dimensional distribution of density and biomass of species from the distribution of abundance, size and weight by species and habitat as well as the substrate type and speed of the river.

The analysis in CHE (2011a) provides information on the relationship between the species, the speed and and the depth of the flow (Table X).

Table X: Relationship between macrohabitat and species in the lower Ebro (CHE, 2011a). The deep-shallow limit (*lento-somero*) is 1.2 m and the fast-slow (*rápido-lento*) limit is 0.7 m/s.

DENSIDADES (ind/m^2)								
Especie		Lento Profundo	Lento somero	Rápido profundo	Rápido somero	Densidad por especie	Abundancia	
		individuos/m^2					%	individuos
Autóctonos	Anguila	0	0,2	0	0,2	0,057	13%	15.842
	Bagre	0,004	0	0	0	0,001	0%	385
	Barbo de Graells	0	0,014	0,012	0,014	0,009	2%	2.434
	Gobio	0,083	0,018	0	0,018	0,032	7%	9.074
	TOTAL	*0,087*	*0,232*	*0,012*	*0,232*	*0,099*	*22%*	*27.735*
Alóctonos	Alburno	0,379	0,194	0,293	0,194	0,293	66%	82.155
	Carpa común	0	0,017	0	0,017	0,005	1%	1.321
	Carpín	0	0,001	0	0,001	0	0%	75
	Gambusia	0,004	0,047	0	0,047	0,014	3%	4.060
	Gardí	0,004	0	0	0	0,001	0%	385
	Lucioperca	0,013	0,005	0	0,005	0,006	1%	1.559
	Pez sol	0,021	0,018	0	0,018	0,012	3%	3.314
	Rasbora	0,008	0,001	0	0,001	0,003	1%	818
	Rutilo	0,021	0	0	0	0,007	2%	1.906
	Siluro	0	0,008	0	0,008	0,002	0%	609
	TOTAL	*0,45*	*0,291*	*0,293*	*0,291*	*0,343*	*77%*	*96.202*
TOTAL		**0,538**	**0,522**	**0,305**	**0,522**	**0,442**	**100%**	**123.937**

BIOMASA (g/m^2)								
Especie		Lento Profundo	Lento somero	Rápido profundo	Rápido somero	Densidad por especie	Abundancia	
		g/m^2					%	kg
Autóctonos	Anguila	0	18,616	0	18,616	5,256	9%	1.473
	Bagre	0,123	0	0	0	0,04	0%	11
	Barbo de Graells	0	3,307	2,925	3,307	2,08	4%	583
	Gobio	0,619	0,135	0	0,135	0,24	0%	67
	TOTAL	*0,742*	*22,058*	*2,925*	*22,058*	*7,616*	*13%*	*2.134*
Alóctonos	Alburno	2,611	1,349	2,018	1,349	2,022	3%	567
	Carpa común	0	69,432	0	69,432	19,602	34%	5.493
	Carpín	0	1,022	0	1,022	0,288	0%	81
	Gambusia	0,006	0,068	0	0,068	0,021	0%	6
	Gardí	0,083	0	0	0	0,027	0%	8
	Lucioperca	0,058	0,07	0	0,07	0,039	0%	11
	Pez sol	0,744	0,345	0	0,345	0,34	1%	95
	Rasbora	0,048	0,004	0	0,004	0,017	0%	5
	Rutilo	2,266	0	0	0	0,738	1%	207
	Siluro	0	97,81	0	97,81	27,614	47%	7739
	TOTAL	*5,816*	*170,1*	*2,018*	*170,1*	*50,708*	*86%*	*14.212*
TOTAL		**6,558**	**192,156**	**4,942**	**192,156**	**58,323**	**100%**	**16.345**

Most species show a preference for slow macrohabitat, whether they are native or non-native. Only *Barbus graellsi* (Ebro barbel), which is autoctonous, appear to have a preference for fast environments although there is little difference in terms of density with the slow ones. The result of this detailed characterization points to a clear correlation between the flow velocity and the dominance of native species, contrary to what is claimed in CHE (2008a).

3.5. - Other studies

3.5.1. - Application of the basic flow method by the University of Lleida

In CHE (2009a) a proposal of environmental flow regime at the Ebro River mouth is carried out by using the basic flow method with daily data from Tortosa gauging station between 1931 and 1968, prior to the commissioning of the large reservoirs in the lower Ebro, obtaining a base flow of 87 m^3/s.

As a preliminary proposal on environmental flows in the Ebro basin, before pending studies to be conducted by the Ministry of Environment, this result is rised up to 100 m^3 /s that, with its corresponding monthly distribution, becomes:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
117,5	134,5	149,3	150,3	139,2	136,9	153,9	148,4	127,9	100	100	100

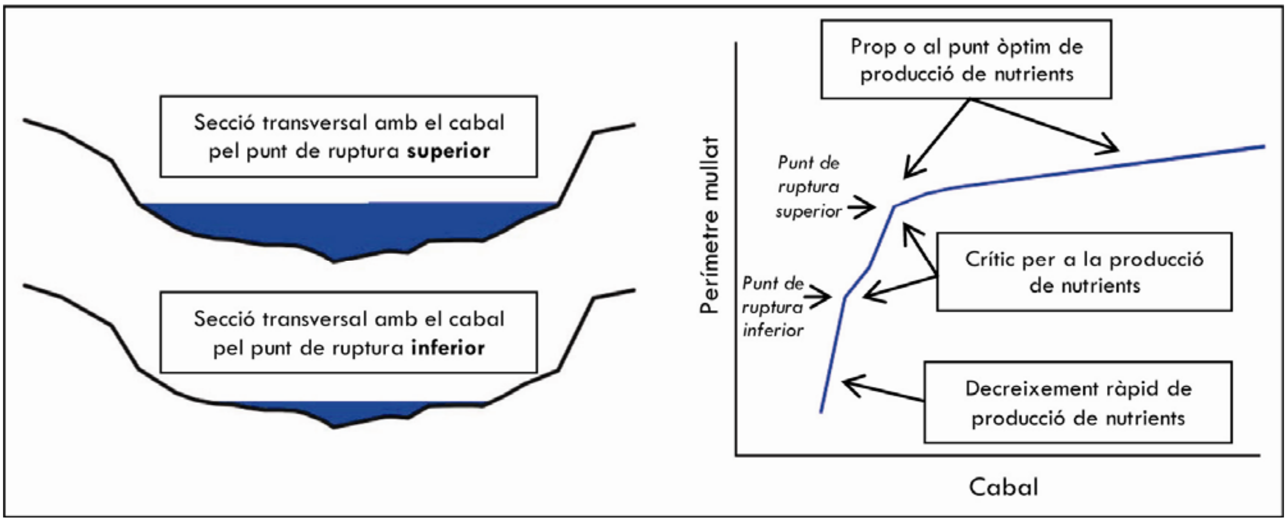
This represents an annual volume to meet the environmental needs of 4.094 hm^3/year, to which two controlled flooding events to reduce macrophytes, must be added.

Habitat simulation methods were used with the flows proposed in the river reach between Flix and Mora de Ebro, considering a combined preference curve that includes common barbel (*Barbus bocagei*) the Iberian nase (*Pseudochondrostoma polylepis*) and the Iberian chub (*Squalius pyrenaicus*) that, from the biogeographic point of view are suitable for the lower stretch of the river Ebro. The main conclusion from the application of such models is that, as it could be expected in this kind of rivers, "*habitat availability is hardly limiting from a certain minimum flow (probably on the order of 60-70 m^3/s) in a section with the geomorphology and hydraulics of the Lower Ebro. In other words and in view of the results, only flows about 40-50 m3/s would behave as allegedly limiting*" (CHE, 2009a, page 65). This supports the ample compatibility of the proposal in CHE (2009a) with the habitat needs set in the Planning Instruction.

3.5.2. - Hydraulic Simulation studies of the river channel in 1863

In Capapé (2010) and Capapé and Martin (2012) the hydraulic geometry is analyzed using the theory of cross sections regime of the river Ebro in 1863 taken from De Mesa (1865), and environmental minimum flows are estimated by applying the wetted perimeter method. This method is based on the representation of flow versus wetted perimeter. Regarding the shape of the curve, there is a sharp increase of the wetted perimeter at first while once a certain point is reached, the growth rate decreases abruptly. This point of rupture of the slope of the curve flow-wetted perimeter is identified with the flow required to protect the habitat (Figure 5).

Figure 5: Schematic representation of the wetted perimeter method (Capapé, 2010).



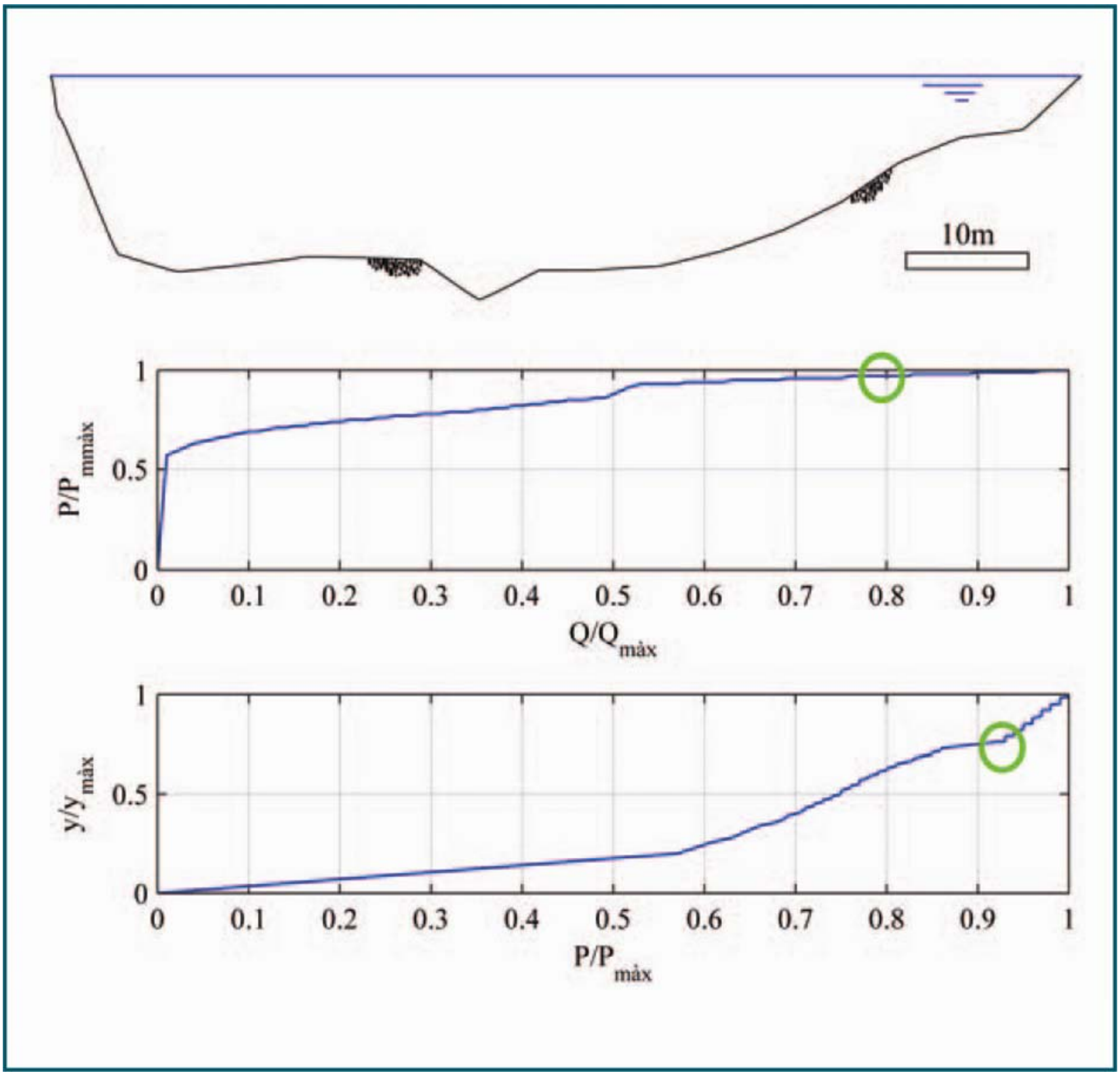
The application in the section of the river Ebro at Flix held in Capapé (2010) allows to obtain a minimum flow of 108.8 m^3/s, which corresponds to 80% of the flow gauged in De Mesa (1865) (Figure 6).

The key issues that can be highlighted in the research by Capapé are:

- The wetted perimeter method is one of the hydraulic methods for determining environmental flows and such methods are not considered in the methodology for determining environmental flow regimes set forth in the Planning Instruction.

- When applying the method in the longitudinal profile of Flix the criteria for selecting the breakpoint at P/Pmax = 0.8 are not clearly stated at are not clearly stated. In view of Figure 6 it would seem more logical the selection of the point at P/Pmax = 0.5, which would led to recommend a minimum environmental flow half of that reported by Pedro de Mesa: 136/2 = 68 m^3/s.

Figure 6: Curves flow (Q)-wetted perimeter (P) and wetted perimeter (P)-depth (y) of the river Ebro at Flix. The green circle indicates the point chosen to determine the minimum flow (80% of peak flow) (Capapé and Martin Vide, 2012).



3.5.3. - Proposal by UPM-COAGRET

In 2007 the School of Forest Engineers of the Technical University of Madrid was hired by the *Coordinadora de Afectados por Grandes Embalses y Trasvases* (COAGRET, Coordinating organisation of the Affected by Large Dams and Water Transfers) carried out a study with funding from the Ebro River Basin Authority (CHE, 2007b), which provides criteria for the implementation of environmental flows in the Ebro basin. A methodological proposal is made, based on the application of a hydrological method to series of daily flows. For dry years, it is adopted the flow obtained by 10th percentile of the smaller moving average for 90 consecutive days in each year of the period considered. For normal years the procedure is similar but with the 30-day moving average. The results obtained are due to be validated with habitat simulation methods.

The application of the method to the gauging station nº 27 River Ebro at Tortosa provides the following results:

Data in m^3/s

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
Dry year	57	104	134	155	153	199	181	160	124	61	45	49
Normal year	94	170	219	252	248	324	294	260	209	100	73	80

which represents a reserve for environmental needs of 3.733 hm^3 for dy years and 6.093 hm^3 for normal years and a minimum in low water months of 73 m^3/s in normal years and 45 m^3/s in dry years.

3.6. - Application of the methodology of the Hydrological Planning Instruction

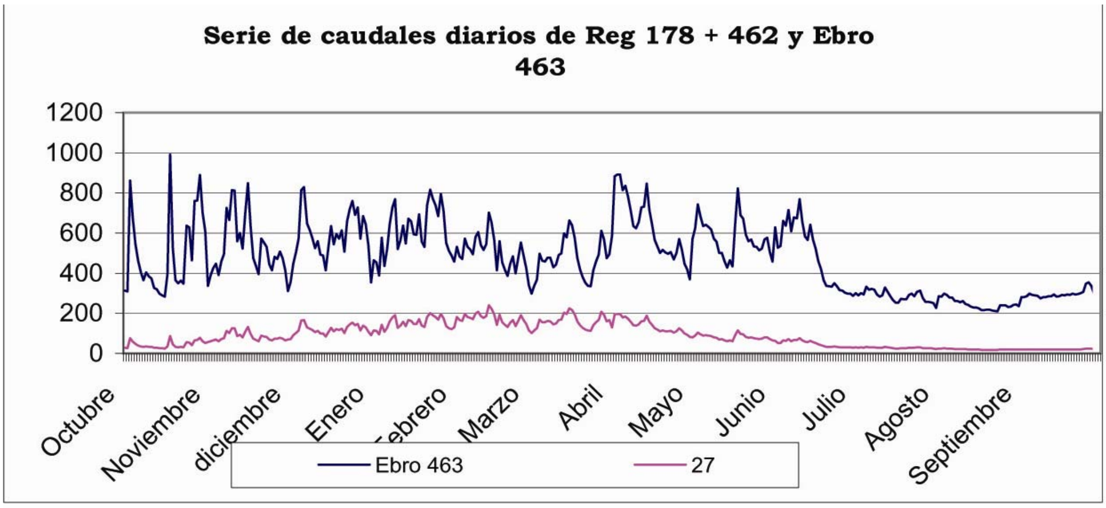
Once the Planning Instruction approved in 2008, the then-called Ministry of Environment, Rural and Marine Affairs awarded a study to determine the environmental flows of rivers of the Ebro basin. The study is entitled: "*Consulting and assistance in performing the tasks necessary for the Establishment of environmental flows and water needs in continental and transitional surface water bodies of the Spanish part of Ebro River Basin District, and the Segura and Jucar River Basin Districts. Technical Paper corresponding to the Ebro River Basin District*" (MARM, 2010). Completion is pending of the consultation process being made, although the technical phase in determining the environmental flow regimes is already finished. The summary of the technical data obtained from the study is included in Annex V of the Memory of the Draft Ebro RBMP (CHE, 2012b).

The first step when determining environmental flows was the estimation of minimum flows considering hydrological methods. The results for the water body where the gauging station nº 27 (Ebro at Tortosa) is located were:

- $Q_{\text{slope change}}$: 160 m^3/s. Method developed by Baeza (2004; in MARM, 2010) and identifies the flow rate at which there is a significant change of slope in the curve flow (moving average at different periods) - size of the interval (days of the period).
- $Q_{\text{25 days}}$: 167 m^3/s. It is the rate that has flowedd during the driest 25 days-period of the series.
- QBM_{average}: 174 m^3/s
- QBM_{median}: 164 m^3/s
- 5^{th} Percentile: 167 m^3/s. It is the 5^{th} percentile of the flow curve.
- 15^{th} percentile: 223 m^3/s. Is the 15^{th} percentile of the flow curve.

For the determination of these flows, the natural regime series SIMPA V2, developed by the Centre for Hydrographic Studies and covering the period October 1986-September 2006, were used. The natural regime series have a minimum monthly average flow in low waters (July to September) of 142 m^3/s in August 1994. To transform the monthly SIMPA series to daily, measured data from the gauging station nº 121 in the river Ebro at Flix were used, for the period between October 1948 and August 1964 (Figure 7).

Figure 7: Reconstruction of daily flow series for the water body 463 (River Ebro from the affluence of Canaleta River to Tortosa gauging station) in an average year used for the application of hydrological methods (MARM, 2010).



Comparing historical minimum flows as analysed in paragraph 3.2.1 together with the estimation of the flows in natural regime from the correlation with data from gauging stations undisturbed by significant uses, provides an estimate of the minimum flow in natural regime for the Ebro at Tortosa, substantially below 100 m^3/s. However the series SIMPA V2 used in MARM (2010) provides significantly higher flow values, suggesting that the minimum flows resulting from the application of this series may be over estimated.

In the framework of the Ministry study a review was conducted (MAGRAMA, 2012) for the application of hydrological methods using historical daily data from the nº 27 gauging station of the Ebro River at Tortosa, for the period 1951/52-1965/66 (Table XI). The following values were obtained:

- $Q_{25\ days}$: 76 m^3/s. It is the rate that has flowedd during the driest 25 days-period of the series.
- $QBM_{average}$: 74 m^3/s
- QBM_{median}: 49 m^3/s

The series of daily flows at Tortosa gauging station is made of real data measured before the construction of the great regulation works of the low Ebro and, although it can be considered to be affected by the water consumption, provide an acceptable reference for the application of hydrological methods for estimating environmental flows with series obtained from the application of mathematical models or any other approach. Therefore it can be concluded that the hydrological methods provide a range of values from 50 to 75 m^3/s.

Table XI: Average monthly flows (m^3/s) from the series of daily flows recorded at the gauging station of Tortosa, used as a contrast to the application of hydrological methods MARM (2010).

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
1951/52	356	545	406	738	1073	709	1161	726	465	295	206	200
1952/53												
1953/54	515	272	437	677	1273	929	425	730	524	171	86	107
1954/55	46	73	342	856	914	659	116	43	173	20	23	49
1955/56	152	332	422	784	550	869	886	866	666	176	131	191
1956/57	154	320	258	232	385	201	114	256	902	158	74	119
1957/58	181	146	161	313	468	862	696	293	122	105	31	82
1958/59	90	194	703	711	438	802	556	739	467	176	75	467
1959/60	656	1086	2171	1272	1595	1407	749	612	707	351	205	161
1960/61	1254	1216	1126	1983	1129	465	312	312	450	123	93	135
1961/62	424	1086	1069	1125	1056	1343	1050	586	425	137	31	67
1962/63	250	463	636	1027	625	768	965	380	455	285	461	413
1963/64	264	709	904	349	563	841	973	476	484	97	53	89
1964/65	270	283	526	659	472	886	426	208	111	102	50	107
1965/66	658	826	867	804	947	938	505	627	617	175	80	140
Average	376	539	716	824	821	834	638	490	469	169	114	166
Percentil 10	109	160	283	324	447	523	175	222	138	98	31	71
percentil 5	75	120	224	285	420	372	115	150	119	70	28	61
Minimum	46	73	161	232	385	201	114	43	111	20	23	49

The water body 463, where the gauging station nº27 of the river Ebro at Tortosa is located, is classified as hydrologically altered so that Planning Instruction allows the threshold of weighted usable area (WUA) acceptable for determining environmental flows is 30% instead of 50%, minimum threshold admissible for the non-altered water bodies (section 3.4.2 of the Planning Instruction).

The simulation of habitat suitability for the body of water463 that was made in MARM (2010) for a reach of the River Ebro in the vicinity of Benifallet and using as reference species the adult common barbel (*Barbus bocagei*) with the preference curve drawn by Martínez Capel (2000 in MARM 2010). The results indicated that a WUA of 30% may be achieved with a low flow rate of 2 m^3/s, a WUA of 50% at a flow rate of 3.4 m^3 , and a WUA of 80% with a flow rate of 15 m^3/s. As habitat suitability methods are to be adjusted with the results obtained with the application of hydrological methods (Section 3.4.1.4.1.1.3 of the Planning Instruction), there is a wide range of values available to establish environmental flows.

Finally, MARM (2010) provides a first approximation of environmental flows, taking into account the legal minimum flow previously established in the RBMP of 1998 for the mouth area:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
100	100	100	120	146,1	154,8	115	105	100	100	100	100

(*) Proposal pending of amendment from the review carried out in this work

representing an annual volume allocated to meet the environmental needs of 3.518 hm^3. In paragraph 4 of this repor, there is a review of the proposal of environmental flow regime from the technical study of the MARM, rendering the proposal of environmental flows at the mouth of the Ebro River which has been included in the Project Proposal for the Ebro RBMP 2010-2015.

4. - PROPOSAL OF ENVIRONMENTAL FLOW REGIME AT THE MOUTH OF THE EBRO RIVER PROVIDED IN THE PROJECT PROPOSAL FOR THE EBRO RIVER BASIN MANAGEMENT 2010-2015

4.1.- Introduction

With the baggage of all the relevant studies carried out by various governmental and research organizations on environmental issues affecting the definition of environmental flows in the lower Ebro, a proposal has been launched.

The main objective was to obtain an environmental flow regime that meets the criteria established in the current regulations (Government of Spain, 2007 and 2008), while taking into account all the possible environmental effects in the lower Ebro and the Delta.

4.2. - Inability to define environmental flows in prolonged droughts

In the lower Ebro, the following sites belonging to the Natura 2000 Network, which includes RAMSAR sites (Figure 8), have been declared:

- LIC[1] Ribera de l'Ebre a Flix-Illes de l'Ebre
- LIC & ZEPA[2] Sierra del Montsant-Pas de l'Ase
- LIC & ZEPA Sistema Prelitoral Meridional
- LIC & ZEPA Delta de l'Ebre

Article 18.4 of the Water Planning Regulations (Government of Spain, 2007) states that the environmental flows during prolonged droughts "*does not apply in the areas included in the Natura 2000 network or in the list of wetlands of international importance according with the Ramsar Convention*".

The impossibility to implement specific environmental flows in case of prolonged droughts in sites of community interest and special protection areas for birds, conditions its applicability in the Lower Ebro and, therefore, a single flow regime has been put forward.

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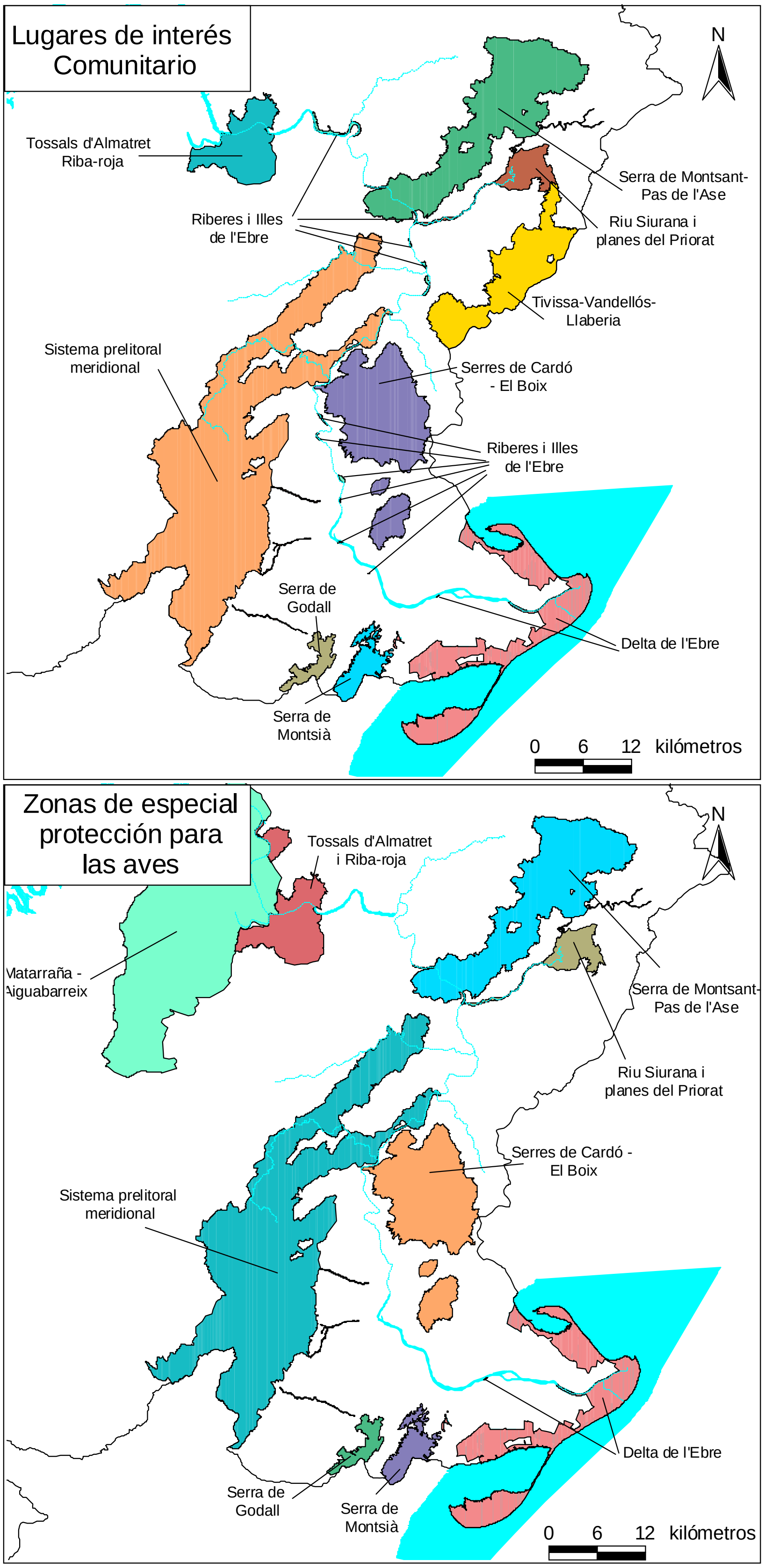
[1] Lugar de importancia Comunitaria – Site of Community Importance

[2] Zona de Especial Protección para las Aves – Special Protection Area for Birds

Figure 8: Sites of Community importance and Special Protection Areas for Birds declared in the Lower Ebro



4.3. - Environmental flow regime in the body of water 463

4.3.1. - Minimum flow in the environmental flow regime

When establishing the lower monthly minimum ecological flow, the results of habitat suitability modelization must be taken into account as the main criterion, even though other elements may be also relevant:

a) The Planning Instruction states that the main argument for determining the environmental flow regime come from the habitat suitability methods. The application of these methods in the lower Ebro has been made by different authors with sometimes uneven results. The differences between the various methods are mainly due to the preference curves considered (Table XII).

The water body 463 is a hydrologically altered water body (MARM, 2010) so that the species selected *as habitat indicators should have a WUA of 30% of the maximum usable area.*

One of the most important aspects in the implementation of this type of model is the preference curve to be used. The following have been applied in different studies so far:

-Three-preference curves for twait shad (*Alosa fallax*) taken from

+ ACA (2008a) using acoustic and visual observations in the reach located between the Cherta weir and Cherta.

+ CHE (2011b) by tagging and tracking by telemetry of individuals also in the reach between Cherta weir and Cherta.

+ MARM (2009) for the Minho River.

- Preference curve for *Barbo bocagei* (MARM, 2010).

- Combined cyprinids curve using information that can be considered representative of the environmental conditions in the lower Ebro (CHE, 2009a).

Table XII: Flow rates for different percentages of WUA assessed in the framework of various studies. Results obtained with ACA curves are shaded, giving substantially higher values than other curves.

Reference	Species	Weighted Usable Area (%)	Flow giving WUA (m^3/s)	Preference curves
ACA (2008a)	Twait shad	20 %	100	ACA 1 -ACA (2008a)
		63 %	252	
CHE (2011b)	Twait shad	30 %	13	Twait shad Ebro 1 - (CHE, 2011b)
		50 %	25	
		80 %	57	
		30 %	13	Twait shad Ebro 2 - (CHE, 2011b)
		50 %	24	
		80 %	60	
		30 %	<7	Twait shad spawning (CHE, 2011b)
		50 %	12	
		80 %	49	
		30 %	130	ACA 1 - ACA (2008a)
		50 %	233	
		80 %	555	
		30 %	85	ACA 2- ACA (2008a)
		50 %	135	
		80 %	294	
		30 %	<7	May 2009 - (MARM, 2009)
		50 %	<7	
		80 %	<7	
		30 %	<7	Mixed twait shad
		50 %	<7	
		80 %	91	
	Cyprinids	30 %	10	Mixed cyprinids - (CHE, 2009a)
		50 %	59	
		80 %	802	
CHE (2009a)	Cyprinids	Limitant conditions	40-50	Mixed cyprinids - (CHE, 2009a)
MARM (2010)	*Barbo bocagei*	30 %	2	(Capel, 2000)
		50 %	3	
		80 %	15	

Curves of preference:

- ACA 1: curve obtained in ACA (2008a) which exclude substrate preference.

- ACA 2: curve obtained in ACA (2008a) substrate preference taken from CHE (2011b).

- Twait shad Ebro 1: curve obtained in CHE (2011b) from twait shad tagging and tracking by telemetry for habitat characterization. Correction on positioning probability 1.

- Twait shad Ebro 2: curve obtained in CHE (2011b) from twait shad tagging and tracking by telemetry for habitat characterization. Correction on positioning probability 2.

- Twait shad spawning: curve obtained in CHE (2011b) from twait shad tagging and tracking by telemetry for habitat characterization. Correction on positioning probability 1.

- May 2009: preference curves developed for the Minho River in MARM (2009).

- Mixed saboga: Combining depth preference cureve from ACA (2008a) and substrate and speed curves in May 2009.

- Mixed cyprinids: autoctonous combined cyprinid curve by Capel (2000 and 2009) obtained in CHE (2009a).

The main conclusion is that all the curves reflect habitat preference to low values of flow according to Planning Instruction levels except from the twait shad curves obtained in ACA (2008a). The methodological effort made in CHE (2011b) to have preference curves with maximum degree of on-site specific information suggest a highest reliability to the results of the application of these preference curves than those in ACA (2008a). Moreover, the application of habitat simulation methods to other species provides consistent results with those obtained with curves drawn by CHE (2011b). Therefore it can be concluded that in view of the information used and regarding habitat availability the environmental flows in the lower Ebro are not a limiting factor even with rather low flows and that, therefore, it is possible to reduce the minimum flow from 100 m^3/s to much lower rates (even below 50 m^3/s) without producing significant effects on fish species.

b) The data of minimum flows available from historical sources (De Mesa 1985; Lorenzo Pardo, 1918 and 1931; Heraldo de Aragón, 1935) and the data recorded since 1913 in the gauging station nº27 (Ebro at Tortosa) show that in dry years, minimum summer flows in natural regime in Tortosa were in the order of 20-50 m^3/s, with occasional values below 10 m^3/s.

A rough estimate of the water consumption in the basin during the nineteenth and the first half of the twentieth century, together with the estimation of flows in natural regime based on its correlation with data from gauging stations with a regime not disturbed by significant uses, allows to assess that minimum flows in natural regime could be significantly less than 100 m^3/s.

The estimation of flows under natural regime has been a complex and difficult question because there is no information to properly validate the estimates made by the different authors.

c) The application of hydrological methods in the lower Ebro has provided different minimum flow rates depending on the application carried out by the authors (Table XIII). These values range from 45 m^3/s and 131 m^3/s with an average value of 81 m^3/s. The application of these methods is always under discussion especially for the series used (Sánchez, 2004). The Planning Instruction makes it clear that the main criterion for determining minimum flows are the habitat suitability methods since the application of hydrological methods provides a very wide range of minimum flows.

Table XIII: Minimum Flow (m3/s) obtained from the application of hydrological methods by different authors

	Methods using series measured at Tortosa gauging station		Methods using reconstructed series
	QBM Method	Others	
Historical	i		70-100
MIMAM (2000)	80		
OPH-CHE (1999)	45		
MARM (2003) in Sánchez (2004)	72		
Sánchez (2004)			131
CPIDE (2003)	70		
IRTA dry years in ACA (2007)			87
Franquet (2009)		118	
University of Lleida in CHE (2009a)	87		
UPM-COAGRET Dry in CHE (2007b)		45	
MAGRAMA (2012)		74	
Average(*)	**81**		

(*) The average of all minimum flows has no statistical significance for defining the minimum flow, included only for descriptive purposes.

d) An analysis of regulations for other deltas and estuaries in the world with similar characteristics to the Ebro basin havs been carried out. Flow rates have been obtained as a percentage of minimum flow in low waters months with respect to average flow in natural regime.

Applying these percentages to the average annual discharge of the Ebro basin in the period 1940/2006 (522 m^3/s - 16,448 hm^3/year) provides environmental flow values for the lowest flow month (Table XIV) which would apply to the Ebro basin so allowing comparison with the level of regulatory requirements in other basins.

The traslation of the level of environmental requirements for the rivers of the Internal Basins of Catalonia to the Ebro River would result in minimum of 80 m^3/s while in relation to the average of all the analysed rivers, this would mean a minimum flow of 72 m^3/s.

Table XIV: Minimum Environmental flows in the lower Ebro by assimilation with those established in other basins with similar hydrologic conditions. These are regulatory flows and in many of the basins, planned for future application even so there are actual difficulties (eg. rivers Po and Internal Basins of Catalonia, among others)

Basin assimilated to Ebro	Percentage of minimum flow rate from the average natural regime in long period	Environmental flow estimate for the lower Ebro basin by assimilation with corresponding one
	%	m^3/s
La Muga	17,2	90
Fluvià	19,8	103
Ter	17,0	89
Daró	6,5	34
Tordera	6,7	35
Besòs	14,2	74
Llobregat	16,4	86
Foix	22,4	117
Gaiá	16,6	87
Francolí	11,4	60
Riudecanyes	18,9	99
Minho River at the mouth	13,7	72
Júcar River at Marquesa Weir	1,9	10
Guadalquivir River in Alcalá Dam	4,0	21
Garonne River (France)	14,5	76
Garonne River (France) critical years	5,4	28
Po River Delta (Italy)	30,2(*)	158(*)
Sacramento River	9,7	51
San Joaquín River	28,4	148
Colorado River Estuary	1,3	7
Promedio	**13,81**	**72**

(*) There is uncertainty about the actual enforcement of the regulatory minimum flow

The Integration of all the criteria for determining environmental flows for the waterbody 463 and especially the methods of habitat suitability support the adoption, taking into account the precautionary principle, a minimum flow of 50 m^3/s.

The water availability scenarios in the RBMPs have been:

- In the RBMP 1998, there were used series for the period 1940-1986 for the allocation of resources in natural regime, which estimated a total annual resource for the basin of 18.217 hm^3 (CHE, 1996).

- In the RBMP 2010-2015 and for the period 1940/2006, it is estimated a total annual resource of 16.448 hm^3 (CHE, 2012B), representing a reduction in the average expected discharge up to 10%. The decrease is due to the incorporation of the period 1986/2006 which, being drier than the period 1940/1986, causes a significant decline in the average.

- However, following the Planning Instruction (Government of Spain, 2008) in the RBMP 2010-2015 hydrological calculations were performed using the period 1980/2006. This represents an annual average discharge of 14.623 hm^3, meaning a 20% reduction in relation to the discharge in the RBMP 1998.

- It must be kept in mind that the incorporation of the effects of climate change is estimated considering a reduction of 5% of the resources in the case of the Ebro basin, representing an annual average discharge of 13.892 hm^3, which represents a 24% decrease in relation to the RBMP 1998.

Despite the decline in water resources due to the time series to be used according to the provisions of the Planning Instruction and the expected effects of climate change, it has been considered feasible to increase the minimum flow up to 50 m^3/s.

The fact that the lower reach of the River Ebro may have higher flow rates due to the existence of the Lower Ebro reservoirs system of Mequinenza-Ribarroja-Flix, together with the availability of resources from efficient water management carried out in the Ebro basin in the Ebro basin, makes it possible a significant increase of the minimum flow.

In the RBMP 1998 it was provisionally established and with regard to future concessions a constant flow rate of 100 m^3/s at the mouth of the Ebro. Although this rate was not backed by technical criteria, there was a consensus within the River Basin Water Council. The preservation of this consensus, as well as the evolution of the delta in recent years, suggests that the flow at the mouth of the Ebro should be similar to that set in the RBMP 1998. To achieve around 100 m^3/s at the mouth, it is necessary to increase the flow in Tortosa from 50 to 80 m^3/s.

This increase from 50 to 80 m^3/s could be reconsidered according to the availability of resources from the regulation system Mequinenza-Ribarroja-Flix.

4.3.2. - Monthly modulation

The main criteria to establish monthly modulation were:

- The minimum ecological flow is 80 m^3/s as concluded in the previous section.

- The annual volume allocated for environmental needs is around 3,000 $hm^3/year$ so that, with the other elements of the environmental flow regime (flood flows, environmental flows in channels and groundwater discharges) environmental water allocation at the mouth of the River Ebro is above that established for guidance purposes in the RBMP 1998.

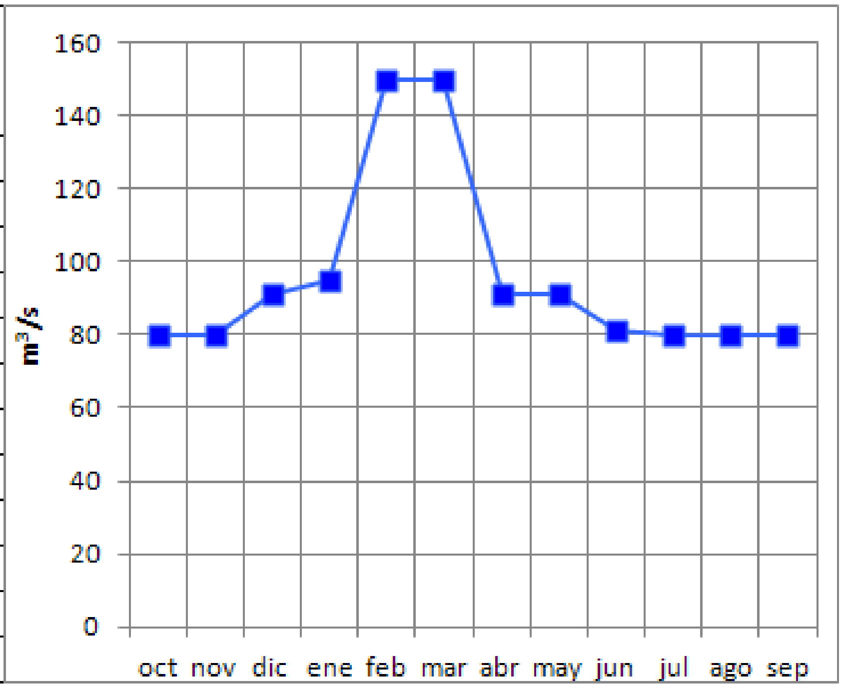
- Monthly modulation should approach the minimum flows recorded in the gauging station nº27 (Ebro at Tortosa) in the periods prior to the commissioning of the Mequinenza-Ribarroja-Flix reservoirs

- Monthly maximum flow should be maintained at 150-155 m^3/s as established in MARM (2010).

Considering all these criteria the proposal of environmental flow regime for the water body 463 (River Ebro from River Canaleta to Tortosa gauging station) has been established as shown in Figure 9. A minimum flow of 80 m^3/s is set for the months of June to November and a maximum flow of 150 m^3/s is set for February and March. This regime represents an annual volume of 3,010 hm^3.

Figure 9: Environmental flow regime for the water body 463 as proposed in this paper.

	Propuesta revisión este trabajo m^3/s
oct	80
nov	80
dic	91
ene	95
feb	150
mar	150
abr	91
may	91
jun	81
jul	80
ago	80
sep	80



4.3.3. - Flood flows

The environmental flow regime in the lower Ebro incorporates the release of flood flows with the objective of reproducing a more natural flow regime as well as hindering the proliferation of macrophytes in the river. These floods have been applied from 2002 (Table XV).

In CHE (2010d) the effects of floods have been described and analyzed. Flood design is changing according to the improved knowledge of the impact they have on macrophyte populations. They usually last for 8-10 hours with peak flows ranging from 1,000 to 1,500 m^3/s.

In CHE (2010d) all these controlled floods have been collected, as performed in recent years: two floods with a maximum flow of 1,350 m^3 an estimated duration of about 10 hours. In any case, the design of these floods must vary according to the circumstances of each moment and the hydrological knowledge that is being acquired on the effects of these floods in the population of macrophytes and other aspects under analysis.

Table XV: Maximum flood flows registered in the period 2001/2010 CHE (2010d).

Date	Maximum flow of the flood (m3/s)	Origin of the flood
5-9/12/2002	1.346	Controlled
2-12/2/2003	2.376	Natural
27/2/2003-10/3/2003	1.900	Natural
8-12/5/2003	1.440	Natural
5-9/12/2003	1.194	Controlled
13-15/3/2006	1.526	Controlled
4/5/2006	1.498	Controlled
28/3/2007-21/4/2007	2.050	Natural
28/5/2007	1.042	Controlled
8/11/2007	1.235	Controlled
15/5/2008	1.261	Natural
26/5/2008	2.142	Natural
3-6/6/2008	1.562	Natural
29/1/2009-16/2/2009	1.110	Natural
18/5/2009	1.065	Controlled
21/10/2009	1.120	Controlled
15-17/1/2010	1.345	Natural
20/5/2010	1.171	Controlled
4/11/2010	1.172	Controlled
30/5/2011[(a)]	1.350	Controlado

(a) Personal communication from CHE Quality Area

4.4. – Environmental flow regime at the Ebro River mouth

The environmental flow regime proposed in CHE (2012b) takes into account, in addition to the above, the circulating flows discharged to the Delta through the channels of the left and right margin of the Ebro with environmental purpose, notwithstanding the precedence of water rights attended by these channels, as well as the natural discharge of groundwater. At the mouth of the River Ebro (as defined in the RBMP 1998) the estimated values ar the following:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
80	100	100	120	150	155	100	100	100	100	100	80

Representing a volume allocated for environmental needs of 3,370 hm^3/year. This volume is above that established for guidance purposes in the RBMP 1998 estimated in 3,154 hm^3/year.

The environmental flow regime will be implemented without prejudice to other circulating flows that also have an environmental function.

4.5. - Compatibility of environmental flows with other environmental issues in the lower reaches of the Ebro River and the Delta

4.5.1. - Subsidence and sediments

According to various authors (Albert, 1989; Canicio and Ibañez, 1999; Molinet, 2006) the formation of the delta started with a postglacial eustatic rise in sea level several thousand years ago. Consequently the river lost transport capacity depositing the coarse sediments that form the basis of delta (Figure 10).

The evolution of the Ebro Delta has responded primarily to factors linked to human activity. As stated in Garcia and Lopez (2009), the size of the Delta has increased as deforestation in the Ebro Basin advanced. 2000 years ago the coastline was in Amposta. The maximum period of delta progradation occurred between the fifteenth and nineteenth centuries, coincident with the general expansion of cereal cultivation and grazing in the Ebro Basin. The Little Ice Age, with subsequent recovery of geomorphic processes is also likely to have had an influence. In the late nineteenth century the Delta reached its peak when rural population reached its maximum development and very marginal areas were cultivated.

The recent decline in sediment delivery to the delta is caused by two factors: a) the increase of forest land in the Ebro Basin throughout the twentieth century due to forest policy and, above all, the abandonment of rural areas meaning less pressure on firewood, and b) the construction of large dams.

The estimation of sedimentation rates in the Ebro basin has been the subject of numerous studies, eventually collected in a very comprehensive and detailed study by Garcia and Lopez (2009). This report includes a description of the data obtained in experimental plots nationwide and data on sediment production obtained from bathymetric surveys in the reservoirs of the Ebro Basin.

A summary of the data collected in Garcia and Lopez (2009) in Spanish experimental basins gives an idea of the distribution of erosion rates based on the different characteristics of each basin under study (Table XVI). It may be observed that the distribution of values is highly variable with rates below 1 ton km^{-2} yr^{-1} in Mediterranean forests with high coverage that protects soils and maximum rates around 60,000 tons km^{-2} yr^{-1} in areas with highly erodible carved channels. The median of all the specific degradation rates from the experiences collected is 120 tons km^{-2} yr^{-1}.

Figure 10: Evolution of the Ebro delta (drawings adapted from Canicio and Ibanez, 1999, in Molinet, 2006)

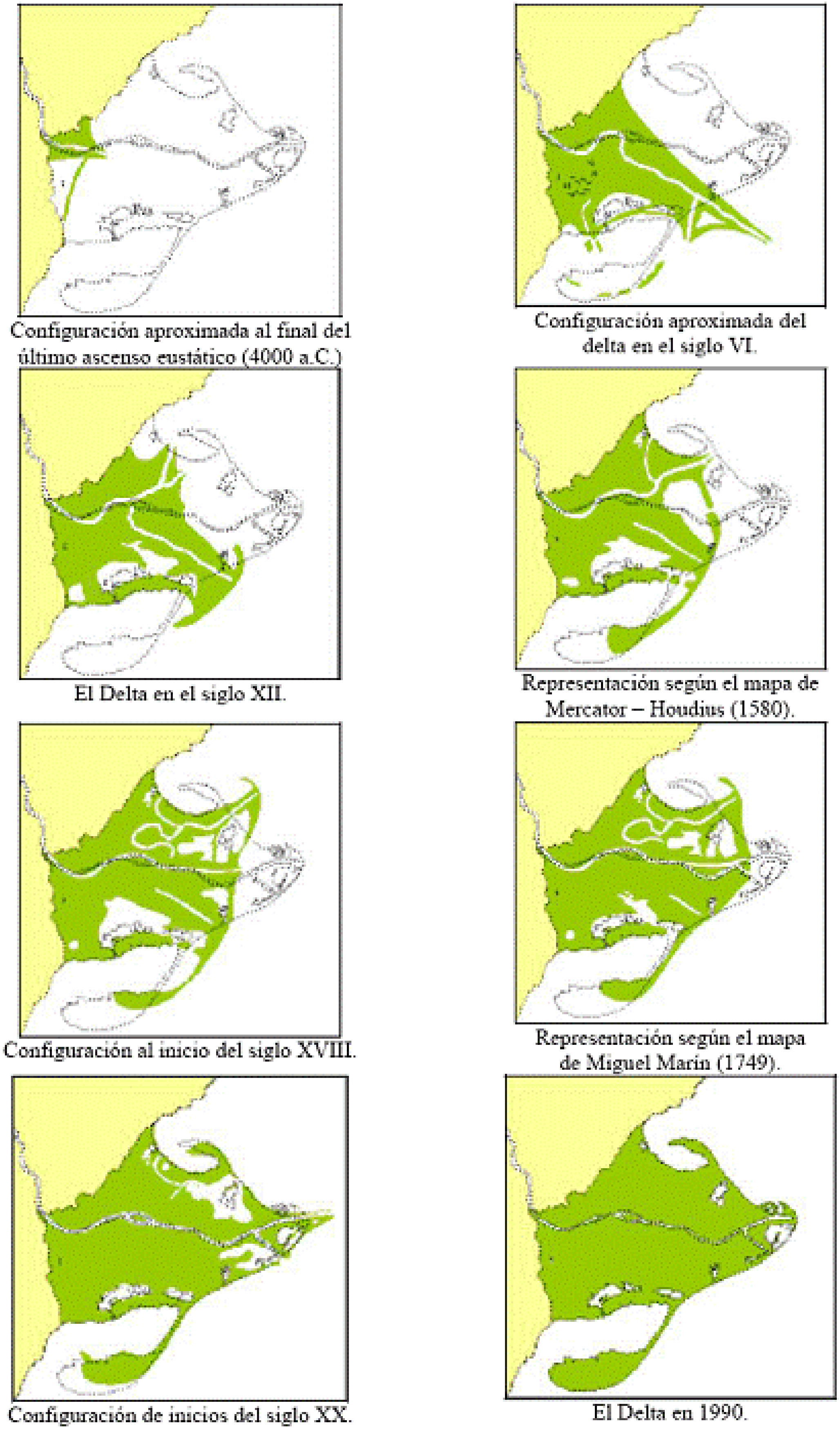
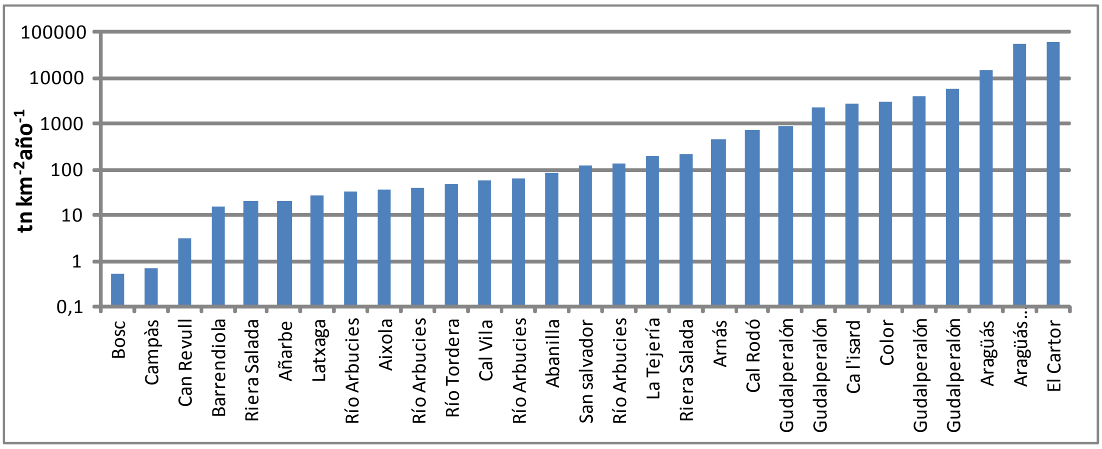


Table XVI: Specific degradation rates in experimental basins compiled by Garcia and Lopez (2009). Own elaboration. **[translation?]**

Cuenca	Superficie km^2	Degradación específica tn km^{-2}año^{-1}	Descripción
Bosc	1,6	0,5	Bosque mediterráneo
Campàs	2,4	0,7	Bosque y un 10 % de cultivos
Can Revull	Pequeña	3,1	Cultivos cerealistas junto a algunos cultivos arbóreos en bancales. Este suelo ha sido drenado desde antiguo mediante canalizaciones subsuperficiale para favorecer la aireación y el cultivo
Barrendiola	4,8	15	Elevada proporción de bosque autóctono con algunas manchas de reforestado
Riera Salada	222	20	Bosque (75 %) y áreas agrícolas (25 %)
Añarbe	48	21	Elevada proporción de bosque autóctono con algunas manchas de reforestado
Latxaga	2,07	28	Ambiente cultivado, cuenca alargada y cauce cubierto de vegetación
Río Arbucies	106	32	Afluente del Tordera
Aixola	3	35	Buena densidad de cubierta pero muy alterada por la reforestación y las frecuentes talas
Río Arbucies	106	38	Afluente del Tordera
Río Tordera	894	50	
Cal Vila	0,56	55	Flysch eoceno. Campos abandonados y bosque (elevada cubierta vegetal)
Río Arbucies	106	62	Afluente del Tordera
Abanilla	0,000759	84	Cuenca río Chícamo (Murcia). Vegetación dispersa y baja pendiente
San salvador	0,92	120	Flysch eoceno. Bosque
Río Arbucies	106	132	Afluente del Tordera
La Tejería	1,69	197	Ambiente cultivado, cuenca redondeada y cauce sin vegetación
Riera Salada	222	210	Bosque (75 %) y áreas agrícolas (25 %)
Arnás	2,84	450	Cuenca abandonada en mitad siglo XX y en proceso de recolonización vegetal
Cal Rodó	4,17	710	bosques, prados y terrazas
Gudalperalón		920	Dehesa. Cubierta de encina y sitios coluviales
Gudalperalón		2210	Dehesa. Laderas
Ca l'isard	1,31	2800	cárcavas, bosques, prados y terrazas
Color	0,000328	2980	Vegetación dispersa y alta pendiente
Gudalperalón		4110	Dehesa. Cárcavas de fondo de valle
Gudalperalón		5850	Dehesa. Áreas con más del 50 % de suelo desnudo
Aragüás	0,45	15300	Margas eocenas en el tramo inferior y flysch en el superior. Cárcavas que acompañan al afloramiento de margas y cabecera reforestada con pino.
Aragüás (sólo Cárcavas)		57500	Cárcavas
El Cartor	0,06	60000	cárcavas
Mediana		**120**	
Mediana		**5308**	



Other relevant information to evaluate large-scale erosion rates comes from the data on silting in reservoirs. Table XVII has compiled the information available on this aspect. There is a significant dispersion of values, with the lowest recorded in the La Tranquera reservoir with 8 tons km^{-2} yr^{-1} and higher in the Pena reservoir (Matarraña basin) with 1,300 tons km^{-2} yr^{-1}. A weighted average in relation to the surface of the watershed renders a value of 120 tons km^{-2} yr^{-1}.

Table XVII: Specific degradation rate obtained from the analysis of the siltation of reservoirs in the Ebro basin

System	Catchment	Erosion	Erosion rate	Source
	km^2	tn $year^{-1}$	tn $km^{-2}year^{-1}$	
Yesa	2.185	2.240.000	1.025	López Moreno et al (2003)
Yesa	2.185	624.000	286	López Moreno et al (2003)
Barasona	1.512	437.000	289	Sanz Montero (1996)
Terradets	2.426	560.000	231	Van Deek et al (1991)
Tranquera	1.870	15.708	8	Avendaño et al (1996)
Santolea	1.221	21.978	18	Avendaño et al (1996)
Cueva Foradada	644	113.256	176	Avendaño et al (1996)
Santa María de Belsué	190	41.040	216	Avendaño et al (1996)
Oliana	2.694	662.724	246	Avendaño et al (1996)
Barasona	1.250	437.500	350	Avendaño et al (1996)
Sotonera	323	362.083	1.121	Avendaño et al (1996)
Pena	64	82.752	1.293	Avendaño et al (1996)
Mequinenza until 1966-1982	51.000	3.766.055	74	Varela et al (1986)
Mequinenza until 1983-2008	51.000	2.490.120	49	Palau (2008)
Weighted average by catchment			127	

Note: López Moreno et al (2003), Sanz Montero (1996) and Van Deek et al (1991) have been consulted in Garcia and Lopez (2009).

The amount of sediments discharged by the river Ebro at its mouth has undergone several assessments. The figures provided in Guillén et al (1992, in Garcia and Lopez, 2009) may be highlighted, distinguishing three periods:

- Prior to the construction of reservoirs, when degradation could range from 400,000 to 2,000,000 tons yr^{-1} (between 5 and 24 tons km^{-2} yr^{-1}).
- In the '60s, after the construction of reservoirs, the rate was reduced to values ranging from 40,000 to 200,000 tons yr^{-1} (between 0.5 and 2.4 tons km^{-2} yr^{-1}).
- Currently, erosion is estimated to be around 1,600 tons yr^{-1} (0,02 tons km^{-2} yr^{-1}).

These results are consistent with those in Varela et al (1996), which measures the sediments volume in Mequinenza and Ribarroja reservoirs in the period between its construction and a bathymetric survey carried out by CEDEX in 1982. The silting of these reservoirs is indicative of sediment deposition that substantially coincides with the discharges to Delta prior to the construction of dams. The average contribution through the basin is 115 tons km^{-2} yr^{-1}. With the construction of Mequinenza and Ribarroja dams, contributions to delta decrease by 94%.

Ibáñez et al (1996) also gives values of sediments discharged by the river in the Ebro delta which are greater than those estimated in Guillén et al (1992), with a value of up to 30 million tons year^{-1} (350 tn km^{-2} years^{-1}) before construction of the Mequinenza and Ribarroja dams, 10,000,000 tons yr^{-1} (200 tons km^{-2} yr^{-1}) in the late 60s, which decreased progressively until the amount of 100,000-200,000 tons yr^{-1} (1-2 tons km^{-2} yr^{-1}).

During the past decade more studies of erosion in the lower Ebro have been conducted. The main ones are those of Vericat and Batalla (2005a, 2005b, 2006) in which:

- The effect of the Mequinenza and Ribarroja dams on the avenues between 2000 and 2004 are analysed, highlighting that these reservoirs retain most of the sediments and that in the lower Ebro a process of fluvial incision is under progress with average of 30 mm/year in the stretch of 27 km downstream of the Flix dam.

- Each year the lower stretch of the Ebro River transports 450,000 tons, of which 60% are suspended materials and the remaining 40% is bedload. This represents 3% of the materials transported by the Ebro River in its lower reaches at the beginning of the Century.

In ACA (2009a) sediment samples carried by the river Ebro at Tortosa were taken during 8 months between March and September of 2008 and an assessment of the current sedimentary deficit of the fluvial system to compensate regression processes and subsidence of the Ebro Delta was made. It was concluded that during the hydrological year 2007/2008 133,452 tons were exported, 89% of which were transported as suspended matter and the rest as bedload. This export occurs primarily during the spring (90% of the sediment) and during flood events (73% of total exports).

The decrease in sediment discharge in the second half of the twentieth century is a clear determining factor for the evolution of the Ebro Delta. Some authors have highlighted the potential impact of this threat (Ibáñez, 1993; Ibáñez et al., 1999; Prat, 2001).

A still unresolved issue is the quantification of the degree of overall subsidence that is currently undergone by the Ebro Delta. Several authors have provided some figures:

- 1 mm/yr, assuming a rate of subsidence similar to the area of Marseille and the Camargue in the Rhone Delta (Sánchez-Arcilla et al, 2005).

- 2-3 mm/yr in Ibáñez et al (1997, in Ibáñez et al, 1999)

- 1.5 to 2.6 mm/yr in ITGE (1996) from the comparison of relative curves of changes of sea level obtained in the Ebro Delta and other nearby areas. This is performed by absolute dating of the peat deposits (assuming these have sedimented in marsh areas, ie, at sea level).

- 1.75 mm/year Somoza et al (1998, in Molinet, 2006). By comparing deposits in the Ebro Delta with others in the Spanish Mediterranean coast. The estimated subsidence rates correspond to an average value of the last 7,000 years, although this figure has varied over time.

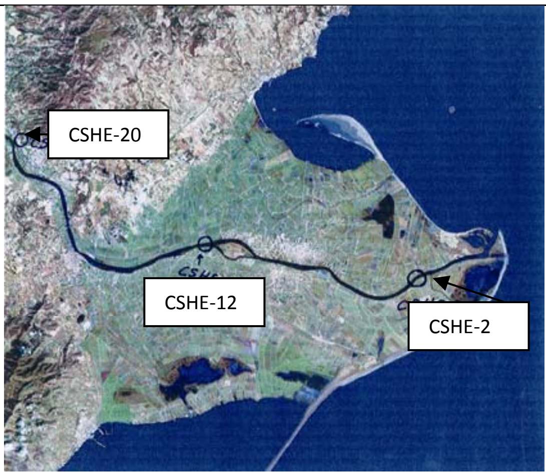
Some authors have studied the evolution of the delta from tests in experimental plots in a scenario of agricultural abandonment (Ibáñez et al, 2010). It is argued that the natural growth of vegetation in them can cause vertical accretion to offset the effect of subsidence and rise of sea level.

Regarding the determination of the degree of subsidence a detailed topographic survey was recently performed (CHE, 2012C) in two topographic reference sites in the channel of the left bank of the river Ebro that were installed during the construction of this infrastructure in 1927 (Figure 11) (CSHE, 1927).

The difference in height level between 1927 and 2012 (Table XVIII) clearly highlights that there has been a process of subsidence since 1927. In the framework of the study CHE (2012C) it has been established a new network of reference sites that allow performing precision topographies in future campaigns.

New precise leveling campaigns in the Ebro Delta will be carried out in order to detect and prove the existence of a widespread process of subsidence. However in view of the available results, for now the delta is stable in terms of subsidence. Therefore, although the current situation has led to a very significant decrease in sediment discharge in the Ebro Delta, it does not seem that this has caused a significant problem of subsidence but a stabilization of the deltaic building.

Figure 11: Location of topographical references installed in 1927 during the construction of the canal on the left bank of the Ebro delta and identification in 2012.



a) Map showing the position of the marks that have been preserved since the construction of the canal in 1927


b) Location of the reference CSHE-20


c) Location of the reference CSHE-12


d) Location of the reference CSHE-2

Tabla XVIII: Elevation measured in the benchmarks of the Channel of the left bank of the Ebro Delta in CSHE (1927) and CHE (2012c).

	Elevation in 1927	Elevation in 2012	Differences
	meters		cm
CSHE-20	5,911	5,911	0,0
CSHE-12	3,743	3,789	4,6
CSHE-2	2,375	2,328	-4,7

4.5.2. - Morphological modification

4.5.2.1. - River Ebro from Ascó to Tortosa

The behavior of the Ebro River section has undergone major changes during the twentieth century. Comparison of aerial images from 1927 to 2002 allows us to observe the differences in the characteristics of the channel (Figure 12a and b). Changes as the increase in temperatures occurred at the end of the century, the decline in river due to the increases both in forest area and water uses and, especially, the regime modification in the river Ebro as a consequence of the construction of the reservoirs of Flix (11 hm^3 in 1948), Mequinenza (1,534 hm^3 in 1966) and Ribarroja (210 hm^3 in 1969), have conditioned the evolution of the characteristics of the river channel.

Sanz et al (2001) performed a study based on aerial photographs from 1927, 1946, 1956, 1982, 1987 and 1997. With the support of field data from the current situation of the Ebro channel, the main processes that have shaped the morphology of the river are described and the following conclusions are set:

- Prior to the construction of reservoirs, from the study of the photographs of 1927, 1946 and 1956:

  + The evolutionary dynamics of the Ebro River was controlled by extreme floods. There were two extreme events in 1937 and 1961, which caused profound changes in the morphology of the river (bank erosion while sedimentation and remodeling of large bars).

  + In the Ebro River channel upstream of the confluence of Ciurana River, floods had no morpho-sedimentary effect, being all the adjustments observed downstream of this point. This fact highlights the prominent role that Ciurana has played in the remodeling of the Ebro channel, providing sediments and liquid. In fact, both the volume of the bar and the particle size significantly increases downstream of the mouth of Ciurana. It is therefore worth noting the important role of Ciurana River Basin in the geomorphological evolution of the Ebro River This following reservoirs were built in this basinthe following: Ciurana (12.4 hm^3 in 1972), Guiamets in Asmat River (10 hm^3 in 1975) and Margalef (3 hm^3 in 1995).

  + Most of sediment reaching the Ebro Delta originates during very energetic events such as sporadic floods and storms.

Figure 12a: Comparison of images of the Ebro River floodplain in the area Benissanet Mora d'Ebre (CHE, 2008c).

Figura 12b: Comparison of the images of the Ebro River floodplain in the area Benissanet Mora d'Ebre (CHE, 2008c).

- After construction of reservoirs and from the analysis of aerial photographs taken in 1982, 1987 and 1997:

+ After the commissioning of the reservoirs in Ciurana and lower Ebro there has been a drastic reduction in the load of suspended solids and bedload materials.

+ As a result, the river channel has changed in two main aspects:

* Armoring. This armoring occurs when clean water released from dams is able to wash fine sediments, but lack enough energy to wash the gravel. The formation of this shell of thick gravel, which can be broken only by very high flows, has prevented a generalized process of fluvial incision (contrary to what is described by Vericat and Battle, 2005a). This process has only been detected in the vicinity of Flix, but in a very limited way so that number and position of the previously existing bars reamins the same, due to the presence of large clasts that have protected and stabilized the channel under the new conditions of discharge and slope.

* Extensive development of vegetation. This development has been favored by the flow regulation, which ensures the preservation of seeds and the growth of plants. This cover has brought stability to the underlying sediments, reducing bank erosion and protecting the escarpment of the floodplain, which has not experienced a significant set-back.

+ These modifications generated by the reservoirs affect, with equal intensity, the 40 kilometers downstream of Fliz assessed, so it is reasonable to consider these changes also affect the entire lower stretch of the Ebro River up to the mouth.

+ Changes in channel conditions occurred in a short time. Aerial photographs taken in 1982 show that the channel was already stabilized, and until now it has remained without remarkable changes. Currently the Ebro River has reached equilibrium within the new conditions introduced by the reservoirs and other human-driven changes.

The effect of the hydrological regime regulation caused by dams in the stabilization of the channels and in favoring the development of a strip of riparian vegetation has been clearly described for the middle stretch of the river Ebro in Magdaleno (2011) and its findings can be also valid for the lower Ebro. A strecht of 250 km (from Rincón de Soto to La Zaida) has been studied, detecting a large increase in flow during the summer months compared to the current regime in the early twentieth century. This has led to intense changes in the morphology of the river leading to channel stabilization with a width loss and the disappearance of many of the inner islands. Riparian vegetation reacts quickly to the new situation colonizing virtually all the original active channel. The original mosaic type distribution has changed to a linear and continuous one that has grown much closer to the permanent channel. The maintenance of higher minimum flows from reservoirs has also had an important role in these changes in teh riparian vegetation. The restoration of these stretches should go through the recovery of the magnitude, variability and seasonality of summer flows.

The proposal of environmental flow regime for the lower Ebro held in CHE (2012b) includes these ideas, intending to recover of the original modulation, with higher flow rates both in periods of low and high waters.

4.5.2.2. - Ebro Delta

The evolution of the Ebro delta has been, since its origin, very dynamic in response to the factors that determine their characteristics. These factors are mainly the discharge of river sediments, the wave and tidal dynamics and the elevations of sea level.

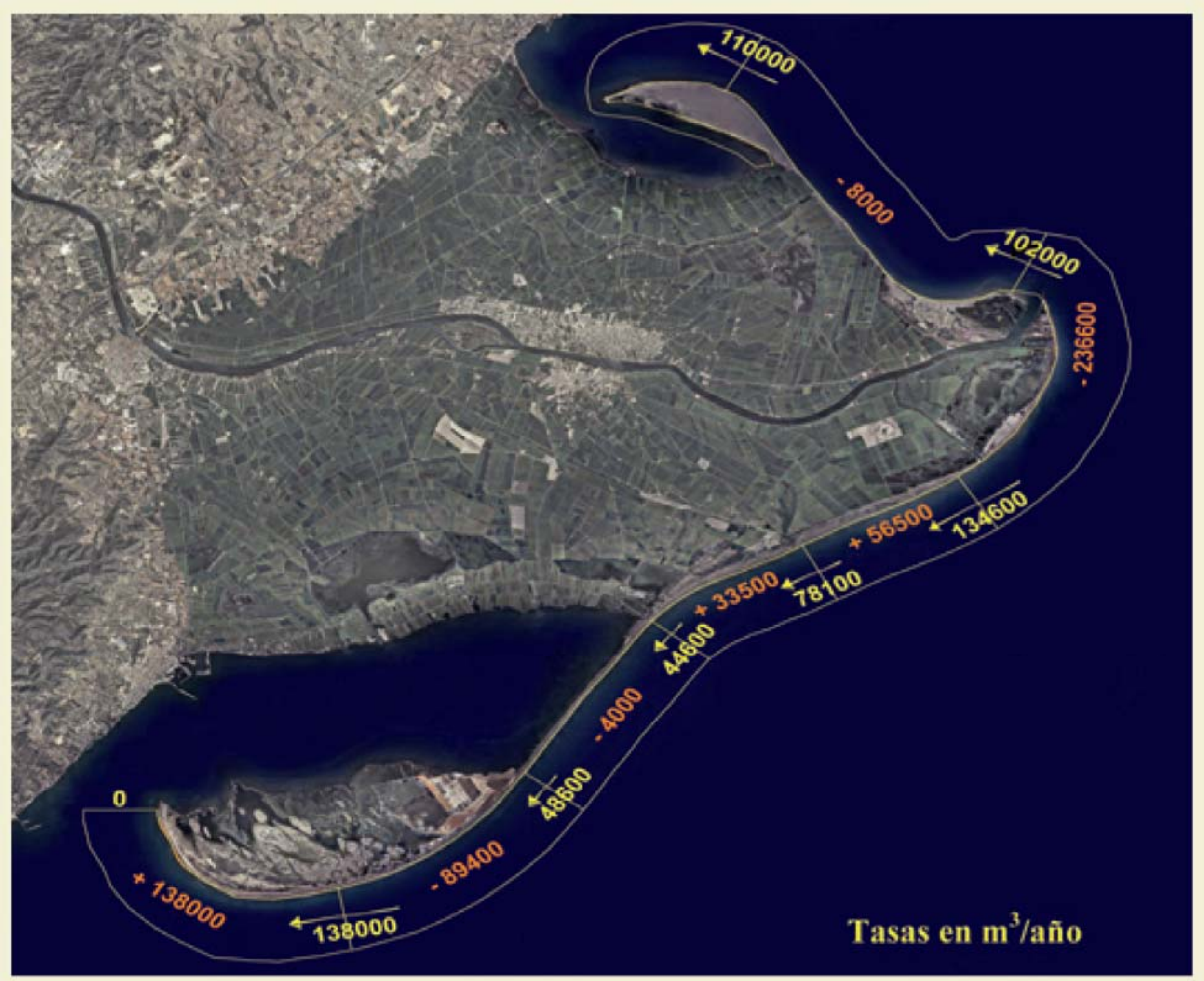
Given its particular characteristics, the main factor that has conditioned the development of the delta has been the river sediments, with a close link between the sediments discharge and the growth rate of the delta. Historically, these changes have been driven by climatic conditions (cold periods with less vegetation and therefore increased runoff and erosion; warm periods with more vegetation and therefore less runoff and erosion) and human factors related especially to deforestation, which has conditioned a higher rate of erosion and therefore a higher sediment discharge to the delta.

These factors justify the historical evolution of the shape of the delta. After the second half of the twentieth century the construction of large dams across the Ebro basin –and especially the Mequinenza Ribarroja-Flix system– provoked a decrease in sediment inputs that, in turn, caused an adaptation of the morphology of the Ebro delta.

The evolution of this morphology has been studied by many authors from available aerial photographs, with the following conclusions (Maldonado, 1986; Lettuce and Lopez, 1997; Sánchez-Arcilla et al, 1997; Rodriguez, 1997; Molinet, 2006):

- Cap Tortosa area is undergoing erosion while El Fangar and Banya are settling areas. Trabucador and Eucalyptus-Migjorn areas are transit zones for sediments coming from Cap Tortosa to the Banya. La Marquesa-Riumar area is another sediment transit area from Cap Tortosa to El Fangar (Figure 13).

Figure 13: Current gains and losses of sediment along the outer coast of the Ebro Delta (Generalitat de Catalunya, 2008). Orange indicates erosion (negative) or gain (positive) of each section. Yellow indicates sediment transport from one cell to another.



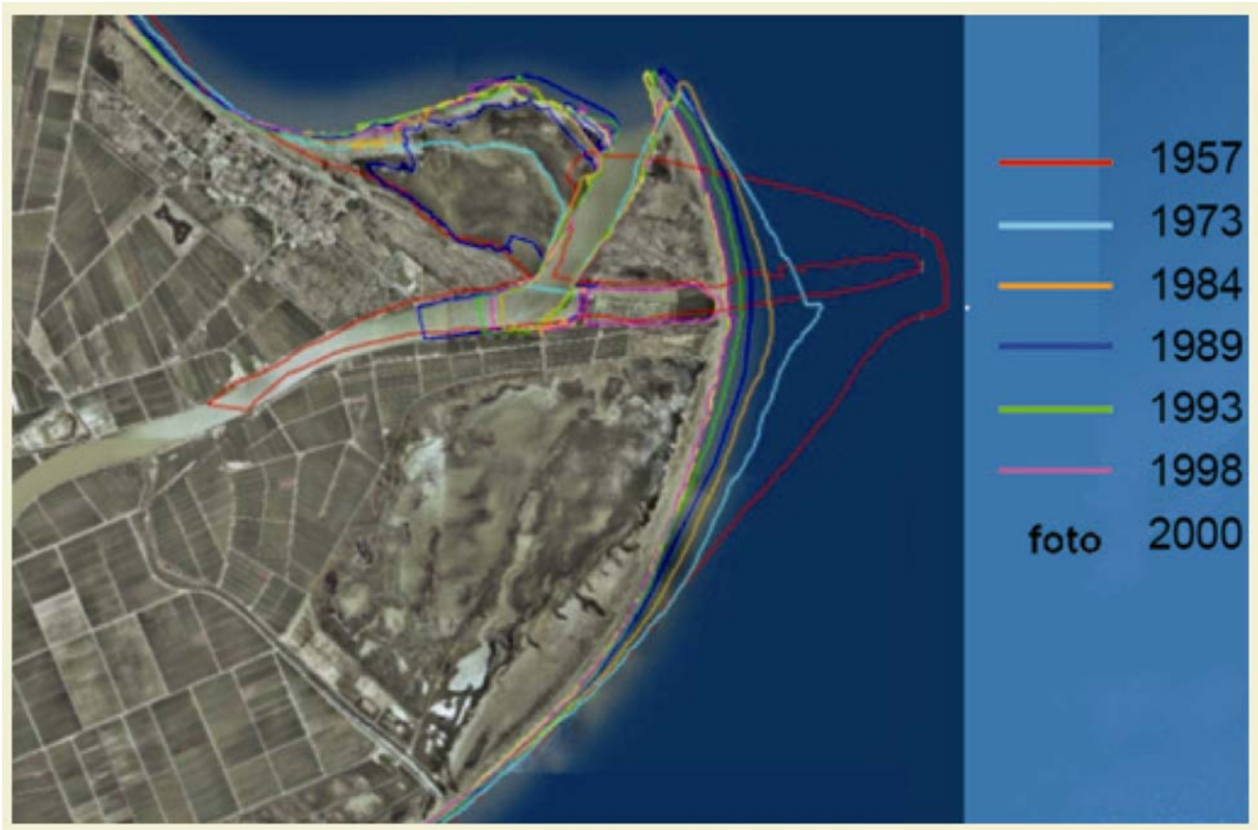
- After the construction of the large dams the delta underwent rapid changes, especially erosion in Cap Tortosa (Figure 14), but these changes have been declining steadily, currently reaching a profile close to balance.

- Overall, it may be said that the process of adaptation of the delta to the new conditions has not led to significant losses of emerged surface or decline in the deposition of sediments. Only an adaptation of its shape has ocurred.

- It is essential to continue to monitor the evolution of the morphology of the delta in order to characterize and evaluate the changes that are taking place at a slow time scale.

Currently there is a sedimentary tendency in both coastal arrows, while zones between the lobe and arrows are acting for sediment transfe, and the Cap Tortosa area has suffered the greatest erosive process.

Figure 14: Evolution of coastline in Cap Tortosa from 1957 to 2000 (Jimenez et al, 2005; in Generalitat de Catalunya, 2008).



4.5.3. – Habitat of remarkable species

The effect of the environmental flow regime included in the Project Proposal for the RBMP 2009 (CHE, 2012B) has been one of the criteria for its definition as described in detail in Section 4.1.1.1 of this report. Therefore, this scheme assures the habitat required by current regulations regarding fish species.

4.5.4. - Environmental effects of the flows discharged into Delta and Bays

The hydrological functioning of the surface waters and the lagoons of the Ebro delta can not be understood without analyzing in detail the evolution of farming practices, in particular, the water distribution that is annually made to irrigate the rice fields.

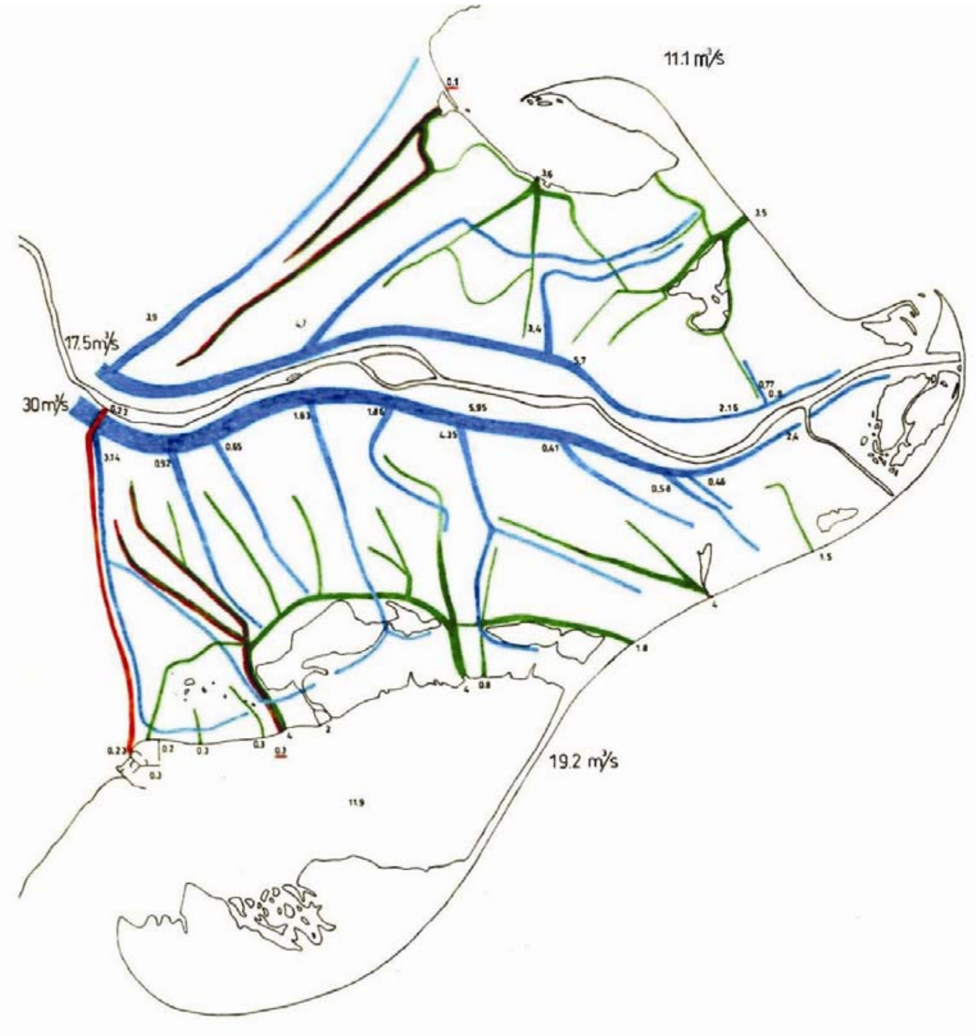
The behaviour of the shallow aquifer with regards to changes in its salinity has been studied in detail in CHE (2008b, 2009b) and Jimenez (2010). The evolution of the salinity of this aquifer is conditioned by irrigation practices (application to fields, seepage from channels and artificial drainage), rainfall and the dynamics between the sea, bays and the Ebro River. From all these components the irrigation of the rice fields is the most important one.

The rice occupies most of the delta plain and fields are kept flooded throughout the culture period, so that infiltration contributes with a substantial volume of artificial recharge that largely exceeds the natural recharge component. The rice cycle lasts 188 days during which the fields receive water continuously, while once the culture is finished, flooding goes on for another 120 days (from October to

January) but with an exclusively ecologic-environmental character. This practice is intended to promote the proper habitat of a wetland as the Ebro Delta. (CGRCMDE-CRSAE, 2008).

The irrigation system comprises two main channels and a network of coated secondary channels. The tertiary network is not coated, nor the drainage network (Figure 15). This drainage network evacuate water by means of stations equipped with Archimedes screws that start running when the rice harvest ends in September, evacuating about 33 m^3/s in the left semidelta and about 50 m^3/s in the right one (MARM-GC , 2006, in Jimenez, 2010).

Figure 15: Major irrigation and drainage networks in the Ebro Delta (Acuamed, 2008, in Jimenez, 2010).



In order to understand in detail the functioning of the recharge in the upper aquifer, in CHE (2008b, 2009b) and Jimenez (2010), elevn piezometers were installed in 2008 at 10 m depth on the right bank of the Ebro River, downstream of Deltebre (Figure 16). Pumping tests were conducted and salinity, water level and other physico-chemical and isotopic parameters were recorded, while conductivity profiles of the wells and of the Ebro River were obtained in six field campaigns including different seasons (irrigation period, environmental irrigation and with drainage) between April 2009 and May 2010. A special focus was placed on the freshwater – saltwater interface in the aquifer and its relationship with the external factors that influence its behavior (Jiménez, 2010).

The main conclussions of CHE (2008b, 2009b) and Jimenez (2010) are:

- The permeability of the aquifer material is significantly lower than that considered in previous literature, with values of $8×10^{-4}$ and $6×10^{-3}$ m/day in levee material (clay) and $3×10^{-2}$ and $4×10^{-1}$ m/day in delta plain materials (fine sand).

- The distribution of groundwater in the shallow aquifer is highly variable throughout the year.

- Ther is a clear distinction between the top layer with less saline waters than the lower layer. This salinity is a function of: a) the proximity to the main irrigation channel; b) the irrigation season; c) the proximity to Ebro in areas close to the river channel.

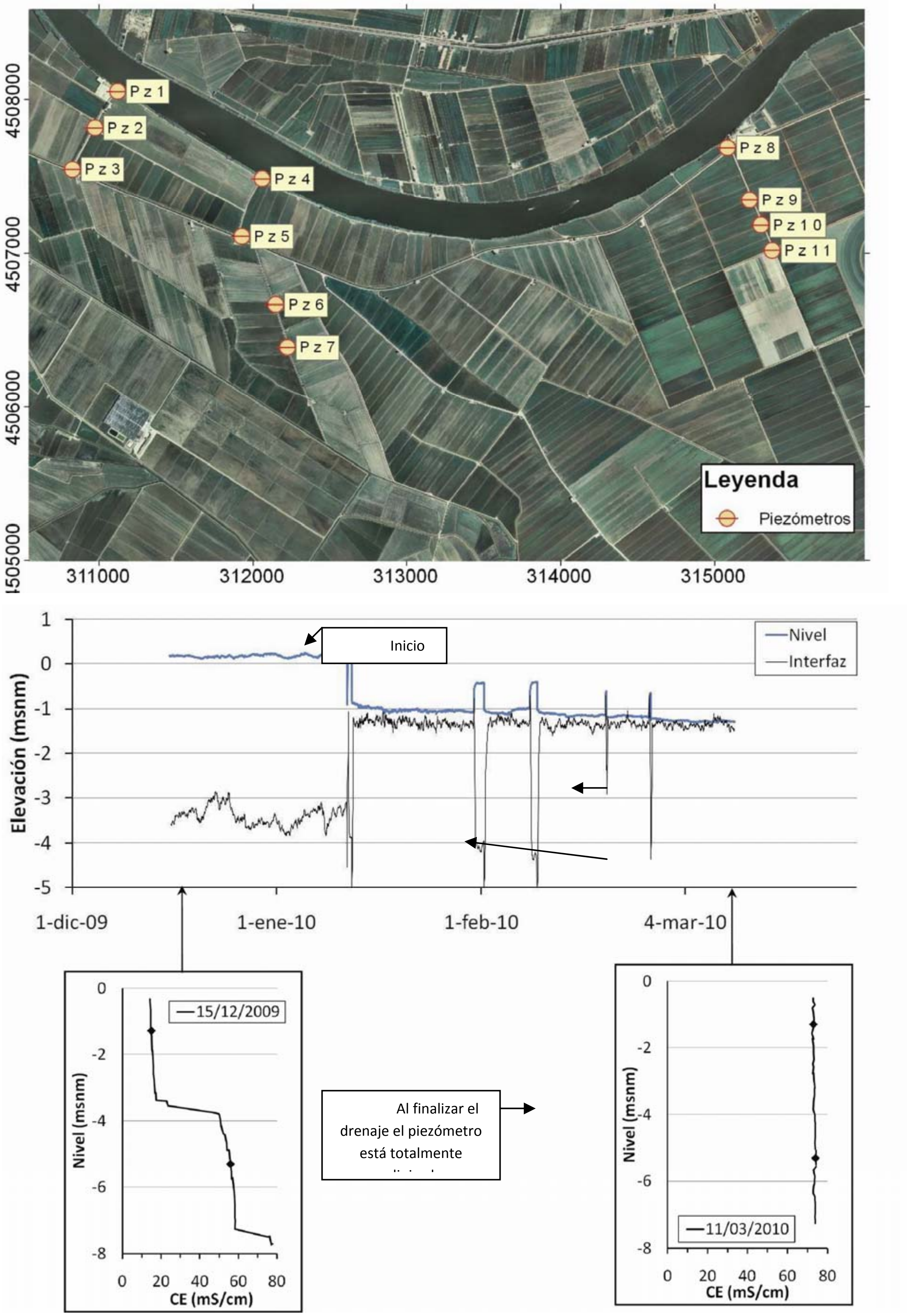
- The lower layer has salinity close to seawater, but sometimes even slightly higher.

- During flooding irrigation periods a widespread aquifer recharge causes the appearance in the upper layer of fresh-brackish water.

- In drainage periods the level of groundwater of the shallow aquifer decreases. This top layer (fresh-brackish) may disappear, and the entire aquifer gets salinized except for the areas influenced by irrigation channels which, despite being covered, have losses that reduce the salinity of the underlying aquifer. Salt water is of marine origin and come from congenital waters in the lower silts level.

- The area of the aquifer affected by the Ebro River is only a few tens of meters wide, limited by the irrigation Channell serving as positive hydraulic barrier. In fact, during the monitoring period, levels were controlled in two artificial floods and a natural one, and it could be observed that these episodes do not produce noticeable effects in piezometers near the river, a fact that is clearly indicative that the low permeability of the upper aquifer materials isolates their water from the functioning of the river (Annex IV).

Figure 16: Location of the piezometers installed in CHE (2008b) downstream of Deltebre and results observed in piezometer 11.



These findings clearly show the importance of irrigation for the Ebro delta and the limited effect of the salt wedge in the salinization of the waters of the delta. Only in those areas where groundwater is pumped near the course of the Ebro, the impact of the salt wedge could be more significant.

The objective of the proposal of environmental flow regime at the mouth of the river Ebro is to properly distribute available waters of the lower Ebro between the minimum flow in the river and the channels of the left and right margin of the Ebro (where water to meet environmental functions are diverted, improving both the emerged delta and the bays). The proposal made in this paper includes the inputs from irrigation concessions, during the 308 days of flooding per year, to preserve the environmental benefits produced by these flows both within the delta as in the bays.

4.5.5. - Groundwater discharges to the Delta

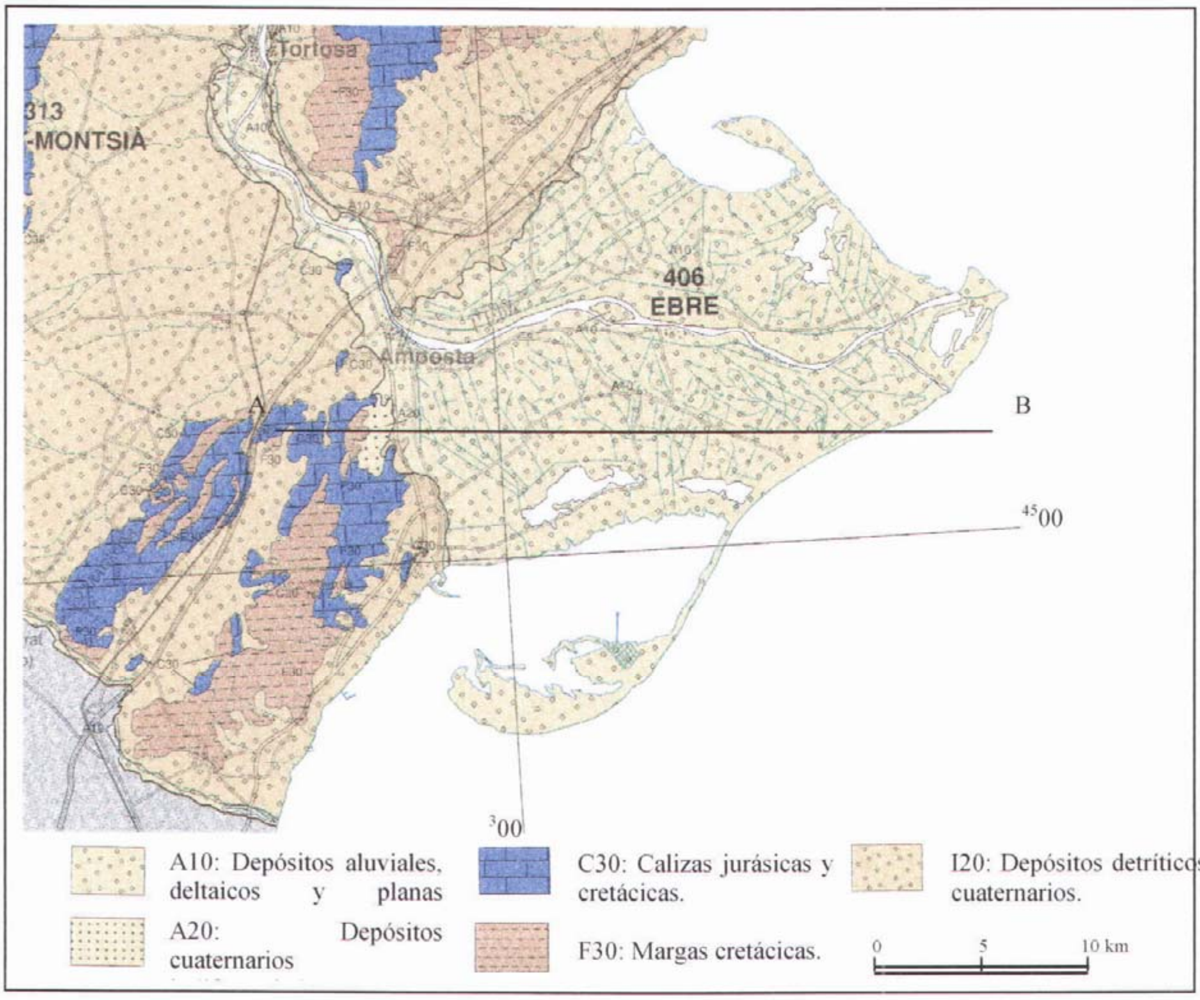
The Ebro Delta materials have a sub-horizontal layout. Following Bayó et al (1997; in IGME, 2005) and Custodio (2010), depending on their hydrogeological characteristics, the following levels may be from top to bottom (Figure 17):

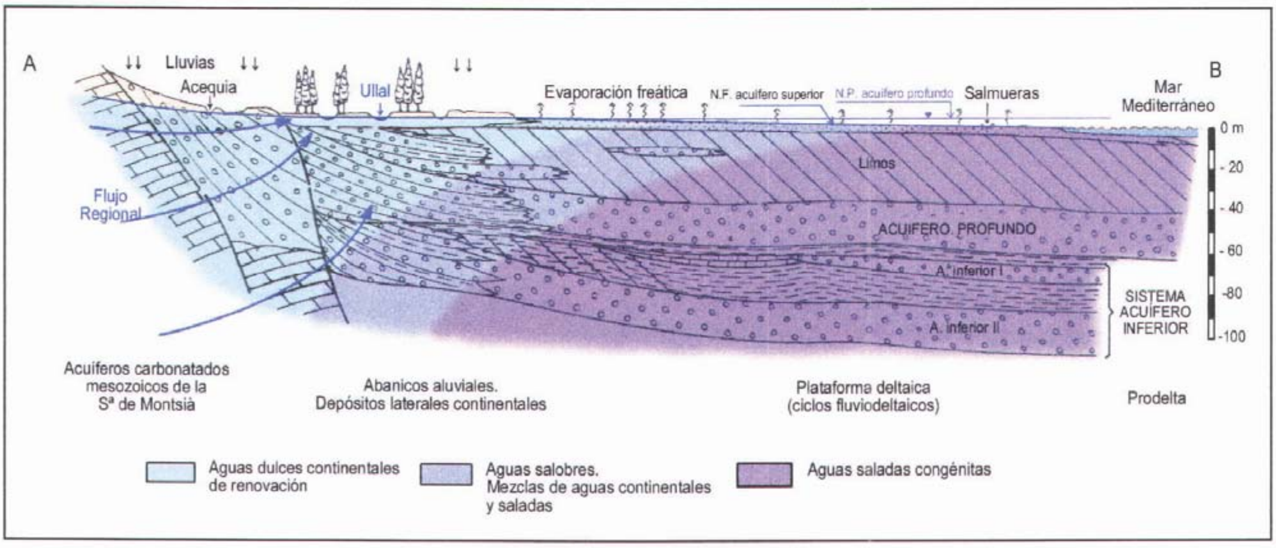
- An upper aquifer with maximum thickness of 10, conformed by fine sands and gravels from paleochannels, beaches and coastal dunes. The permeability is very low. Although average values have been set in the order of 1-5 m/day (CHE, 1991), recent studies have substantially decreased the estimate of this permeability with the basis of pumping tests conducted in piezometers with values ranging between 8×10^{-4} and 4×10^{-1} m/day (CHE, 2008b). It works as an unconfined aquifer. It has salinized water starting at 1 m depth. In areas close to the continent, flows from the carbonate aquifers of the lower Ebro run over salt water resulting in slightly saline springs known as *ullals*.

- A layer of 20 to 100 m thick formed byorganic silt that behaves as an aquitard, confining the deep aquifer.

- A deep aquifer consisting of of 20-30 m of gravel. This is a spouting type aquifer containing congental marine waters that maintain a high degree of the original salinization. Only in the areas closest to the mainland, the draining of Mesozoic formations favors a certain degree of mixing, resulting in lower salinity groundwaters that are exploited.

Figure 17: Map and geological section of the Ebro Delta: Taken from IGME (2005), which in turn takes the map of the Geological Survey of Catalonia while the section is from Bayó et al (1997)



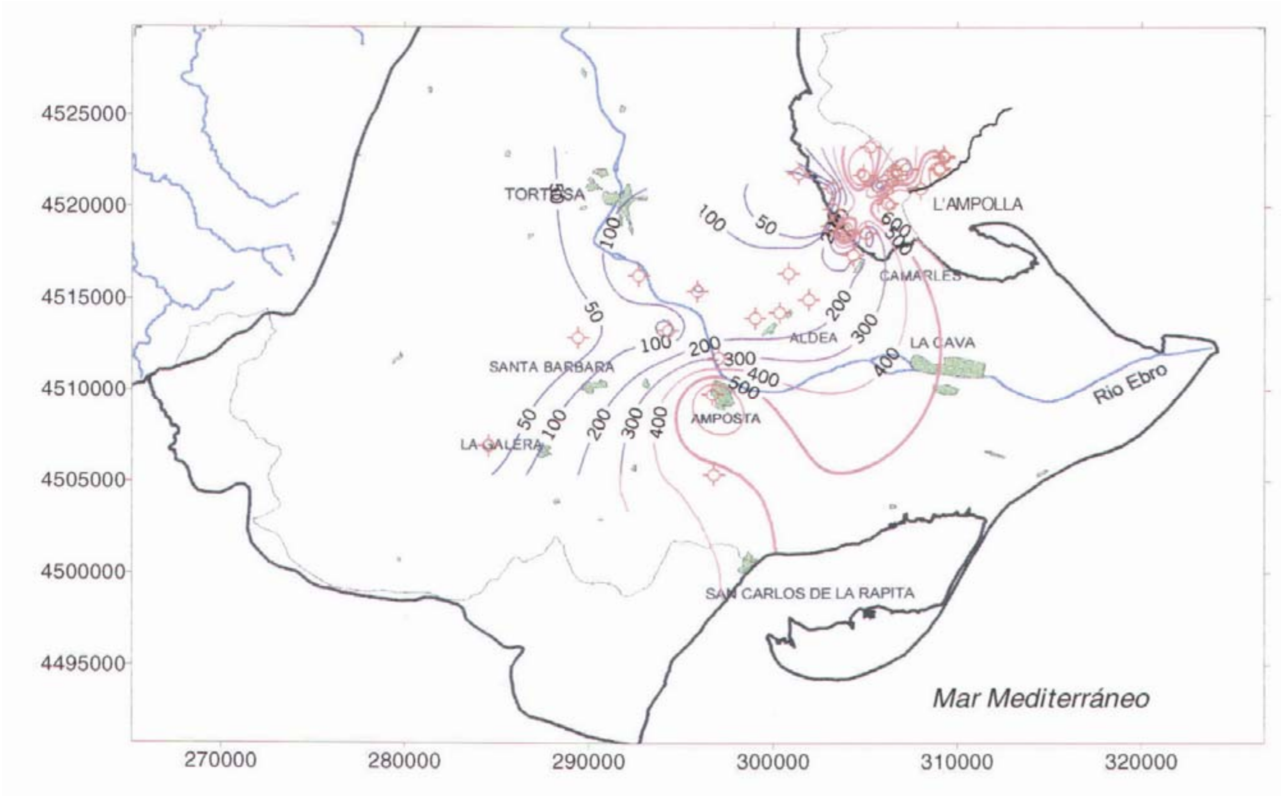


- A multilayer aquifer system, deep and confined, which is found between 70 and 500 m depth. River gravels are interbedded with deltaic sediments containing water with salinity similar to sea.

The aquifer recharge is estimated (CHE, 1991) at 135.5 hm^3/year and occurs primarily by infiltration of water from the rice fields (79 hm^3), by groundwater discharge from adjacent continental formations (35 hm^3/year) and by infiltration of rainwater (21.5 hm^3). Discharge occurs: through drainage ditches (97 hm^3); as groundwater discharges to the river Ebro, the Mediterranean Sea and the lagoons and wetlands (34 hm^3); and by extractions (4.5 hm^3/year).

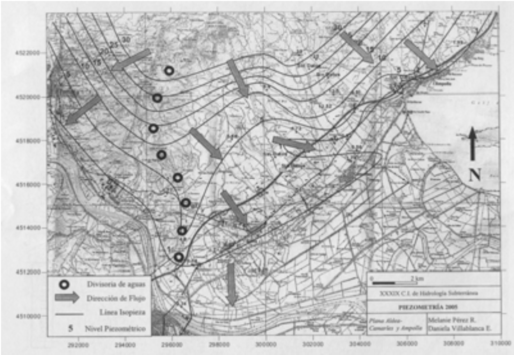
The salinity of the quaternary aquifer inside the delta increases as it approaches the sea, starting from 200-300 mg/l of chloride recorded at L'Aldea and northern Amposta (Figure 18). In some areas the content is below 200 mg/l of chlorides because Mesozoic discharge flows are directed towards the top and deep aquifer. Locally, in the areas of L'Ampolla and Amposta, there are high salt concentrations due to the existence of local intrusion processes favored by groundwater pumping. The first incoming of seawater occurs through the coast and the second takes place through the channel of the river Ebro. It has not been observed a general trend to salinization of water nor in those boreholes where salinity has been recorded nor in the *ullals* (IGME, 2005).

Figure 18: Map of iso-chloride concentration in the upper aquifer in September-October 1999 (IGME, 2005).

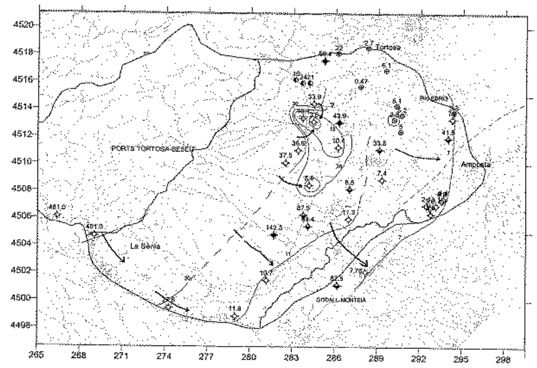


The three quaternary aquifers of the delta (upper, bottom and multilayer) contain congenital water, which is the seawater trapped during the formation of the sediment. The low hydraulic gradient of groundwater levels (Figure 19) and the low permeability impede effective cleaning of these waters. The salinity balance of the delta is a function of two main factors:

Figure 19: Maps of isopiezas to the north (CHE, 2005b) and south (CHE, 2001) from which Mesozoic discharges into the Ebro delta have been estimated



Map of aquifer isopiezas pliocuaternario de la Plana de l'Aldea-Camartes in March-May 2005 (CHE, 2005b)



Piezometry of the Pit of La Galera-opened in March, 2002 (CHE, 2001)

a) Water abstractions, so that if they exceed a certain threshold, highly localized intrusion problems may appear, as in l'Ampolla and Amposta.

b) Discharges of freshwater from the Mesozoic. These discharges have been evaluated:

- For the sector between Ampolla and Amposta:

  + In CHE (1991) they are estimated at 20 hm^3/year. The calculation is made considering that average transmissivity of the Mesozoic aquifer is 1,200 m^2/day, a gradient of 0.003 and a length out to the delta between l'Amella and Amposta of 15.2 km (Q = 1,200 × 0.003 × 15,200 = 54,720 m^3/day = 20 hm^3/year).

  + In CHE (2005b) they are estimated at 2.1 hm^3/year. The calculation is made considering an average transmissivity of the Mesozoic aquifer of 450 m^2/day, a gradient of 0.001 and an exit to the delta length of 13 km (Q = 450 × 0.001 × 13,000 = 5,850 m^3/day = 2.1 hm^3/year).

- For the sector located south of Amposta

  + In CHE (1991) they are estimated at 15 hm^3/year. The calculation is made considering an average transmissivity of the Mesozoic aquifer of 700 m^2/day, a gradient of 0.006 and a length out to the delta of 9.8 km (Q = 700 × 0.006 × 9,800 = 41,160 m^3/day = 15 hm^3/year).

  + In (CHE, 2001) they are estimated at around 0.8 hm^3/year, as 50% of the discharge southeastward considering that an average transmissivity of the Mesozoic aquifer is 370 m^2/day, a gradient of 0.0009 and a length out to the delta of 13.33 km to delta (Q = 370 × 0 , 0009 × 13,330 = 4,439 m^3/day hm^3/year = 1.60).

4.5.6. - Contribution of salts and nutrients

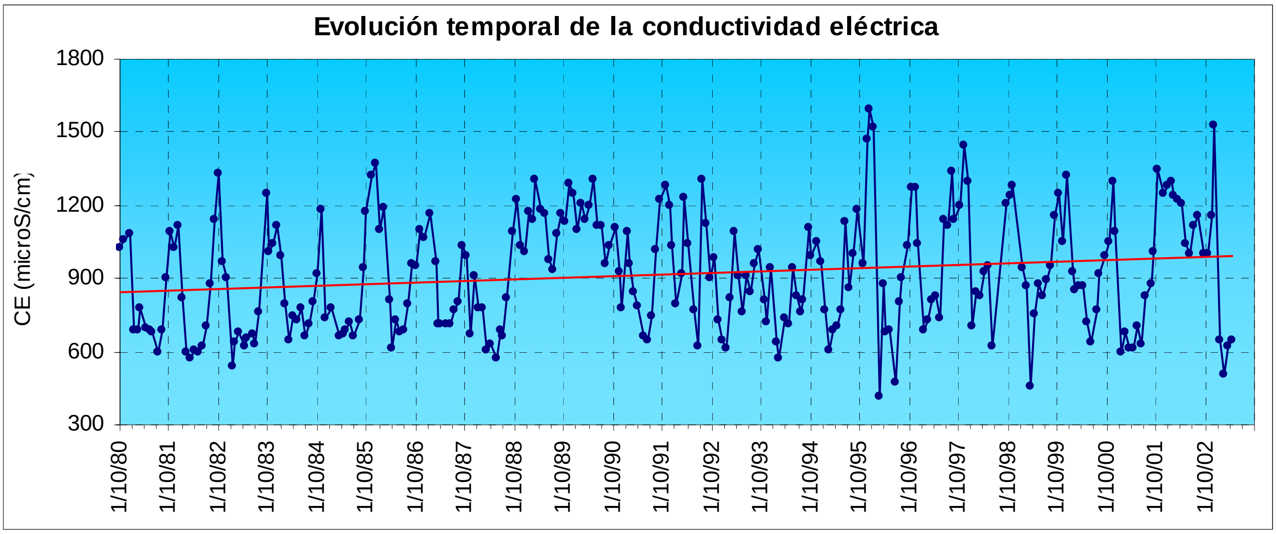
The statistical analysis of the evolution in time of the chemical parameters in the Ebro basin has been carried out in numerous studies (Bouza et al, 2004; Bouza, 2006, Valencia, 2007). This section highlights the most significant aspects regarding the physical and chemical quality of water in the lower reaches of the river Ebro.

4.5.6.1. - Salinity of surface water

In the Ebro axis, it may be observed an increase of the average salinity as the river moves on its way up to the tail end of the Mequinenza reservoir in Sástago, where it reaches an average conductivity of 1.329 mS/cm (period 1980/2002). Due to sedimentation of particles in the Mequinenza reservoir and lesser saline contributions from the Segre River, salinity in Ebro downstream Mequinenza reservoir is lower than upstream. Thus, in Ascó the average for the same period is 908 mS/cm and in Tortosa is 918 mS/cm.

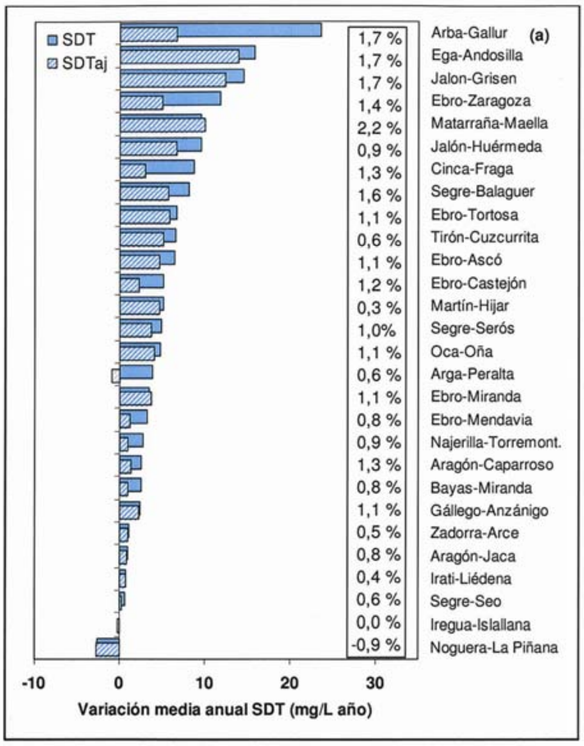
The characterization of saline concentration and the total mass of salts in the Ebro basin has been conducted in CHE (2009c) from statistical analysis of the data of total dissolved solids in 28 gauging stations in the period 1975-2008. It has been identified a trend to increasing salt concentration in most (93%) of the quality stations (Figures 20 and 21). In Tortosa an annual rise of about 6 mg/l year has been detected.

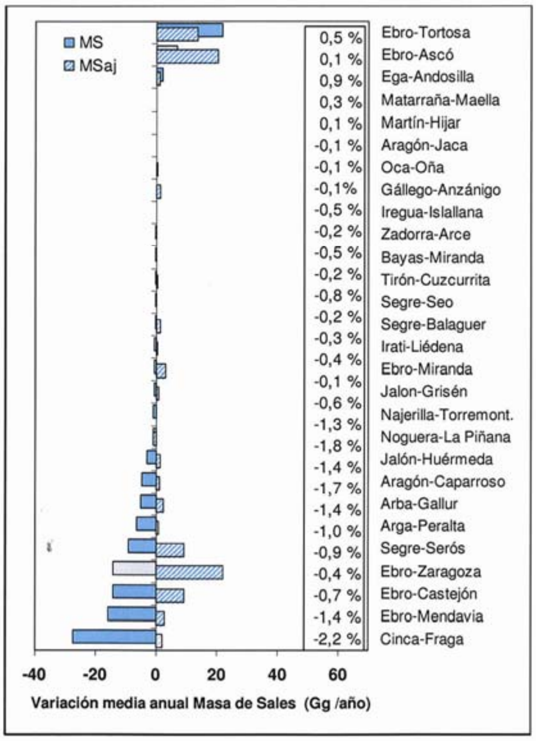
Figure 20: Evolution in time of total dissolved solids at station 27 (river Ebro at Tortosa). CHE (2008d).



The effect of increasing concentration is influenced by the trend to less volume of water flowing. In the Ebro basin a clear correlation has been established between flows and concentrations of salts, so that the lower the flow, the higher the concentration. From the evaluation of the mass of salts mass actually exported in each control station, it may be observed that, although the concentration is tending to increase, this is not the case with the mass of salts. The analyses carried out in CHE (2009c) clearly show that most of the stations do not have an increase in the mass of salts in the period 1975 to 2008 (Figure 21). Tortosa and Ascó stations are the only ones that reflect a tendency of increasing exportation around 20 tons/year. However, it is important to consider that the analysis indicates that there is no overall trend of increasing the mass of salts exported from the Ebro basin to the Mediterranean Sea.

Figure 21: Concentration of salts (left) and mass of salts (right) recorded at 28 gauging stations of the Ebro basin in the period 1975-2008 (CHE, 2009c)





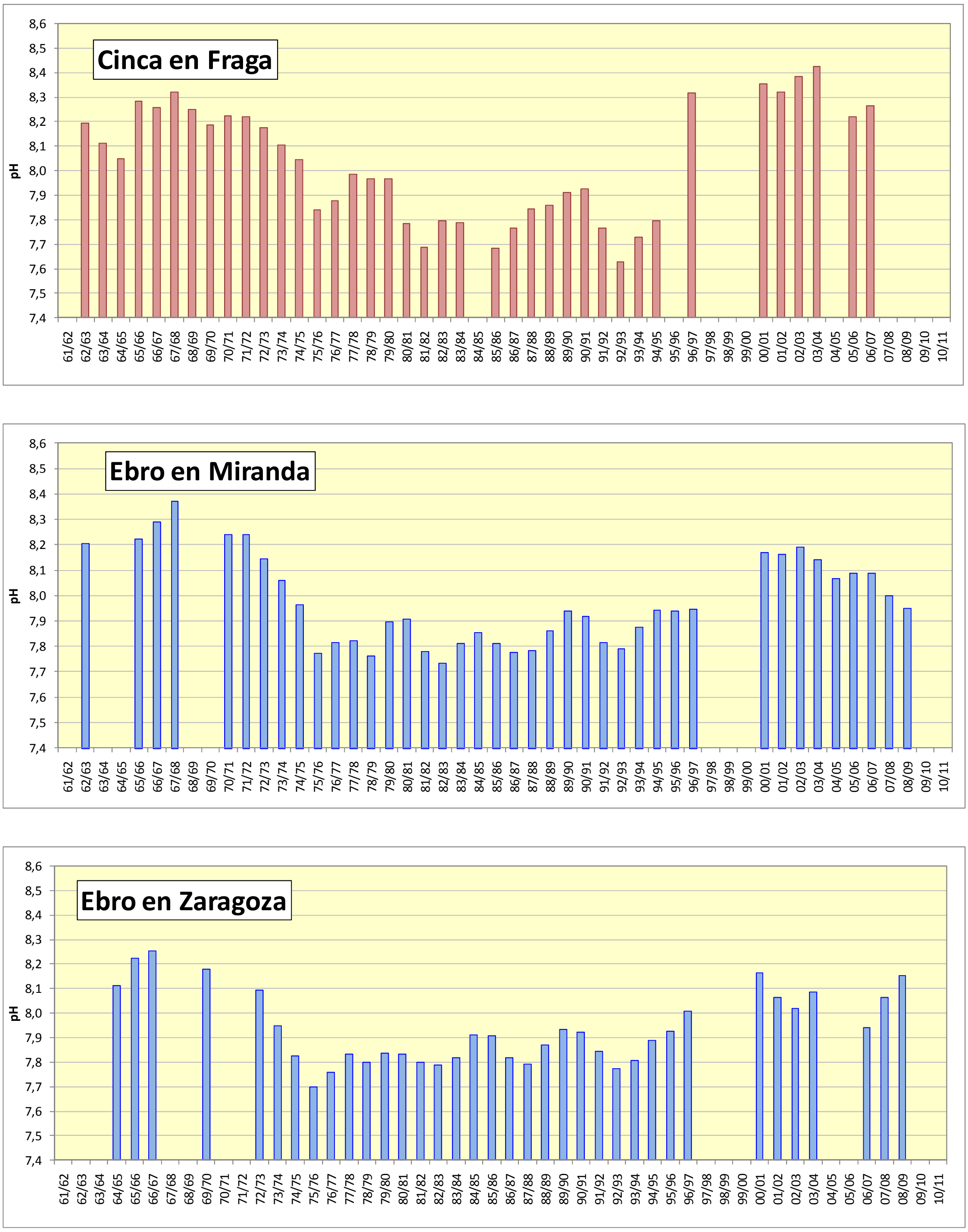
4.5.6.2. - Evolution of pH

One general aspect that has been highlighted in several studies analyzing the spatio-temporal trends regarding physical and chemical parameters in the Ebro basin is a tendency to increase pH of surface waters (Valencia, 2007). It has been raised the possible relationship of this evolution with the effect of increased water temperature due to climate change.

CHE (2012d) performed a detailed analysis of the evolution of pH in the stations of the water quality network of the Ebro basin incorporating data from 1960 (Figure 22). It may be observed that, as had been detected, there is an increase in pH from the years 1995-2000, but when analyzing the series since 1960, it is noticeable that in the period prior to 1970 pH values were similar to those obtained at present.

From the analysis of the various factors that could explain the observed evolution, it is concluded that the most plausible one to account for this relationship is the operation of power stations that were installed in the northern part of the Iberian peninsula closer to the basin and with significant potential to impact its waters: Andorra (Teruel) in 1981, Escucha (Teruel) in 1975, Escatrón (Zaragoza) in 1990, As Pontes (A Coruña) in 1976, Aboño (Asturias) in 1974, Compostilla (León) in 1972 Soto de Ribera (Asturias) in 1962, La Robla (León) in 1971, Guardo (Palencia) in 1964, Lada (Asturias) in 1967, Anillares (León) in 1971, and Pasaia (Guipúzcoa) in 1968.

Figure 22: Evolution of pH in quality stations since 1960 (CHE, 2012d)



The commissioning of most of these plants occurs between 1965 and 1980, a period when it seems to appear a general decrease of pH due to acid rain. Beginning in 1993, it may be noted a general increase of pH both in Ebro and its tributaries, while since 2000 pH has remained stable and significantly higher than those recorded in the last three decades. The most likely cause of this rise in pH are certain actions taken in the 90's that have made a significant reduction in emissions such as installing filters and desulfurization plants (eg in Andorra and Cercs) and changes in the fuel source to coal with lower sulfur content. The relationship of this increase in pH with urban wastewater treatment is unclear since the rise of pH is observed at stations not affected by treatment plants. Nor is there a clear cause-effect relationship between increasing pH and industrial and agricultural activities.

4.5.6.3. - Evolution of temperature

Characterization of the temperature of the water in the lower reaches of the river Ebro has been widely developed in Prats (2011) by studying the thermal regime of the lower Ebro River, between Escatrón and Miravet and the alterations caused by the system of reservoirs Mequinenza - Ribarroja - Flix and Ascó nuclear plant. The main conclusions are:

- Apparently, there is an increase in water temperature at Escatrón station troughout the 1955-2000 period, which is consistent with the increase of the average air temperature observed in this period.
- The system Mequinenza - Ribarroja - Flix produces an increase in average monthly temperature of 3-4 °C in autumn and winter, and a decrease of 3-4 º C in spring and summer. There isalso a delay in annual maximum and minimum as well as a reduction of the temperature range on a yearly basis and less variability on a daily basis.
- The disturbance caused by the three dams is mainly due to Mequinenza reservoir. The discharges of the rivers Segre and Cinca partially counteract this alteration. Subsequently, as the water flows downstream alteration decreases.
- The Ascó nuclear power plant induces an increase in average annual temperature of 3 °C. This effect depends on the flow, so that at high flow rates alteration is smaller.
- The nuclear plant corrects the alteration caused by the reservoirs in spring and summer and increases it in autumn and winter.

4.5.6.4. - Evolution of phosphates

The evolution of phosphates has had a marked overall decline around the year 1995. This has been clearly detected in Valencia (2007) by statistical analyses for the whole Ebro basin (Figure 23). As an example, the evolution of the Ebro River Station in Tortosa is shown in Figure 24.

Figure 23: Evolution of phosphate by annualized series and by moving averages (in mg/l) (Valencia, 2007).

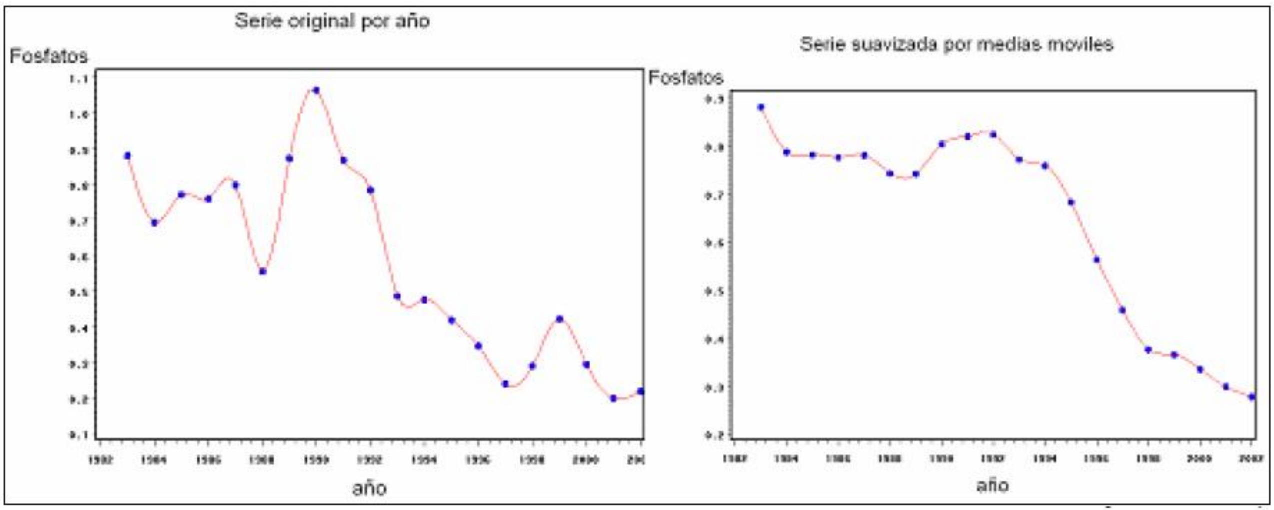
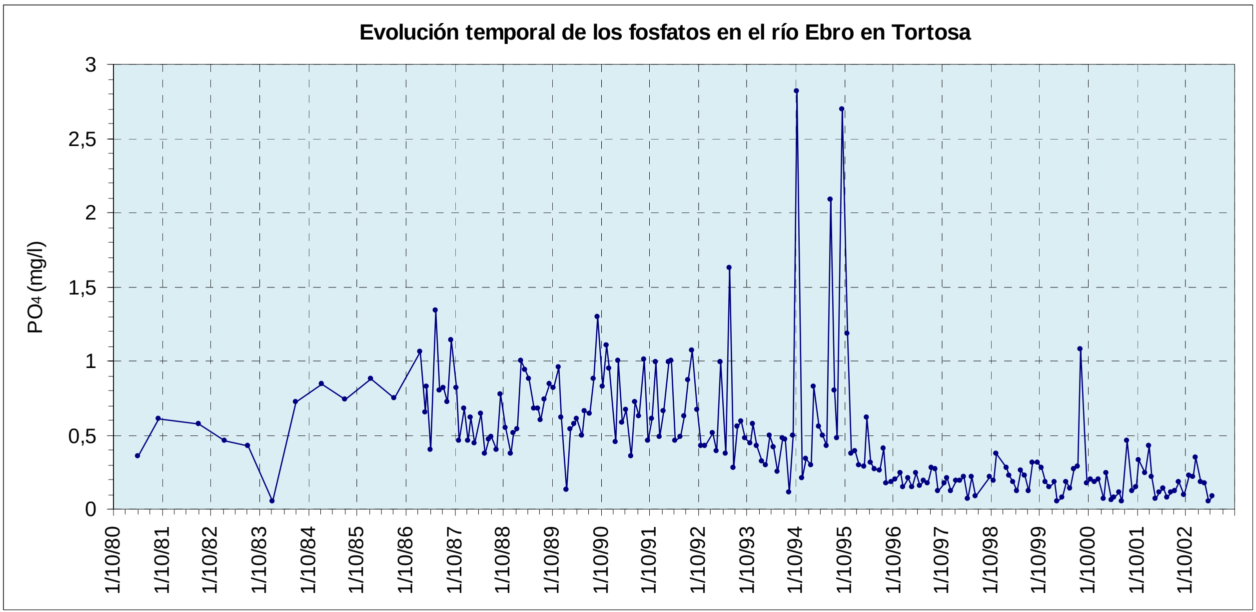


Figure 24: Evolution of the phosphate content in the river Ebro at Tortosa (CHE, 2008d).

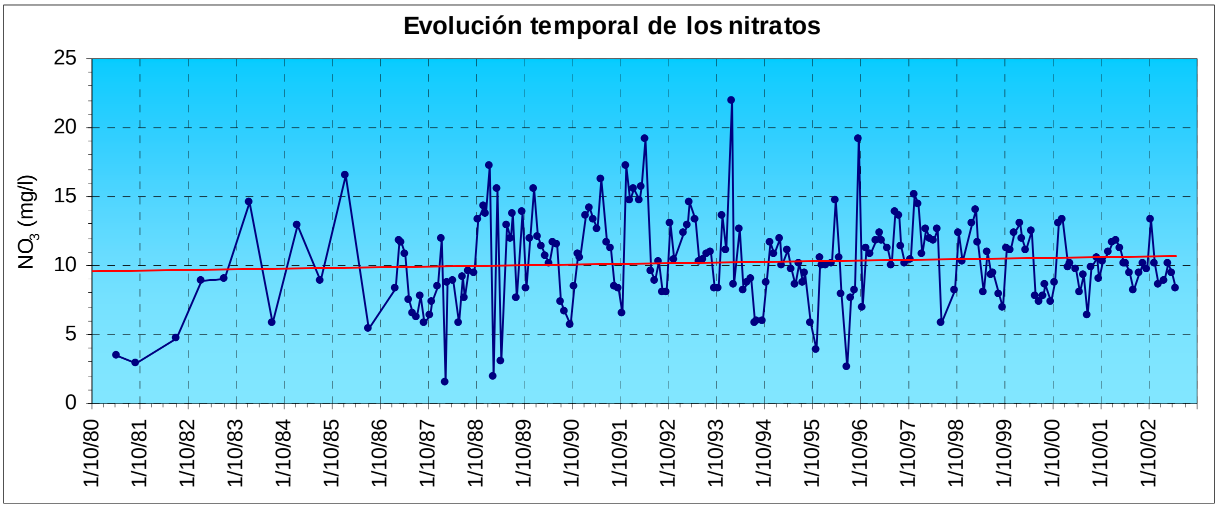


The environmental implications of this reduction of phosphates will be analyzed in the section on macrophytes. Regarding which hypothesis may justify this diminution; on the one hand it is explained in terms of better water treatment and, on the other, by the reduction of phosphates in detergents that took place around the year 1995. The first hypothesis is not clearly justified since there are stations where this decrease is observed and is not related to the operation of any waste water treatment plant. In any case, what is clear is that in 1995 there was a significant environmental improvement with decreasing phosphate content in waters.

4.5.6.5-Evolution of nitrates

The nitrate content in the water of the Ebro basin is related to agricultural and industrial activities in low-and middle areas of the basin. Waters in the upper reaches have very low concentrations (0.5-2 mg/l) and as they progress downstream in their travel, the content of nitrates increases. The average concentration of the river Ebro in Sástago is 16 mg/l in the period 1980-2002 while in Ascó and Tortosa stations it is 10 mg/l for the same period (Figure 25).

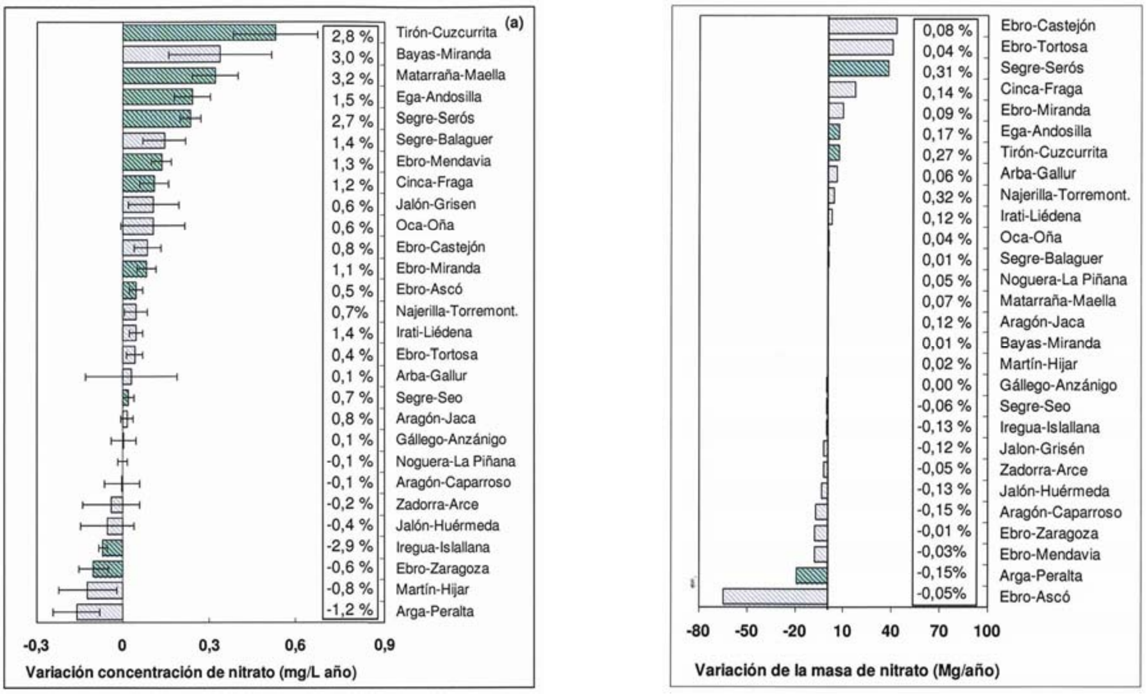
Figure 25: Evolution of the concentration of nitrates in the river Ebro at Tortosa (CHE, 2008d).



The evolution of this parameter has been analyzed for 28 water quality stations in CHE (2009c). It is observed that in 29% of the analyzed stations, the trend is significant and positive (Figure 26). If the same trend analysis is performed for the mass of nitrates exported, it shows that most of them do not have a marked tendency, while in the two stations of the lower Ebro –Ascó and Tortosa– there aer, respectively, a decrease and an increase in the nitrate mass, showing that there is no strong trend regarding this parameter.

Lassaletta (2012) makes a global balance of nitrates in the Ebro basin. It is concluded that the Ebro basin receives a high amount of nitrates (5,118 kg N km^{-2} yr^{-1}), 50% in the form of synthetic fertilizer. Only 8% of this nitrogen is exported to the Ebro delta, indicating nitrogen retention of 91%, which is a very high value. This high rate of retention within the basin prevents, on the one hand some severe problems of eutrophication by nitrogen release in the coastal zone and, on the other hand, that problems may appear within the watershed, such as pollution of aquifers and rivers, as well as elevated atmospheric emissions.

Figure 26: Concentration of nitrates (left) and mass of nitrate (right) recorded at gauging stations28 of the Ebro basin in the period 1975-2008 (CHE, 2009c).



4.5.6.6-Final conclusion regarding nutrients

The description of the content of nitrates and phosphates in the waters of the lower Ebro carried out in this section suggests that the mass of nutrients exported to the Ebro delta is currently stabilized. It should be noted the significant reduction of phosphates observed around the year 1995.

The environmental flow included in the Project Proposal for the RBMP 2009 (CHE, 2012b) maintains a regime similar to that implemented so far and therefore a significant increase of the content of nitrate and phosphate –threatening the water quality– must not be expected. However it is considered advisable to maintain operational control of water, as being done to date, for an early detection of any trend that might recommend a revision of the proposed water planning measures in relation to the better management and practices affecting the nutrient content of the waters of the Ebro basin.

4.5.7. - Macrophytes

Since half of 1995 there has been a progressive profusion of macrophytes in the lower reaches of the rivers of the Ebro basin. Initially the phenomenon began in the lower Ebro to later be located in the lower Segre and currently this problem has expanded to the middle stretch of the Ebro.

The evolution of macrophytes in the lower Ebro has been analyzed in several studies (CHE, 2008e; Montesinos, 2009; CHE, 2010d; ACA, 2008b and 2009b). All of them include works in the characterization of macrophytes c (species, habitat, spatial and temporal distribution...), suggest various factors that explain their proliferation and evaluate the effects of artificial floods that have been conducted since 2002.

Macrophytes are native species in the Ebro basin but had not been previously detected in such an abundance. The species are:

- *Potamogeton pectinatus L.*
- *Miriophyllum spicatum L.*
- *Ceratophyllum demersum*

The factors that have determined the abundance of these species are manifold:

- Reduction of the phosphate content in the waters from the year 1995. This aspect is described in Section 4.5.6.3. The decrease in phosphate caused a lower abundance of phytoplankton, which favored greater transparency of the water, improves the brightness of the river and thus better conditions for the development of macrophytes. (Ibáñez, 2008; Sabater et al, 2008).

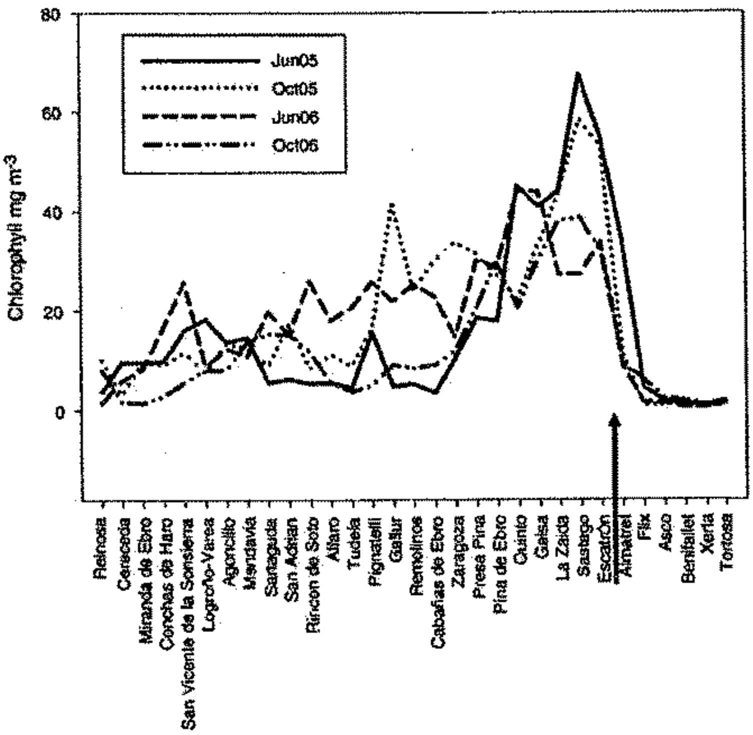
- Change in the water regime of the waters. This variation is characterized by:

+ Increased stability of minimum flows during the months of low waters. Since 1996, it is maintained a constant minimum flow of 100 m^3/s. This has caused a very regular flow conditions that favor the development of vegetation.

+ Less probability of floodings due to the effect of the reservoirs of the Ebro basin and especially the Mequinenza reservoir.

- The residence time of water in the river. This factor has been described in Sabater et al (2008) that studies the evolution of chlorophyll along the Ebro River and notes that there is a significant reduction downstream of Mequinenza-Ribarroja-Flix reservoirs (Figure 27). The author considers that this reduction is due to the fact that circulation along the river from these reservoirs to the mouth lasts about two days. In this short time and favored by the decrease iof the levels of nitrates in the reservoirs, phytoplankton does not get to develop, creating transparency conditions that, in turn, favor macrophytes.

Figure 27: Longitudinal evolution along the Ebro axis of the planktonic chlorophyll in four sampling campaigns. The presence of reservoirs in the lower stretch is marked with an arrow (Sabater et al, 2008).



- Other factors that have been mentioned are the commissioning of the urban wastewater treatment plants, increased water temperature as a result of climate change, the presence of allochthonous fish, a longer time residence in reservoirs (causing increased sedimentation so that there is greater transparency while larger eutrophication increases potassium content of the water) and the lower occurrence of flood events leading to more transparent water.

The abundance of macrophytes has negative consequences for:

- Ecosystems since the structure of biological communities is affected.

- The physical and chemical parameters of the water (temperature, incident light, nutrient dynamics).

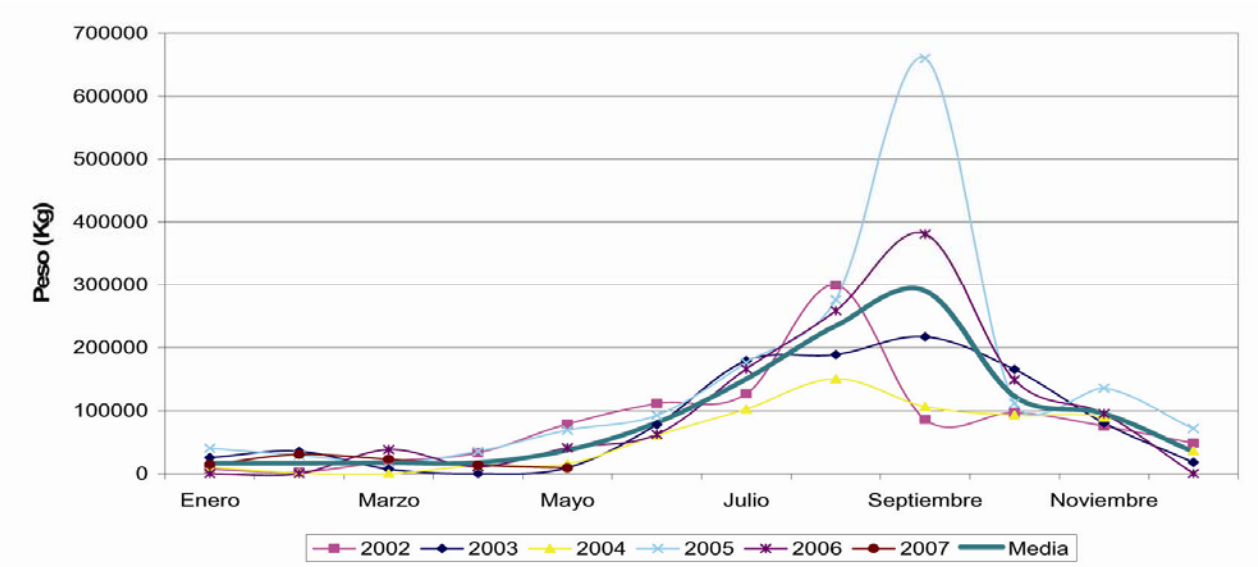
- Effects on sedimentation and flow regulation. It produces an over-elevation of the water level by loss of transport capacity in the channel from variations in the hydraulic section.

- Impacts on irrigation and on water storage. The General Community of Irrigators of the Right Bank studied the most effective measures to prevent problems caused by macrophytes in the channels CGRCMDE (2011). In the framework of this work, different types of membranes were tested in the irrigation channels and the process of fixing algae and macrophytes was analyzed in order to evaluate different methods to prevent the proliferation of these organisms. The installation of membranes was evaluated, as well as the effects of other strategies as the use of chemicals limiting the biological activity, desecation, light reducing meshes, cut and collection. The final conclusion is that the cheapest method is the desecation for as long as possible. The best period for drying and cleaning is after heavy rain or sand drop. The use of mesh shading is also recommended especially in areas inaccessible to mechanical cleaning.

- Clogging of intakes for water uses. The most remarkable problems affect the grids of the water intakes for the cooling of Ascó nuclear plant, where an intensive cleaning process must be carried out during the period of greatest abundance of macrophytes (June to September) (Figure 28).

- Effects on navigation.

Figure 28: Mass of macrophyte removed from the water intake system of the Ascó nuclear plant for the years indicated and average value.



CHE (2010d) proposes a collection of measures for management improvement among which it may be highlighted the improvement of artificial flood hydrograph, from a total additional volume of 36 hm^3 for the flood of to 81 hm^3. Other measures that have been raised are the mechanical pruning with debris collection in some localized spots, monitoring, tracking and study of floods and also, posed as a possibility, to study the option of reducing minimum flows of the river in some periods to cause drying of macrophytes in riparian zones.

The environmental flow regime for the lower Ebro in the Project Proposal for the RBMP 2009 (CHE, 2012b) includes the continuation of controlled flooding as a measure for contributing to the cleaning and removal of macrophytes and also slightly reduces the flow rate in the summer months as a measure aimed at increasing plant stress during the period of maximum growth.

4.5.8. - Salt wedge

Although during the 1990s some characterization field studies on the status of the salt wedge were made (Ibáñez et al, 1999; project PIONEER UPC-UPV), it is from the year 2000 when the most detailed studies of modeling the salt wedge in the Ebro River estuary are carried out.

In MIMAM (2001) Cantabria Hydraulic Institute conducts a study of the salt wedge in the Ebro delta with hydrodynamic modeling calibrated with field data (Figures 29 and 30). A first assessment of the rate of advance and retreat of the salt wedge depending on the flow of the river Ebro concludes that it is necessary to manage the hydrograph so as to maintain a pulsating regime of the salt wedge. Some simulations with a simplified model to reproduce flow pulses between 100 and 800 m3/s are conducted with the main conclusion that the pulse flow of the wedge is moved about 2 days while the decrease of the flow in full retreat takes place in about 12 days (Figure 31).

Figure 29: Evolution of the position of the wedge-flow in the lower Ebro according to different sources (MIMAM, 2001). PHN 2000 data are obtained from the study of the linear relationship between the average daily flows recorded in the Tortosa gauging station and the depth of the freshwater-saltwater interface in two control points located at 6 and 13 km from the mouth.

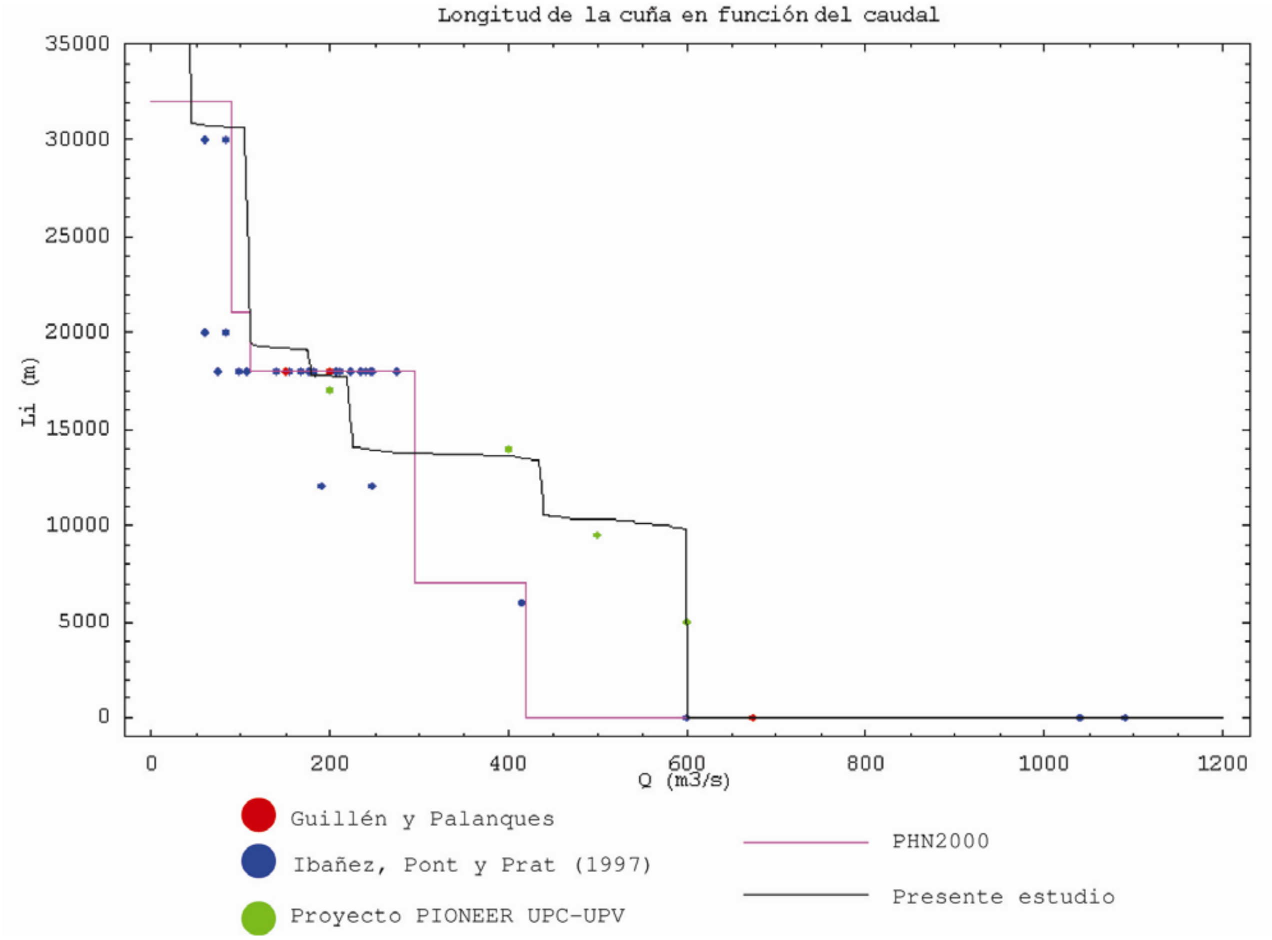


Figure 30: Results of the modeling of the salt wedge in the lower Ebro with different flows: 40, 100, 168, 200, 300, 400, 500 and 600 m^3 and comparison with calibration data MIMAM (2001).

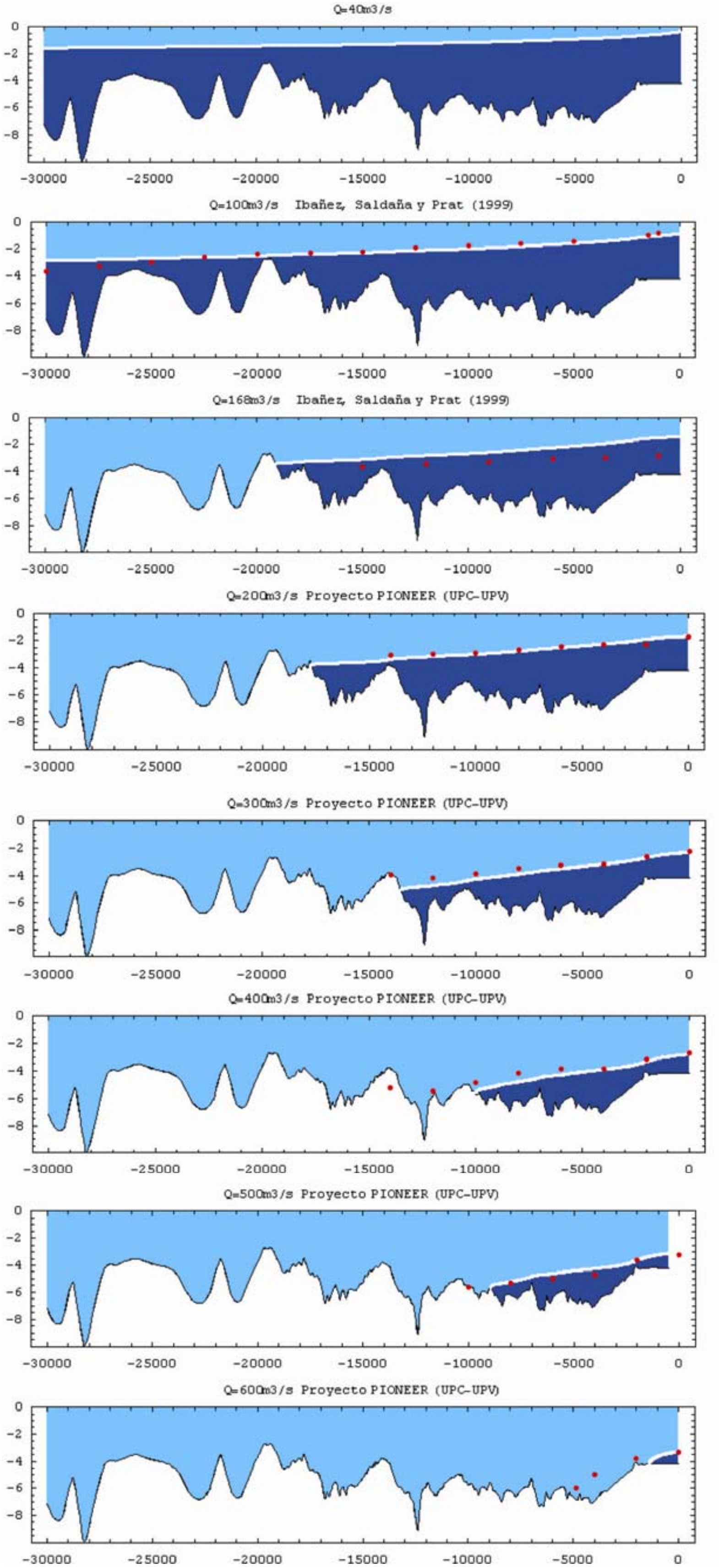
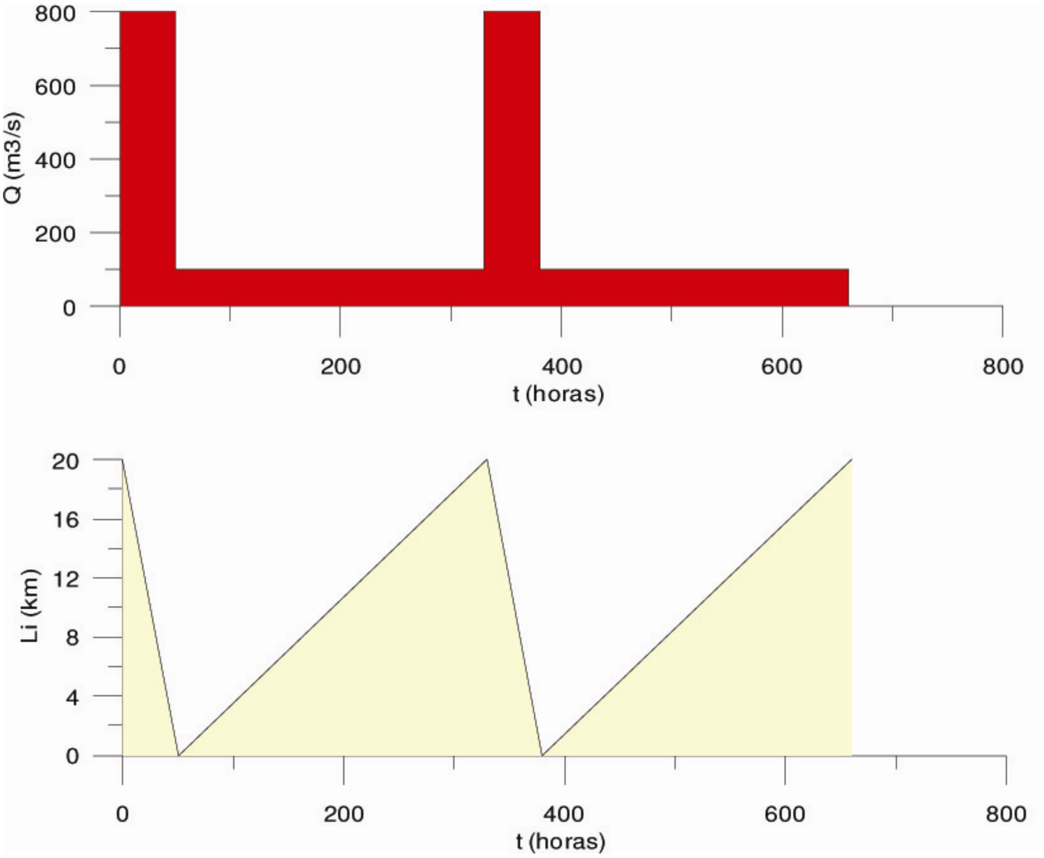
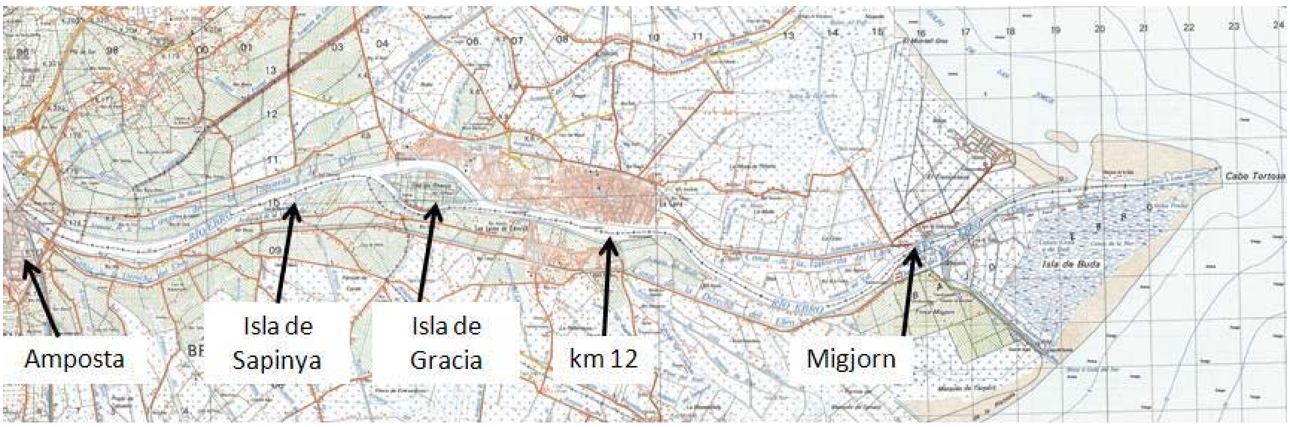


Figure 31: Simulation of the evolution of the wedge between two flood pulses (MIMAM, 2001).



Subsequently, Movellán (2003) and Sierra et al (2002) also start form data from PIONEER Project and simulate saline wedge with the advection-dispersion model MIKE 12. As a result of the model, duly calibrated, it is concluded that the position of the wedge flow varies as shown in Figure 32:

Figure 32: Locations of the points of breakthrough points of the salt wedge at different flow thresholds (see text).



+ With flows lower tan 130 m^3/s reaches Amposta wedge.

+ With flow rates between 130 and 200 m^3/s the wedge gets the Isla de Gracia - Sapinya

+ With flow rates between 200 and 300 m^3/s the wedge reaches 12 km from the mouth.

+ With flow rates between 300 and 400 m^3/s the wedge reaches Migjorn.

+ With flows greater than 400 m^3/s ther is no salt wedge.

These values are consistent with the results of the models applied for the CPIDE Report (2003).

The flow data measured during low waters show that the end of the salt wedge is located in Amposta when flow rates range between 80 and 150 m^3/s and that the wedge moves to Isla de Gracia with flows between 130-200 m^3/s (CPIDE, 2003). This indicates that the proposed minimum environmental flow will ensure the salt wedge moving between Amposta and Isla de Gracia. With flood waters and wedge unregulated in most cases will move toward the mouth. Occasionally, floods and unregulated waters will displace the wedge to the mouth of the river

It can be concluded that in the light of available information the decrease of the minimum ecological flow from 100 m^3/s to 80 m^3/s is unlikely to affect the penetration of the salt wedge. The modulation of environmental flows proposed in CHE (2012B) which incorporates flood pulses will provide greater mobility to the marine wedge. This increased mobility is considered beneficial to the state of the estuary as it favors water renewal.

To prevent the wedge penetrating beyond Amposta it is recommended to amend the environmental flow regime. In previous studies it has been assumed the condition that the wedge must not exceed Amposta, although there have been historical episodes of very low flows, during which the wedge has reached even Tortosa. The discussion on the optimal penetration of the wedge and the replacement rate are issues that must be analyzed in future studies.

As demonstrated in CHE (2008b, 2009b) and Jimenez (2010) the salt wedge has no effect on the group of delta aquifers since their permeability is very low. The renewal of the salt wedge, recovering episodes of stress and floods, is a factor to be taken into account to improve the water quality in the lower reaches of the river Ebro.

4.5.9. - Eustatic component and climate change

The greatest impact of climate change that is expected for the Ebro delta is the rise of sea level. Other effects of lesser magnitude could be a reduction in the contributions from the Ebro basin, which have been evaluated around 5% for the horizon 2027 in relation to 1980-2006 series (Government of Spain, 2008).

In MARM (2011) it is performed an evaluation of climate impact on Spanish water resources and for the Ebro basin it is concluded that the average runoff decrease over the period 1967-1990 would be up to 9% in the period 2011-2040, 13 % in the period 2041-2070 and 16% in the period 2071-2100. The groundwater recharge to aquifers would decrease by 7, 11 and 14% respectively.

In Pisani et al (2011a and b) and Samper et al (2011) it is performed a study on the impact of climate change in the alluvial aquifer of Tortosa and La Plana de La Galera, concluding that the average decrease in the recharge is 20% over the period 1959-2008. In the Tortosa alluvial decreases are 5% in the period 2021-2050 and 13% in the period 2070-2099. These reductions in the recharge values are associated with similar reductions in the discharges to the river.

But the most important effect of climate change on the delta is given by the relative elevation of the sea caused by the expected rising of sea levels and the phenomenon of subsidence. In Ibáñez et al (2010) it is stated that sea level has raised 3 mm/year (based on estimates of the ICCP in 2007) with an average subsidence rate of 2 mm/year in the central part of the Delta and of 6 mm/year in the areas of greatest subsidence located near the sea. This value represents an average relative rise in sea level between 5 and 8 mm/year for the Ebro delta These figures are comparable to those estimated for the Mississippi delta (greater than 1 cm/year), Nile delta (5 mm/year); in Venice the groundwater abstraction between 1940 and 1960 caused a subsidence of 8 mm/year, while the extraction of natural gas in the Po delta has caused subsidence of up to 3 meters in some zones (Day, 1996). Subsidence values in the Ebro Delta were analyzed in Section 4.5.1, concluding that is not clearly proven the process of overall subsidence of the delta from the construction of the Mequinenza-Ribarroja-Flix dams.

The effects of climate change on the Ebro Delta have recently been studied in detail in Generalitat of Catalonia (2008), which has conducted a simulation of the status of the Delta in:

- A: Time horizon of 2050 with a rise in sea level of 15 cm (scenario A1B of IPCC, 2007)
- B: Time horizon of 2100 with an increase in sea level of 40 cm (scenario A1B of IPCC, 2007)
- C: Time horizon of 2100 with an increase in sea level of 1 m (pessimistic scenario of IPCC, 2007)

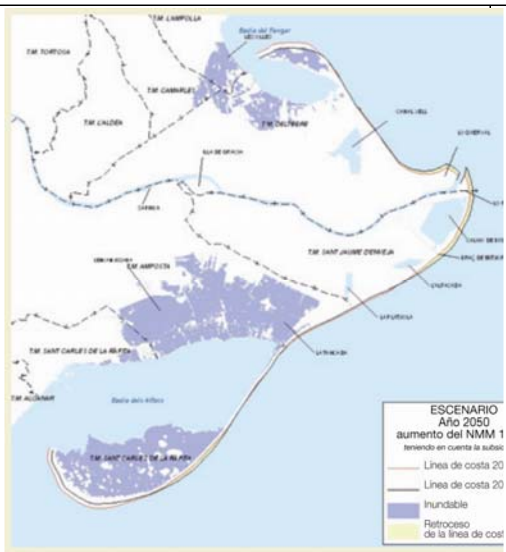
The simulation results show a decline of the coastline as shown in Table XIX, where setbacks may be observed in the entire front of coast except in the headlands of El Fangar and Banya and also on the beaches of Eucalyptus, Serralo and Migjorn.

It has been estimated that only 6.688 ha of paddy are not at risk of being flooded (Figure 33). This represents 27% of the total area under rice cultivation in the Ebro delta. In addition, ther will be other impacts to economic sectors as marine and inland fisheries, aquaculture, tourism and urbanized areas (Riumar, Poblenoy del Delta, Els Muntells or Els Eucalyptus) and natural areas.

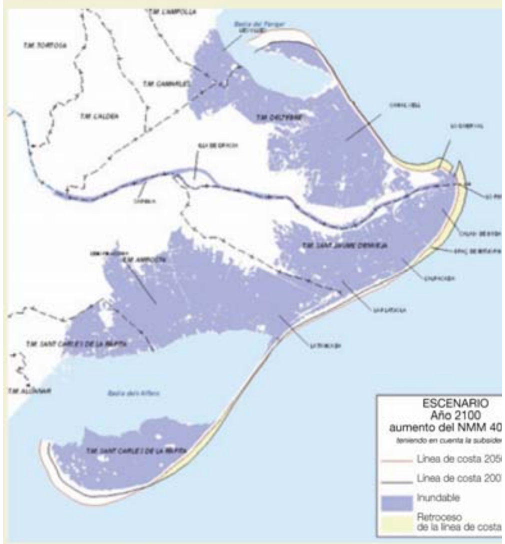
Table XIX: Average total setback of the shoreline in meters to the 2007 waterfront (Generalitat de Catalunya, 2008). In positive: coastal retreat; Negative: coast advance.

	Scenario A 2050-0,15m	Scenario B 2100-0,40 m	Scenario C 2100-1,00 m
Fangar Peninsula	-339	-729	-694
La Marquesa Beach	20	50	90
Riumar and Cap Tortosa Beaches	205	448	488
Serrallo and Migjorn Beaches	-111	-235	-197
Eucaliptus Beach	-68	-142	-106
Trabucador Beach	16	40	76
La Trinidad Salinas	158	346	383
La Banya Headland	-245	-526	-494

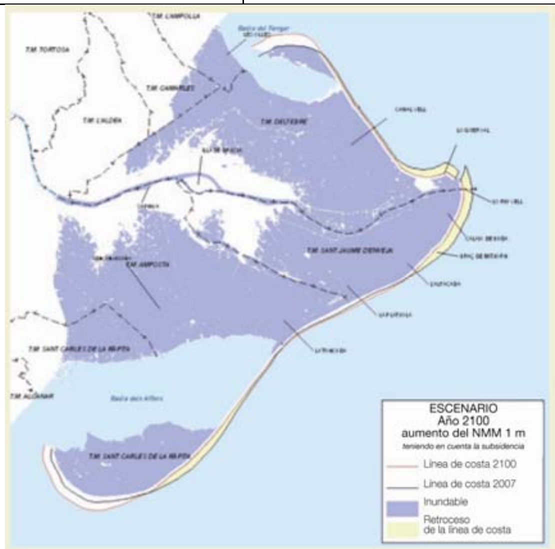
Figure 33: Prognosis of floodplain considering several hypotheses of average increase in sea level (Generalitat de Catalunya, 2008).



A- 2050 y 15 cm



B- 2100 y 40 cm



C- 2100 y 1 m

Adaptation measures in the Ebro delta for climate change proposed in Generalitat de Cataluña (2008) are:

- Measures of management, planning and policy: creation of a figure of observation and monitoring of the effects of climate change in the delta; development of a Master Plan for prevention and adaptation measures; adequacy of public domain shoreline to the prognosis of risk of sea level rise; adaptation of territorial and sectoral plan; adaptation of urban planning in the areas of irrigation, Adaptation of the boundaries of protected areas; inclusion of the necessary construction criteria and technical evaluation; establishement of monitoring and health prevention systems; establishment of control systems to anticipate and prevent pests and diseases affecting agricultural production, fish and shellfish; and establishment of systems of environmental quality control.

- Measures for the collection and management of data and development of studies; implementation of bathymetry and detailed maps of the coast; subsidence monitoring; status of the salt wedge; populations of individual species; conservation of genetic patrimony; control of lagoons, bays and wetlands; impact on the productive sectors; study on the use of rice varieties with lower water requirements; optimization systems for water resources; control of parasites and other pest vectors; assessment of coastal infrastructure functionality; valuation of sand reservoirs; prognosis and monitoring. The importance of rigorous technical and scientific studies has been emphasized recently.

- Measures for information and public awareness: specific programs and development of early warning systems.

- Measures of direct intervention:

+ On environmental issues: measures to address the lack of vertical accretion (use of reservoir sediments, enhance wetlands, use of silt bays to fill the lower areas of the deltaic plain); measures to solve the salt wedge issues; minimization of the rigidization on the coast; installation of green filters and regulation of effluents discharged into lakes and bays.

+ General: on the waterfront measures of various kinds are propsed depending on the area (no intervention, managed redefinition, hard measures and soft measures, measures to reclaim land from the sea): formation of dune systems; natural habitats compensation; progressive abandonement of urban zones and activities in risk areas; construction of levees, beach regeneration; measures for the maintenance of a minimum flow in the river Ebro and measures to guarantee the free movement of sand.

4.5.10. - Navigation

The Ebro delta was an important waterway until the nineteenth century, when social changes led to a neglect of rural areas and a transformation of the means of transport in the development of internal combustion engine. This was coupled with the construction of the Mequinenza, Ribarroja and Flix dams around half century, which turned into hydraulic barriers that prevented the passage of ships.

During the 80's and early 90, different studies were conducted for the recovery of navigation in the river Ebro. The goal of river navigation was the tourism development in the area. In 1996 the agency responsible for managing the recovery and maintenance of navigability in the lower Ebro is the Institute for the Development of Ebro Region (*Instituto para el DEsarrollo de las Comarcas del Ebro*, IDECÉ) which proposed a series of actions to promote navigability.

These actions include the construction of 24 piers, six of which have a ramp fro vehicles vehicles (Amposta, Tortosa, Cherta, Mora la Nova-Mora d'Ebre and Garcia) as well as the restoration of the Cherta lock to facilitate the passage of vessels. With these measures a navigable river from Ascó to the mouth has been accomplished with the following features:

- From Ascó to Tortosa, with a navigable channel between 20 and 50 m wide and 1.5 meters deep. This will allow the passage of boats which have a depth of 0.8 m.

- From Tortosa to Amposta, a navigable channel between 20 and 50 m in width and a depth of 2 m to allow the passage of vessels with a draft of 1.5 m.

- Downstream of Amposta the channel deepens and adaptation measures are not required.

The minimum flow for the river to be navigable is 125 m^3/s from Ascó to Cherta weir and 80 m^3/s from the weir to Tortosa (Generalitat de Catalunya, 2010). These values are consistent with the environmental flows established in CHE (2012B) which enables the development of boating activities. Historical experiences of navigation with summer low water flows indicate that the flows proposed by Generalitat of Catalunya (2010) are clearly on the side of safety.

5. - CONCLUSIONS

A review of studies related to the main environmental aspects of the lower Ebro has been carried out. As a result, it has been proposed an environmental flow regime for the water body nº 463 (River Ebro from River Canaleta to Tortosa gauging station) and for the mouth. In the Tortosa gauging station the minimum ecological flow has been set in 80 m^3/s, well above the rate observed in the historical series before the commissioning of the Mequinenza Ribarroja-Flix reservoirs, so that there is empirical evidence on these flows to be assumable by the natural environment.

The monthly environmental flow regime for Tortosa gauging station is:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
80	80	91	95	150	150	91	91	81	80	80	80

Representing an annual volume of 3,010 hm^3 for meeting the environmental needs of the river at this point, to which must be added two artificial floods of 1,000-1,500 m^3/s intended for renaturing the flow regime and especially for reducing the invasion of macrophytes. This flow rate is 300% higher than the rate established for the rest of the rivers of the Ebro basin. This is (mainly) possible because of the regulation capacity of the Mequinenza reservoir.

Environmental flows set for the Delta are formed by minimum flows established for the Tortosa gauging station, floods released to restore river configuration, contributions from the delta channels in the left and right margin of the Ebro with environmental significance, notwithstanding the prominence of concession rights that assist such channels, and natural discharge of groundwater. At the mouth of the River Ebro the following values are estimated:

Data in m^3/s

oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
80	100	100	120	150	155	100	100	100	100	100	80

Representing an annual volume of 3,370 hm^3 designed for meeting the environmental needs.

A comprehensive study has been carried out on the environmental aspects of the lower reaches of the river Ebro and its delta (subsidence and sediments, morphological changes, habitat of remarkable species, environmental effects of flow discharged to the delta and bays as well as groundwater discharges, inputs of salts and nutrients –salinity, pH evolution, temperature, phosphates and nitrates–, macrophytes, salt wedge, eustatic component, navigation and climate change). The main conclusion of the analysis is that the proposed flow regime is consistent with the preservation of the environmental characteristics of the Ebro delta. However, taking into account the precautionary principle, it is considered necessary to continue conducting all the necessary studies to assess the future development of the environmental performance of the Ebro delta.

The principle of basin unity and integrated management from Reinosa to the Delta and from the Pyrenees to the Iberian Cordillera strengthens the maintenance of the whole water environment of the Ebro basin.

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ANNEXES

ANNEX I. Bibliography on regulatory environmental flows in the Delta of the California Bay

GENERAL VALUES FOR THE DEFINITION OF THE BASINS

Basin of the Sacramento River:

http://www.waterplan.water.ca.gov/docs/cwpu2009/0310final/v3_sacramentoriver_cwp2009.pdf

- Area: 70.567,14 km^2 (27.246 $miles^2$)
- Length of the river: 526,3 m (327 miles) (http://ca.water.usgs.gov/sac_nawqa/study_description.html)
- Average discharge in natural regime: 27.616,4 hm^3/year or 875,7 m^3/s (22.389.000 acre-foot/year)

Basin of the San Joaquín river:

http://www.waterplan.water.ca.gov/docs/cwpu2009/0310final/v3_sanjoaquinriver_cwp2009.pdf

- Area: 82.879,6 km^2 (32.000 $miles^2$)
- Length of the river: 482,8 m (300 miles)
- Average discharge in natural regime: 2.220,3 hm^3/ year or 70,4 m^3/s (1.800.000 acre- foot/year)

Minimum flows required in the Delta of California Bay

http://deltacouncil.ca.gov/sites/default/files/documents/files/Fifth_Staff_Draft_Delta_Plan_080211.pdf (pages 84-86)

The competent authority in the areas of water rights, protection of water quality and definition of the criteria required minimum flows or is "State Water Resources Control Board" (SWRCB). The agency is currently working on the definition of these flows in the Delta and its major tributaries, the Sacramento and San Joaquin rivers, the process is expected to be completed in June this year 2012. Meanwhile, current flows are established by the SWRCB in the Water Law Decision 1641 (D1641), available at: http://www.waterboards.ca.gov/waterrights/board_decisions/adopted_orders/decisions/d1600_d1649/wrd1641_1999dec29.pdf (Table 1).

The SWRCB has recently other studies related to updating the flow requirements for the delta and its major tributaries. In 2010, they published the paper entitled "Development of flow criteria for the Delta ecosystem of the Sacramento-San Joaquin rivers" ("Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem"), available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/final_rpt080310.pdf. This report proposes the flows that would be required in the Delta if the sole purpose was the protection of fishery resources. Therefore, this report presents the findings in relation to the request flow to meet one of the factors taken into account, lacking flow analysis for the fulfillment of the objectives of satisfying demands and other uses, such as recreation.

Table 1. Average monthly minimum flows at the mouth of the Sacramento and San Joaquin (D1641).

	Monthly minimun average flow (m^3/s)[1]			Monthly minimun average flow (m^3/s)[2 y 3]					
	Gauging Station D-24 (RSAC101)			Gauging Station C-10 (RSAN112)					
	Sacramento river at Río Vista			San Joaquín river at Way Bridge Airport, Vernalis					
	Hydrological year type[4]			Hydrological year type[4]					
	All	W, AN, BN, D	C	All	W	AN	BN	D	C
October		113,27	84,95	28,32[5]					
November		127,43	99,11						
December		127,43	99,11						
January									
February					60,31 or 96,84	60,31 or 96,84	40,21 or 64,56	40,21 or 64,56	20,10 or 32,28
March					60,31 or 96,84	60,31 or 96,84	40,21 or 64,56	40,21 or 64,56	20,10 or 32,28
1 to 14 April					60,31 or 96,84	60,31 or 96,84	40,21 or 64,56	40,21 or 64,56	20,10 or 32,28
15 to 30 April					207,56 or 244,09[6]	162,26 or 198,78[6]	130,82 or 155,18[6]	113,83 or 138,19[6]	88,07 or 100,24[6]
1 to 15 May					207,56 or 244,09[6]	162,26 or 198,78[6]	130,82 or 155,18[6]	113,83 or 138,19[6]	88,07 or 100,24[6]
16 to 31 May					60,31 or 96,84	60,31 or 96,84	40,21 or 64,56	40,21 or 64,56	20,10 or 32,28
June					60,31 or 96,84	60,31 or 96,84	40,21 or 64,56	40,21 or 64,56	20,10 or 32,28
July									
August									
September	84,95								

[1] The 7-day average shall not be less than 28.32 m3/s below the monthly target.

[2] In this period averaged partial months. For example, the average flow for the period from May 1 to April 14 was calculated on 14 days. The 7-day average shall not be less than 20% below the target flow, with the exception of the period between April 15 and May 15, as a pulsatile flow period.

[3] The water year classification for purposes of flow in the San Joaquin River will be established using the best available estimate for the classification of the water year in the San Joaquin Valley 60-20-20 with 75% level of improvement. The higher flow objective applies where an 2-ppt isohaline (measured as 2.64 mmhos/cm surface salinity) at or west of Chipps Island.

[4] The water year categories are: W for a wet year to one year AN above normal BN dbajo for one year by the normal D to dry one year to one year and C critical.

[5] Sumar up to 34.5 additional hm3 flow situation or pulsed flow of attraction for migratory species during all types of water year. The amount of additional water is limited to the amount necessary to provide a monthly average flow 56.63 m3/s. The additional 34.5 hm3 not require critical year in the second row. The pulse rate will be scheduled eh by the Department of Water Resources California (California Department of Water Resources (DWR)) and the Bureau of Reclamation (Bureau of Reclamation (USBR)) in collaboration with the American Fisheries and Wildlife (U.S. Fish and Wildlife Service (USFWS)), the National Marine Fisheries (National Marine Fisheries Service (NMFS) and the Department of Fish and Game (Department of Fish and Game (DFG)). Consultation with the Operations Group CALFED Program established under the framework agreement will satisfy the requirement of the query.

[6] This period between April 15 and May 15 can vary depending on the actual flow rates obtained. A pulse, or two separate pulses equals the combined duration single pulse, should be scheduled to coincide with the migration of fish in the tributaries of the San Joaquin River and the Delta. The Bureau of Reclamation (Bureau of Reclamation (USBR)) will schedule the time period of the pulses in collaboration with the American Fisheries and Wildlife (U.S. Fish and Wildlife Service (USFWS)), the National Marine Fishery Resources (National Marine Fisheries Service (NMFS) and the Department of Fish and Game (Department of Fish and Game (DFG)). Consultation with the Operations Group CALFED Program established under the framework agreement will satisfy the requirement of consultation. planning is subject to approval by the Executive Director of the Control Body of water resources of the State (State Water Resources Control Board (SWRCB)).

Clasification of the hydrological year in the Sacramento River:

The clasification of the hydrological year is determined using the following formula:

INDEX = 0.4 . X + 0.3 . 0.3 . Y + Z

where:

X = The natural flow of a typical year in the Sacramento River Valley in the months of April to July

Y = The natural flow in the Sacramento River Valley in the months of October to March

Z = Index of the previous year (with a maximum of 12,335 hm^3 as a reserve for the required flood control during wet years)

The natural flow in the current year (from October 1 of the previous year to 30 September of this year) in the Sacramento River Valley, as published in Bulletin 120 of the Department of Water Resources, of California, is a estimate of the sum of the following spots: Sacramento River upstream of Bend Bridge near Red Bluff, Feather River, total water input in the Oroville Reservoir, Yuba River in Smartvill, American River, total water input in the Folsom Reservoir. Preliminary assessments of the clasification of the hydrological year must be made in February, March and April with a final determination in May and should be based on hydrologic conditions to date plus the natural flow planned for the future assuming normal rainfall for the rest of the hydrological year.

Hydrological year Clasification[1]	Índice (hm^3)
W- Wet	Equal to or above 11.348
AN- Above normal	Above 9.621 & below 11.348
BN- Below normal	Equal to or below 9.621 & above 8.018
D- Dry	Equal to or below 8.018 & above 6.661
C- Critical	Equal to or below 6.661

[1] The type of hydrological year assessed for the previous one will remain in forcé until the preliminary assessment of natural flow for the current year becomes available.

Clasification of the hydrological year in the San Joaquín River:

The clasification of the hydrological year is determined using the following formula:

INDEX = 0,6 . X + 0,2 . Y + 0,2 . Z

where:

X = The natural flow of a typical year in the San Joaquín River Valley in the months of April to July

Y = The natural flow in the San Joaquín River Valley in the months of October to March

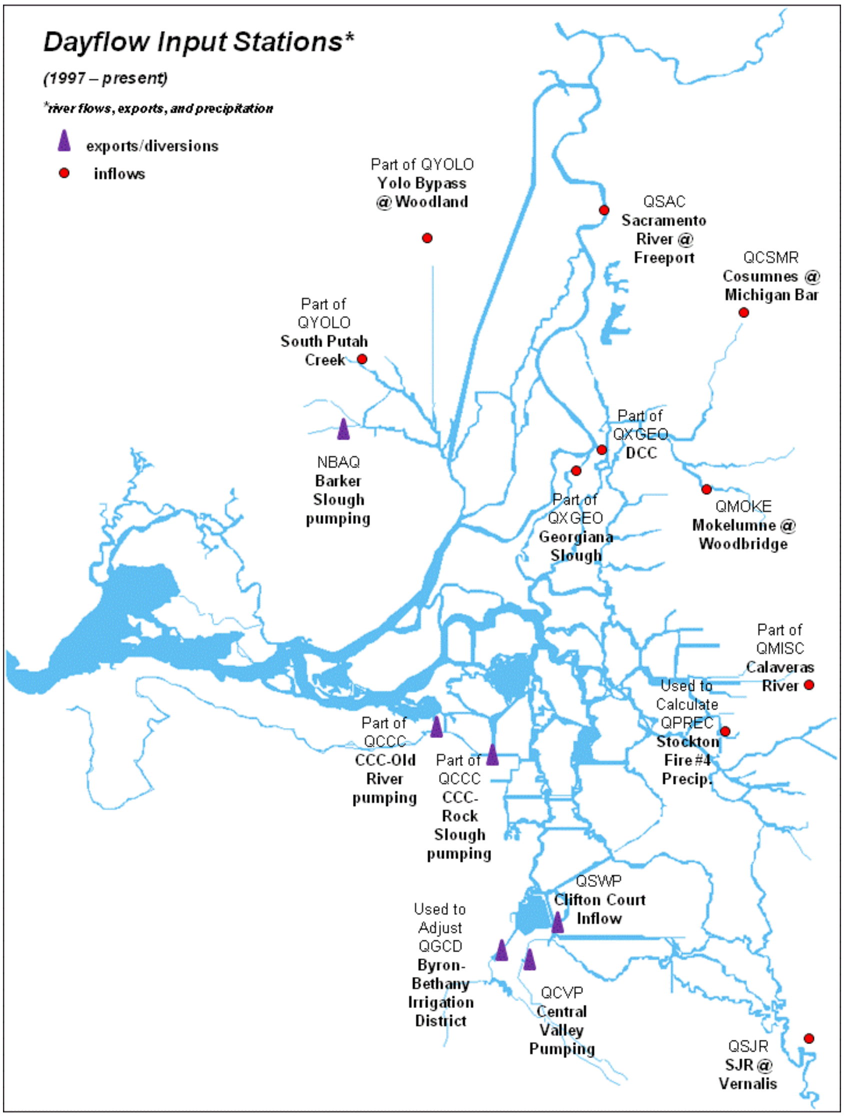
Z = Index of the previous year (with a maximum of 5.551 hm^3 as a reserve for the required flood control during wet years)

The natural flow in the current year (from October 1 of the previous year to 30 September of this year) in the Sacramento River Valley, as published in Bulletin 120 of the Department of Water Resources, of California, is a estimate of the sum of the following spots: Stanislaus River, total water input in the New Melones Reservoir, Tuolumne River, total water input in the Don Pedro Reservoir, Merced River, total water input in the Exchequer Reservoir, San Joaquín River total water input in the Millerton Lake. Preliminary assessments of the clasification of the hydrological year must be made in February, March and April with a final determination in May and should be based on hydrologic conditions to date plus the natural flow planned for the future assuming normal rainfall for the rest of the hydrological year.

Hydrological year Clasification[1]		Índice (hm^3)
W-	Wet	Equal to or above 4.687
AN-	Above normal	Above 3.824 & below 4.687
BN-	Below normal	Equal to or below 3.824 & above 3.084
D-	Dry	Equal to or below 3.084 & above 2.590
C-	Critical	Equal to or below 2.590

[1] The type of hydrological year assessed for the previous one will remain in forcé until the preliminary assessment of natural flow for the current year becomes available.

http://www.water.ca.gov/dayflow/



ANNEX II. Bibliography on regulatory environmental flows in Murray Darling River Basin (Australia)

Murray River Basin:

http://www.mdba.gov.au/draft-basin-plan/draft-basin-plan-for-consultation

- Extension: 1.060.000 km^2
- Average discharge in natural regime (Table 1 - Schedule 1, page 127): 31.599 GL/year

Table 1. Long term average water inout and water use in the Murray-Darling River Basin

MDB average long-term annual inflow and water use	
Surface water	**GL**
Inflows	
Inflows to the Basin	31,599
Transfer into the Basin	954
Total	**32,553**
Water Use	
Watercourse diversions	**10,903**
Interceptions	2,720
Water used by the environment & losses	13,788
Outflows from the Basin	5,142
Total	32,553

Minimum flows required at the mouth of the Murray River

http://www.mdba.gov.au/bpkid/bpkid-view.php?key=yYwsBnGLSc4VQrHGEAqDviQmAfWf1/YV4EE/1ZKRWxo=

For the assessment of the water needs to meet the environmental requirements in the Proposal of the Murray-Darling Basin Plan, it was produceed a Report entitled "Water Resource Assessments for without-development and baseline conditions", published in November of 2011. This paper provides an estimate of the water balance of the watershed through the implementation of the two following hydrological models (data for the period from July 1895 to June 2009):

"Baseline Scenario": The baseline scenario represents the existing water withdrawals in June of 2009, also taking into account the water rights trading on the same date. Some of the assumptions made for the River Murray are:

- Aditional dilution flows up to 3.000 ML/d, if the volumen stored in Menindee Lakes is above 1.650 GL in the months of June and July, 1.500 GL in August and 1.300 GL in the rest of the year and the combined storage in the Hume and Dartmouth reservoirs is above 2.000 GL.
- Environmental flows released by Darling Anabranch during the periods with no allocation in the low Darling River.
- Allocation of environmental flows above 150 GL/año for the Barmah-Millewa Forest.
- Water recovered through current projects up to 500 GL (project "The Living Murray" and others).
- Water recovered through "Water for Rivers" Project and a 70 GL flow increase from thawing.

"Without-development Scenario": The model simulates the natural regime of the river. Starting from the Baseline Scenario all the dams, irrigation systems, infraestructures and consumptive uses are removed.

The results (Table 2) show that in the natural regime scenario, 76% of water contribution from the Murray Basin and the low area of the Darling River reaches the sea through the mouth of the Murray River. Nevertheless in the reference conditions, this percentage decreases by 42%, which corresponds to only 31% of the total inflows in natural condition.

Table 2. Water Balances for the Murray River system with the two models.

Water balance (GL/y)	Without-development	Baseline
Storage		
Total change in storage	-13.0	-75.4
Inflows		
Darling (inflow to Menindee Lakes)	3,092.1	1,723.2
Murrumbidgee (Balranald)	2,724.2	1,257.0
Murrumbidgee (Darlot)	123.5	320.7
Catchment managed by Snowy scheme	616.9	1,132.8
Ovens at Peechelba	1,728.2	1,686.0
Goulburn at McCoy's Bridge	3,368.0	1,665.2
Campaspe at Rochester	280.8	151.9
Loddon at Appin South	144.7	67.8
Directly gauged Murray sub-catchments	4,047.1	4,035.9
Indirectly gauged Murray sub-catchments	260.2	327.6
Total inflows	16,385.6	12,368.1
Diversions		
NSW Murray diversions	-	1,680.2
NSW lower Darling diversions	-	54.7
Victorian Murray diversions	-	1,657.0
SA Murray diversions	-	665.0
Total diversions	-	4,056.3
Losses		
Total net evaporation	427.6	611.6
Net groundwater loss	-	47.0
Total loss including SA	3,593.9	2,585.4
Total losses	4,021.4	3,244.0
Outflows		
Barrage outflow	12,377.2	5,142.4
Unattributed flux		
Unattributed flux	0.00	0.02

http://www.mdba.gov.au/draft-basin-plan/science-draft-basin-plan/assessing-environmental-water-requirements

From the document presented above, independent work for each of the major sub-basins of rivers or the Murray-Darling Basin were developed. The goal is to meet one of the requirements of the Basin Plan, namely establishing environmentally sustainable limits on the amount of surface water that could be diverted for consumptive use, called Sustainable Diversion Limits (SDLs). These limits are the máximum average annual volume of water to be drawn from the basin in the long-term, representing what is called "Environmentally Sustainable Level of Take" (ESLT).

To determine these environmental water requirements, the first step is the selection of a flow indicator in a specific spot where ecological targets haave to be met. At the mouth of the Murray River, the place selected as hydrologic indicator is one of the most important wetlands in Australia (140.500 hectareas) which includes a wide range of freshwater, estuarine and marine habitats that support unique flora and fauna species.

The development of several models for the drafting of the Basin Plan proved the impact of dams building on water resources, particularly during periods of drought. The lowest average flow for three consecutive years corresponds to the period between 2006-07 and 2008-09 for both scenarios (baseline conditions and natural regime). This average decreases by 96% in the current situation, compared to natural conditions for the same period (Table 3).

Reduced river flows linked to a greater probability of closure of the mouth of the Murray River threaten the ecological function of the Coorong Area since it tends to cause higher salinity in the system, changes in water level regime and obstruction or blockage of the fish migration paths.

Table 3. Modeled barrage flows in both scenarios (1895-2009) for the area of the mouth of the Murray River "The Coorong, Lower Lakes and Murray Mouth"

Modelled barrage flows	Without development	Baseline (current development)
Average annual	12,500 GL	5,100 GL
Wettest five years	49,000 GL (1956–57)	42,600 GL (1956–57)
	36,400 GL (1917–18)	28,300 GL (1917–18)
	34,700 GL (1955–56)	24,800 GL (1955–56)
	29,400 GL (1974–75)	23,000 GL (1974–75)
	27,700 GL (1952–53)	18,100 GL (1975–76)
Driest five years	400 GL (2006–07)	0 GL (2008–09)
	1,800 GL (1914–15)	50 GL (2007–08)
	1,800 GL (1982–83)	60 GL (1902–03)
	2,400 GL (1902–03)	80 GL (1914–15)
	2,800 GL (2008–09)	240 GL (1944–45)
Lowest three-year rolling average	2,500 GL (2006–07 to 2008-09)	100 GL (2006–07 to 2008-09)

Specified flow indicators (Table 4) are indicative of a long term flow regime necessary to achieve specific environmental objectives in the area of the mouth of the Murray River and are used to evaluate possible scenarios for the Basin Plan.

Table 4. Environmental objectives and flow indicators associated to the area of the mouth of the Murray River, called "The Coorong, Lower Lakes and Murray Mouth."

Site-specific ecological targets	Required characteristics	Site-specific flow indicators	Results under modelled without development conditions	Results under modelled baseline conditions
Maintain a range of healthy estuarine, marine and hypersaline conditions in the Coorong, including healthy populations of keystone species such as *Ruppia tuberosa* in South Lagoon and *Ruppia megacarpa* in North Lagoon	**South Lagoon salinity**	**Barrage flow**		
	average long-term salinity <60,000 mg/L.	Long-term average at least 5,100 GL/y.	12,500 GL/y	5,100 GL/y
	maximum salinity <100,000 mg/L in 95% of years.	Rolling 3-year average >2,000 GL/y in 95% of years.	100% of years	79% of years
	maximum salinity <130,000 mg/L in 100% of years.	Rolling 3-year average >1,000 GL/y in 100% of years.	100% of years	91% of years
		Maintain at least the proportion of years with high flows (5,100–10,000 GL/y) that is experienced under baseline conditions.	Flows >5,100 GL/y: 89% of years	Flows >5,100 GL/y: 36% of years
	North Lagoon salinity average annual salinity <20,000 mg/L in a proportion of years; maximum salinity <50,000 mg/L	Same as above	Same as above	Same as above
Provide sufficient flows to enable export of salt and nutrients from the Basin through an open Murray Mouth	**Salt export** 2 million tonnes per year, reported on a rolling 10 year average basis.	NA	NA	NA
Provide a variable lake level regime to support a healthy and diverse riparian vegetation community and avoid acidification	**Lake levels** Lakes Albert and Alexandrina water levels >0 m AHD.	None additional to those above. Modelling will test the assertion that delivery of above flows will provide appropriate lake levels.	N/A	N/A

Hydraulic Models in the Murray-Darling River Basin

http://www.mdba.gov.au/draft-basin-plan/science-draft-basin-plan

The Basin Plan Proposal recommends Long-Term Average Sustainable Diversion Limits (SDLs), which are expected to come into force in 2019, along with a series of measures to improve water management in the basin. These SDLs are proposed water volume limits that can be extracted for different uses (including households, urban and agricultural uses) and are determined on the basis of the evaluation of an Environmentally Sustainable Level of Take (ESLT).

Hydrological models are used to represent and evaluate the environmental requirements and necessary water flow regimes. Two different approaches are used: the first is to estimate the environmental flows that can be obtained from a specific reduction of withdrawals; and the second is to estimate the reduction needed to achieve specified environmental water requirements.

The surface water resources of the basin are represented from the joint of twenty-four sub-basins, allowing to evaluate a wider range of posible responses to changes in flow regime as a result of water recovery in different parts of the basin.

Modeling for the Basin Plan is done by simulating a reduction in consumptive water use, releasing an equivalent volume of water available for environmental uses in the current reference conditions.

The key scenarios modelled are "Without development" –natural regime, "Baseline"– current conditions in June of 2009 and a reduction of 2,800 GL of water in the basinSensitivity analysis were also performed for one of the systems (Southern Connected System – basins of the Murray, Murrumbidgee and Goulburn-Broken), based on two other scenarios with a reduction of withdrawals of 2,400 GL and 3,200 GL.

Therefore, in the Murray River basin three scenarios are modeled, reductions in consumptive use of 2,400 GL/year, 2,800 GL/y and 3,200 GL/year in four areas: Yarrawonga, Torrumbarry, Euston and southern border of Australia. The results show that there are significant environmental improvements. However, the objectives for environmental indicators requiring high flow events for the benefit of communities are not met due to capacity constraints in the channels. A reduction in consumptive use of 2,400 GL/year is not enough to get the key environmental objectives in the Murray River downstream of the inflow of its tributary Murrumbidgee (including the mouth), while a reduction of 3,200 GL/year allows little additional benefit tan the scenario of 2,800 GL/year.

Apart from the sensitivity analysis, the general conditions in the other two simulations are:

- "Without-development scenario": It is a model that simulates the natural river regime. Starting from the baseline scenario and considering that all the dams, irrigation systems, infrastructure and consumptive uses of the system are eliminated.
- "Baseline scenario": The baseline scenario represents the existing water withdrawals in June of 2009, also taking into account the water rights trading on the same date. Some of the conditions used for the River Murray are:
  - Aditional dilution flows up to 3.000 ML/d, if the volumen stored in Menindee Lakes is above 1.650 GL in the months of June and July, 1.500 GL in August and 1.300 GL in the rest of the year and the combines storage in the Hume and Dartmouth reservoirs is above 2.000 GL.
  - Environmental flows released by Darling Anabranch during the periods with no allocation in the low Darling River.
  - Allocation of environmental flows above 150 GL/año for the Barmah-Millewa Forest.
  - Water recovered through current projects up to 500 GL (project "The Living Murray" and others).
  - Water recovered through "Water for Rivers" Project and a 70 GL flow increase from thawing.

The results for the environmental water needs are shown in Table 5.

Table 5. Withdrawals in the reference conditions and necessary anual reduction for the three scenarios: 2.800 GL, 2.400 GL y 3.200 GL.

Diversions (GL/y)	Baseline	BP-2800	BP-2400	BP-3200
Murray	**4017**	**2852**	**3107**	**2710**
NSW	1696	1182	1302	1124
Victoria	1656	1159	1253	1082
South Australia	665	511	552	504
Lower Darling	**55**	**39**	**42**	**36**

In the area of the mouth of the Murray River, environmental indicators to be met are (Table 6):

Table 6. Environmental flows and indicators of salinity in the area called "The Coorong, Lower Lakes and Murray Mouth".

Indicator	Target
Average salinity (g/L) in Coorong southern lagoon over model period	less than 60 g/L
Maximum salinity (g/L) in Coorong southern lagoon over model period	less than 130 g/L
Max period (days) salinity in Coorong southern lagoon is greater than 130 g/L	0 days
Proportion of years salinity in Coorong southern lagoon < 100 g/L	greater than 95%
Average salinity (g/L) in Coorong northern lagoon over model period	less than 20 g/L
Maximum salinity (g/L) in Coorong southern lagoon over model period	less than 50 g/L
Max period (days) salinity in Coorong northern lagoon is greater than 50 g/L	0 days
Proportion of years 3 year rolling average barrage flow greater than 1,000 GL/yr	100%
Proportion of years 3 year rolling average barrage flow greater than 2,000 GL/yr	greater than 95%

Table 7 presents the the water balances results, showing that water inflows vary as a result of the different withdrawal reduction in the three scenarios of the Basin Plan, leading to an increase in the flow of Murray river tributaries of 1,069, 1,159 and 1,358 GL/year respectively. Also, a reduction in the withdrawal of, respectively; 948, 1,178 and 1,349 GL/year is reached for the Murray and Low Darling rivers under the three scenarios considred. Moreover, as a result of the release of water to the environment and the reduction of withdrawal, the outflows of the reservoirs are increased by an average of 1,728, 2,068, 2,389 GL/year respectively for the three scenarios, indicating that an amount of significant additional water can be recovered for the environment and reach the mouth of the Murray river, although it will be used in other areas, benefitting the river and its floodplain.

Tabla 7. Key water balances in the Murray River Region.

Water balance Items	Without development GL/y	Baseline GL/y	BP-2400 GL/y	BP-2800 GL/y	BP-3200 GL/y
Inflow (GL/y)	**16386**	**12383**	**13399**	**13542**	**13741**
NSW	5940	3317	3905	3975	4069
Victorian	5782	3866	4294	4367	4472
Shared	4664	5200	5200	5200	5200
Diversions (GL/y)	0	4070	3122	2892	2721
NSW Murray	0	1696	1277	1180	1099
NSW Lower Darling	0	55	42	40	36
Victoria	0	1654	1251	1161	1081
South Australia	0	665	522	511	504
Loss (GL/y)*	4008	3225	3461	3494	3543
Outflow (GL/y)	12377	5088	6816	7156	7477

* Loss includes unattributed loss and change in storage

Water regulation and water withdrawals in the current situation are leading to a 59% reduction of flow at the mouth of the Murray-Darling system, compared to the natural regime scenario. Flows at the end of the system increases in all three scenarios of the Basin Plan. Increases in the quantity of reclaimed water in the basin of 2,400-3,200 GL correspond to long-term average increase of of 661 GL/year at the end of the system. At the mouth of river the magnitude of the flow also increases while the zero flow period decreases for the three scenarios, when compared to baseline conditions. The effect of this flow iimprovement is a substantial difference in lake levels and salinity in the Coorong area.

In the area of the mouth of the Murray River, called "Coorong, Lower Lakes and Murray Mouth", the simulations show that the specified environmental objectives are achieved in the following cases (Table 8):

Tabla 8. Achievement of flow and salinity indicators in the area of the mouth of the River Murray in all simulated scenarios.

Indicator	Target	Without development	Baseline	BP-2400	BP-2800	BP-3200
Average salinity (g/L) in Coorong southern lagoon over model period	less than 60 g/L	24	62	47	44	41
Maximum salinity (g/L) in Coorong southern lagoon over model period	less than 130 g/L	67	291	138	119	97
Max period (days) salinity in Coorong southern lagoon is greater than 130 g/L	0 days	0	323	64	0	0
Proportion of years salinity in Coorong southern lagoon < 100 g/L	greater than 95%	100%	82%	96%	96%	100%
Average salinity (g/L) in Coorong northern lagoon over model period	less than 20 g/L	12	29	22	21	20
Maximum salinity (g/L) in Coorong northern lagoon over model period	less than 50 g/L	49	148	75	56	47
Max period (days) salinity in Coorong northern lagoon is greater than 50 g/L	0 days	0	604	163	75	0
Proportion of years 3 year rolling average barrage flow greater than 1,000 GL/yr	100%	100%	91%	99%	99%	99%
Proportion of years 3 year rolling average barrage flow greater than 2,000 GL/yr	greater than 95%	100%	79%	96%	98%	99%

ANNEX III. Bibliography on regulatory environmental flows in the Colorado River Basin (USA-México)

Colorado River Basin

http://www.waterencyclopedia.com/Ce-Cr/Colorado-River-Basin

- Extension: 637.000 km^2
- River Length: 2.330 km
- Average discharge in natural regime: 700 m^3/s (22.075 hm^3/year)

Note: Natural regime between years 1916 and 2003according to the article "Response of Colorado River runoof to dust radiative forcing in snow" (http://www.pnas.org/content/107/40/17125.full) is 18,3 bcm/año or 18.300 hm^3/year (reference to webpage http://www.usbr.gov/lc/region/g4000/NaturalFlow/current.html).

Mínimum flows required in the lower Colorado River

http://www.lcra.org/library/media/public/docs/water/wmp/ExhibitA_ProposedWMP_with_Appendices_Mar2012.pdf (pages 2-8 y 2-9)

Minimum flows in Colorado River upstream Matagorda Bay and California Gulf are determined in the "Lakes Buchanan and Travis Water Management Plan and Drought Contingency Plans".

Tabla 1. Minimum monthly flows of Colorado River in Wharton.

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
Subsistence[1]	4,20	4,94	5,77	9,00	8,66	5,83	7,71	8,69	10,60	6,06	3,06	5,37
Base-Dry[2]	10,29	13,86	13,43	14,06	17,06	15,17	16,03	28,14	28,11	16,49	8,97	11,71
Base-Average[2]	21,40	21,83	21,31	23,94	25,89	29,60	28,89	39,91	43,20	25,86	14,91	17,63

[1] Represent minimum conditions at which water quality is maintained at acceptable levels and aquatic habitats are expected to be consistent with those found in natural settings during drought conditions.

[2] The base flow recommendations provide habitat conditions and year-to-year variability sufficient to maintain a sound ecological environment.

The study for assessing minimum flows recommends to keep the flow above the subsistence level all the time. In relation to the base flow, it is recommended, on a long-term basis, maintain the Base-Dry recommendations about 80% of the time and Base-Average recommendations about 60% of the time.

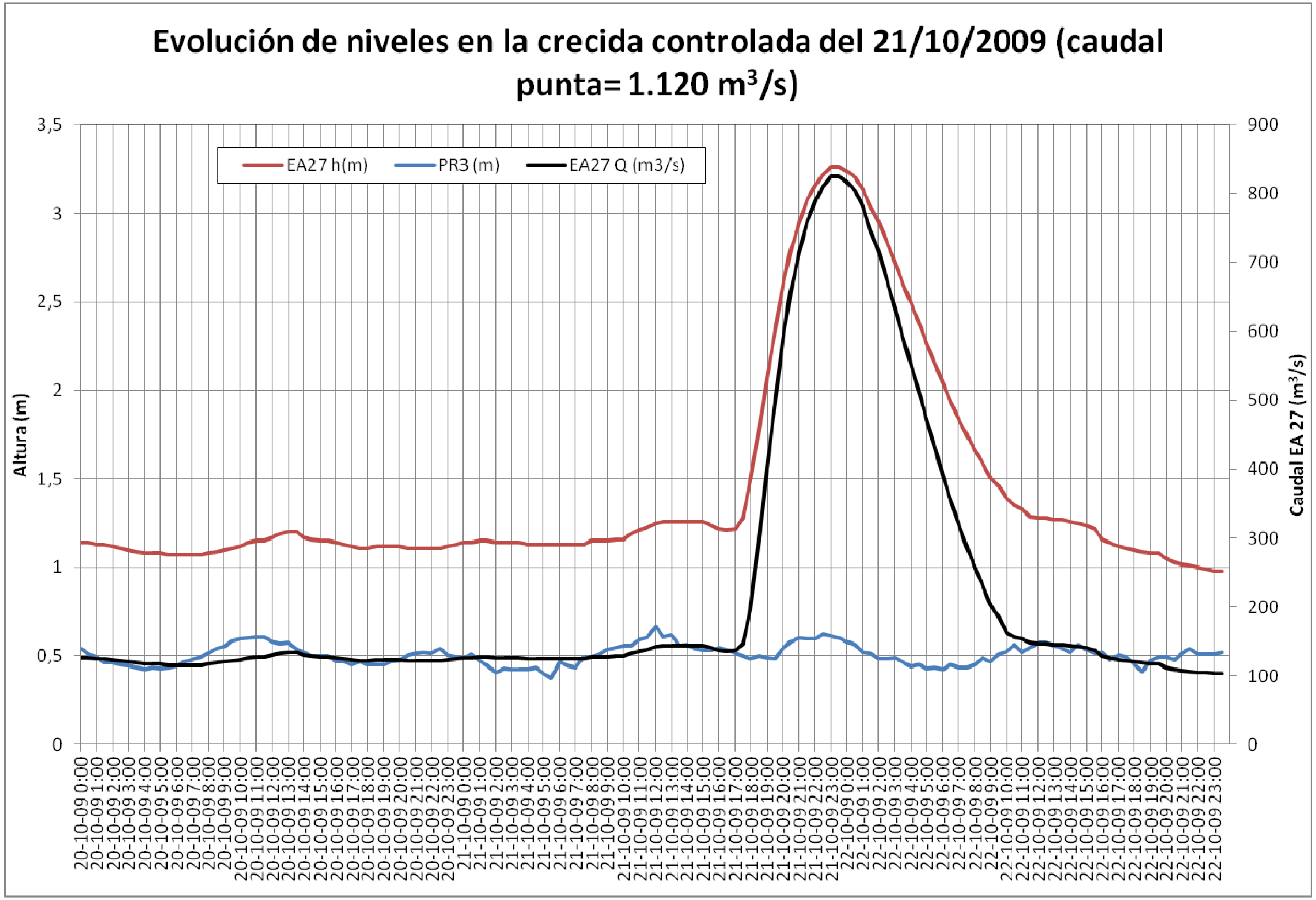
Actual flows in the lower Colorado River

http://waterdata.usgs.gov/nwis

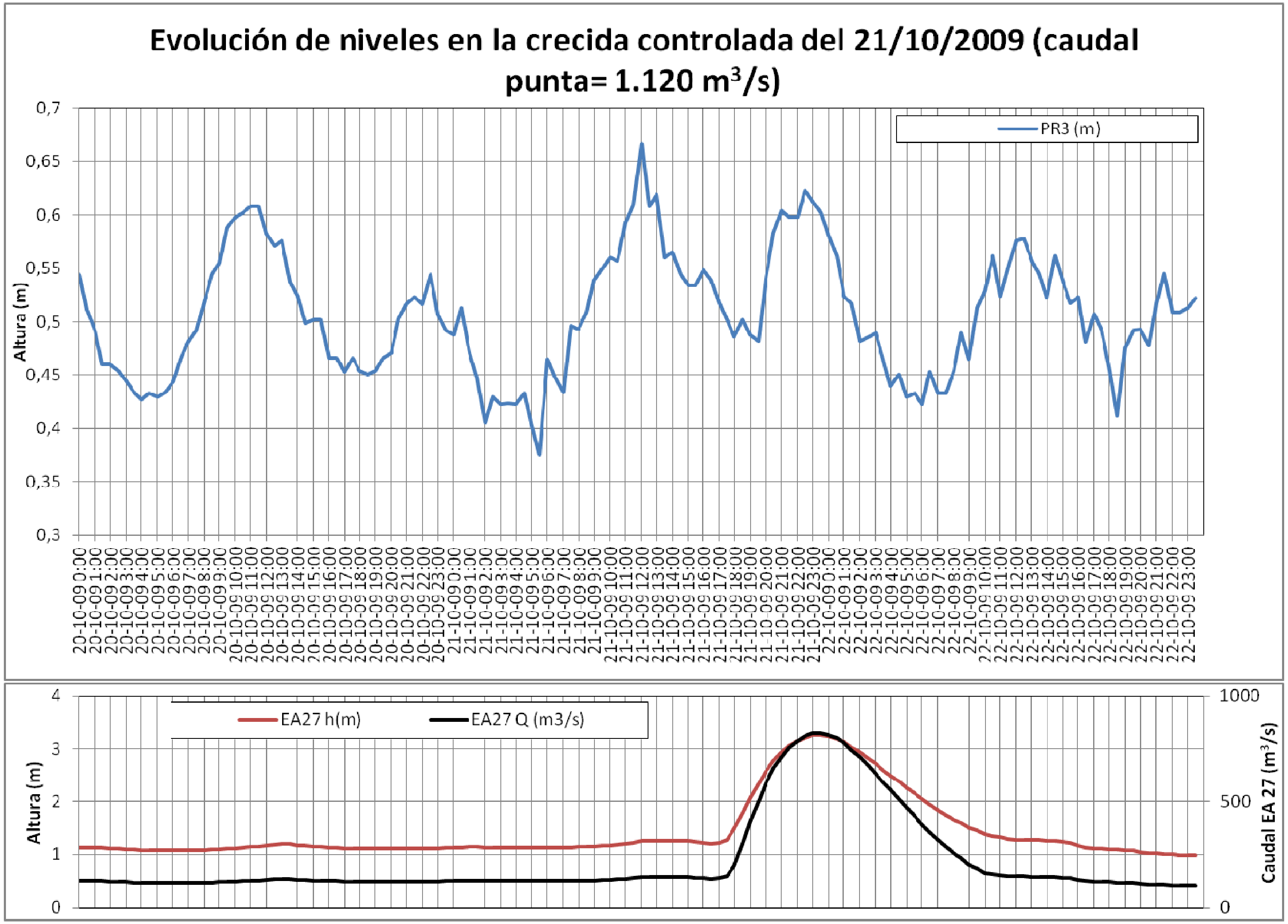
The data are recorded by the gauging station number 08162000 of Colorado River at Wharton belonging to USGS (U.S. Geological Survey), period 1938-2011.

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
Mínimo	3,06	3,51	2,43	4,94	6,11	4,20	3,46	3,00	2,34	2,69	1,20	4,54
Percentil 5	10,06	8,76	8,60	7,97	8,80	9,29	12,40	15,58	20,00	18,06	12,40	12,80
Percentil 10	12,06	10,23	9,83	10,20	11,26	10,97	16,17	19,57	23,39	21,20	15,72	15,80
Percentil 25	16,71	15,14	14,66	16,56	17,57	17,17	23,86	28,13	32,57	28,43	21,94	22,24
Percentil 50	28,00	26,67	27,94	36,00	35,71	35,43	42,00	47,71	49,71	39,14	30,86	34,29
Percentil 75	56,57	69,07	73,14	80,00	86,79	92,29	89,71	103,14	105,93	71,71	45,43	53,64
Percentil 90	118,06	156,29	128,23	137,14	173,31	186,57	172,29	230,23	282,89	144,11	70,29	86,29
Máximo	2.088,57	2.411,43	1.745,71	1.234,29	1.597,14	1.457,14	1.494,29	1.437,14	1.708,57	2.588,57	362,86	1.582,86

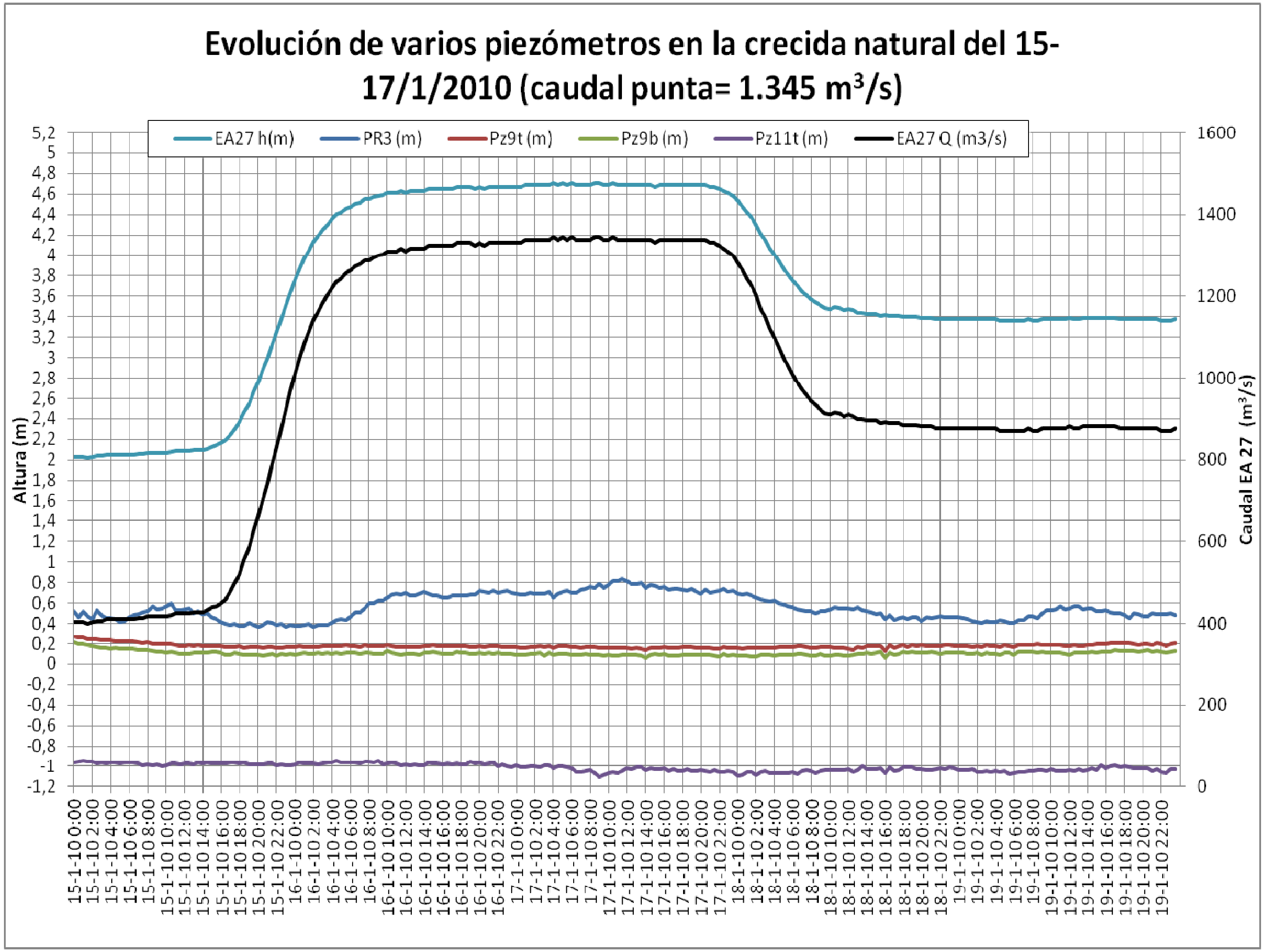
ANNEX IV. Evolution of piezometers close to the Ebro River during three flood events



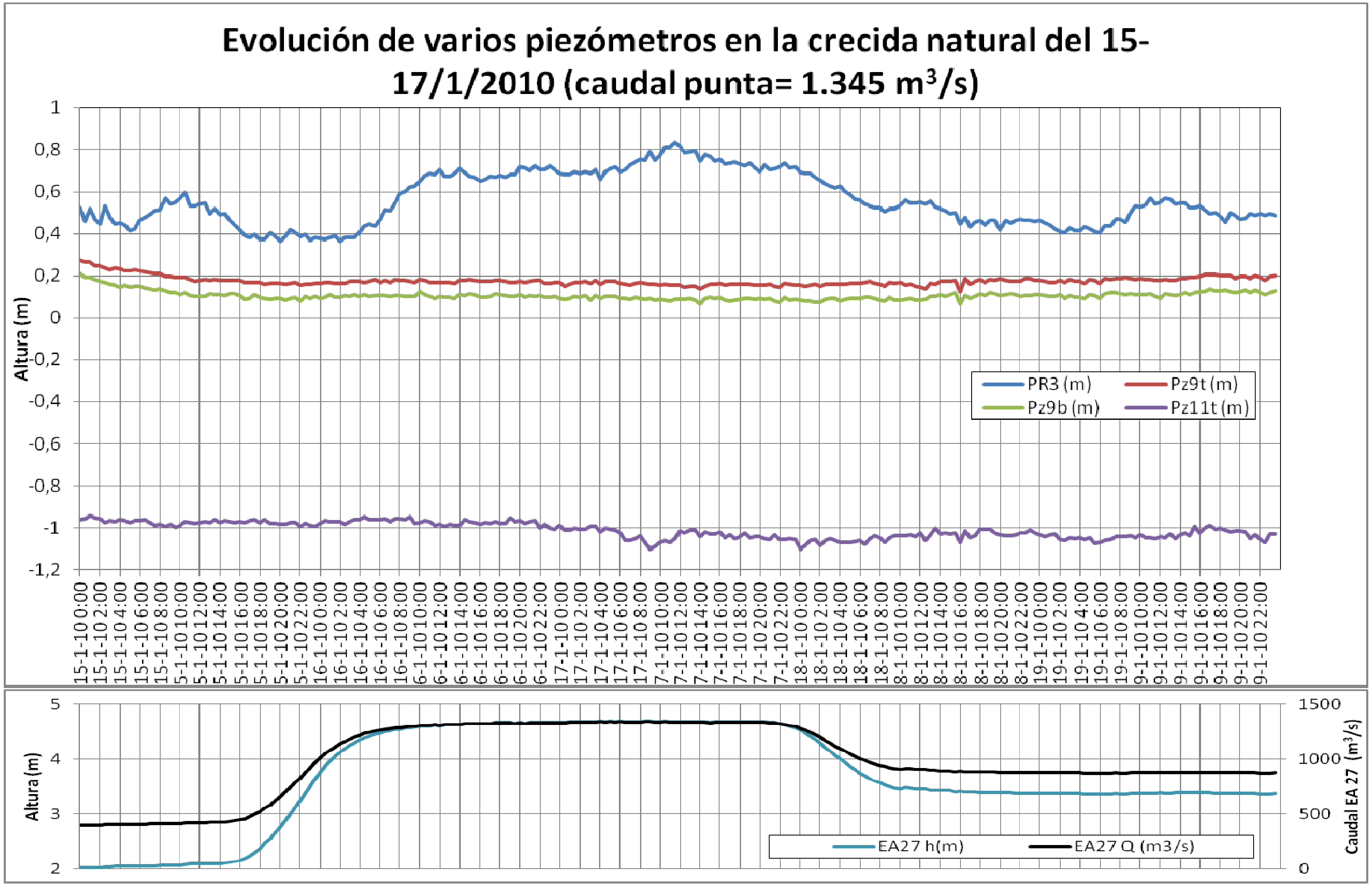
Level Evolution during the controlled flood of 21/10/2009 (máximum flow 1,120 m^3/s)



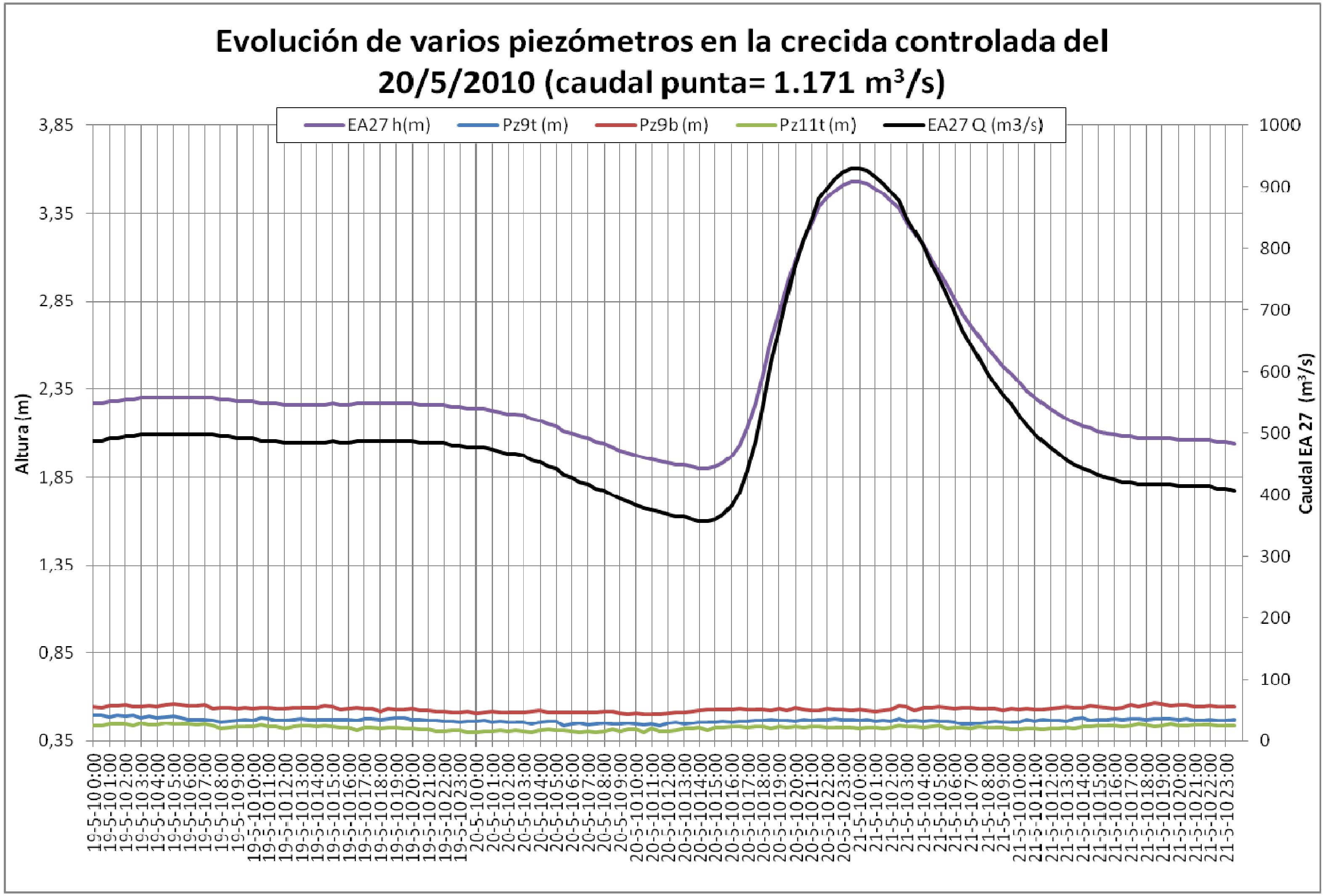
Level Evolution during the controlled flood of 21/10/2009 (máximum flow 1,120 m³/s)



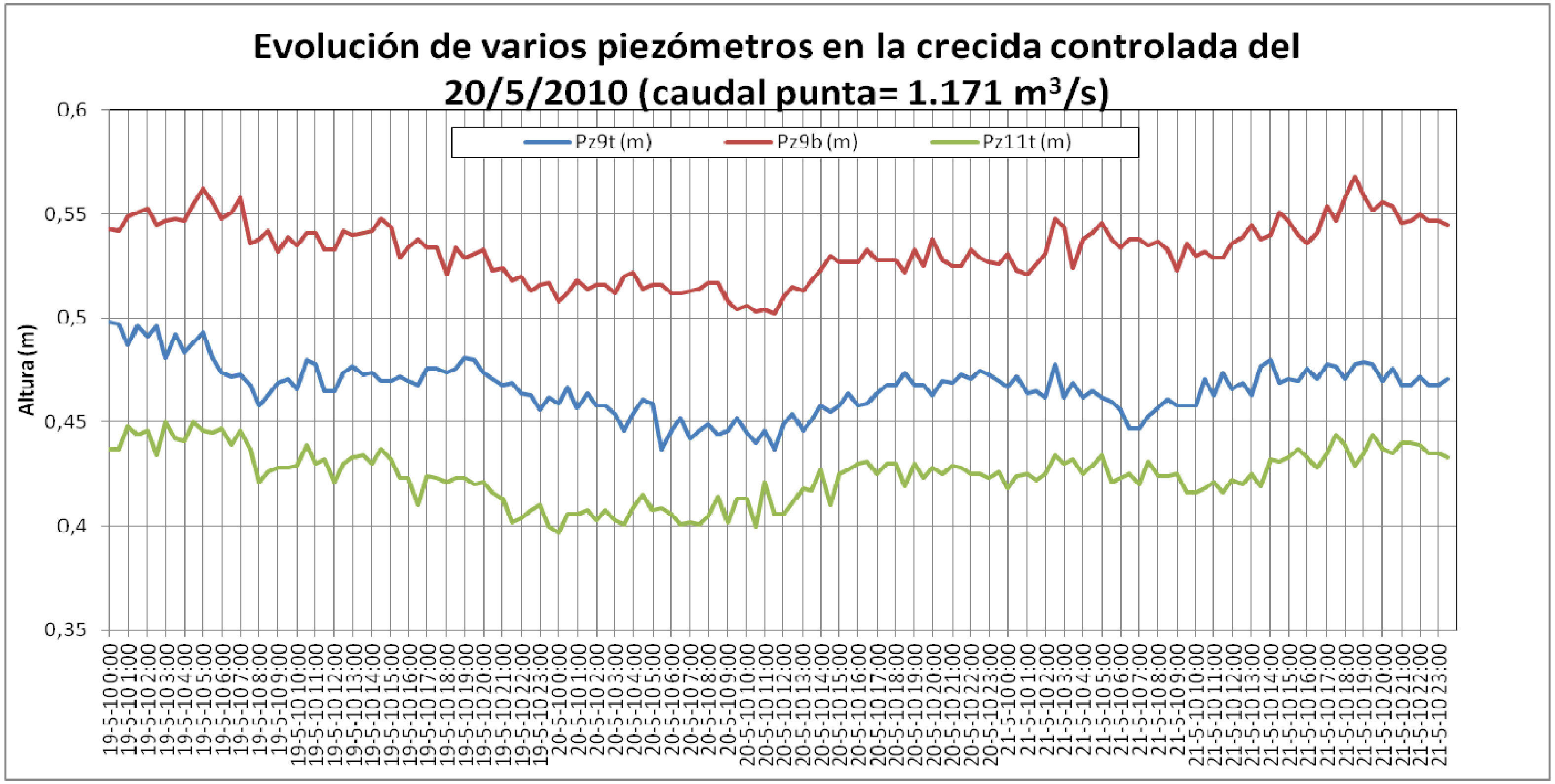
Evolution of piezometers during the natural flood of 15-17/01/2010 (máximum flow 1,345 m^3/s)



Evolution of piezometers during the natural flood of 15-17/01/2010 (máximum flow 1,345 m^3/s)



Evolution of piezometers during the controlled flood of 20/05/2010 (máximum flow 1,171 m^3/s)



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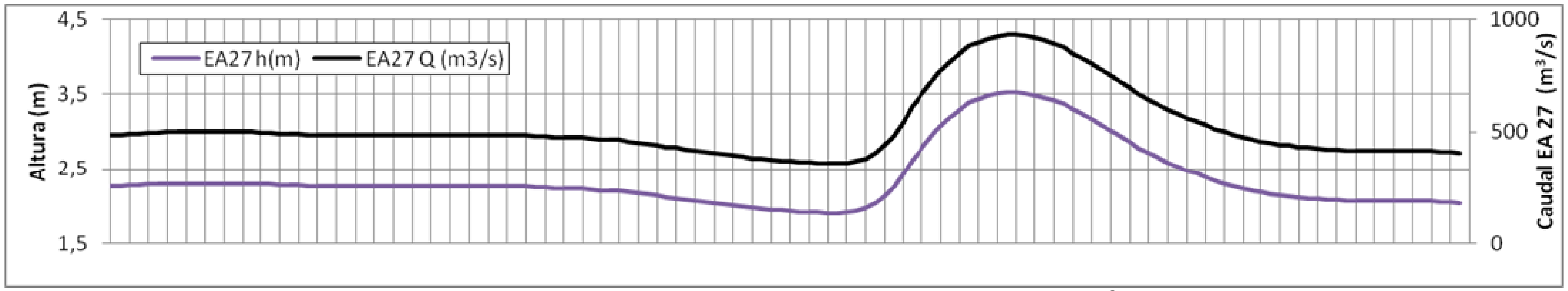

Evolution of piezometers during the controlled flood of 20/05/2010 (máximum flow 1,171 m³/s)