An. Aula Dei 20(1-2):149-162.

Lithological control on the gypsum supplies to the surface waters in the Ebro river basin

by A. NAVAS

Estación Experimental de Aula Dei. Apartado 202. ZARAGOZA

Key words: Dissolved gypsum transport. Surface waters. Gypsiferous lithofacies. Gypsum load. Ebro river basin.

ABSTRACT

Navas, A. (1990). Lithological control on the gypsum supplies to the surface waters in the Ebro river basin.**An. Aula Dei 20(1-2):149-162.**

A quantification of gypsum load in the sampling stations of the Ebro river network during the hydrological period 1970-85 has been carried out. The gypsum load has been calculated from the data sets available trough a load computation procedure for each one of the 68 sampling stations. In each of these, the surface area occupied by gypsiferous lithofacies in the catchments has been planimetered. It can be stated in general terms that the gypsum load in each catchment depends directly on the surface area that the gypsum occupies and on the volume of water supplied.

INTRODUCTION

The Ebro river basin located in the NE of Spain drains an area of 85,000 km^2. In its central sector it is underlain by thick, evaporitic facies deposited during the Tertiary era. These deposits are mainly gypsiferous. Calcareous and saline lithologies are also present. Dissolution of these evaporitic rocks is the main source of high ionic concentrations in the Ebro river network. The dissolution of soluble rocks and solute mobilization by hydrological processes is an important geomorphological process affecting landform evolution and surface water quality. The extensive presence of gypsum either in geological formations or soils, which cover 22% of the total surface area in the basin (ALBERTO & NAVAS 1986), significantly determines the chemistry of surface and subsurface waters. Therefore it is important to quantify the gypsum supplies in the different reaches of the Ebro river network.

In this paper an attempt to relate the gypsum load supplied in each catchment to the surface area occupied by the gypsiferous lithofacies is made.

Load computation procedure

Studies about salt transport by surface waters in semiarid regions have been carried out by MAGARITZ et al. (1984) and in USA by RILEY et al. (1982). Research specifically concerning the hydrogeochemistry of surface waters draining gypsiferous areas in Germany has been carried out by BRANDT et al. (1976) and KEMPE et al. (1976).

The estimation of gypsum transport in the surface waters of the Ebro river network (COCA water quality network) was carried out for the hydrological years (September-October) from 1970 to 1985. The data-sets currently available are records of discharge (MOPU 1970-1978) and water quality (MOPU 1972-1985) corresponding to the 68 sampling stations of the COCA network. Sampling frequency varies according to the type of sampling station. Daily discharge data are recorded at 47 sampling stations, although some years are sometimes lacking over the considered period, and the remaining 21 stations record monthly data. Water quality data are recorded on two occasions (at high and low flows) over each water year at most of the sampling stations, on four occasions in some and on twelve occasions in the sampling stations along the Ebro river.

As a starting point in the analysis, either the calcium or the sulphate ion (as the best indicator of the gypsum participation), is selected according to the methodology proposed by NAVAS (1989). This approach assumes the existence of chemical equilibrium, and linear regressions between ions are used in order to identify the salt that produced them. The lithological and hydrogeochemical characteristics of each catchment are also considered in order to assess the amount of calcium derived from carbonate dissolution, by means of equations of charge balance and chemical equilibrium equations in the calcite-dolomite system. Once this contribution is subtracted from total calcium concentration, it is decided whether the sulphate ion or the calcium ion is the best indicator of gypsum, based on the existence or lack of correlation between them both and also on the analysis of other relationships between the ions that contribute to salinity.

Loads are calculated by the following procedures:

1) Establishment of power relationships between electrical conductivity (EC, μScm^{-1}) and discharge (m^3s^{-1}) (Table 1).
2) Estimation of discharges and electrical conductivities as a function of the existing data available for the sampling stations of the COCA network (Table 2), according to the following criteria:
   A) Daily discharge records exist for more than eight years in the period 1970-85.
      Aa) Calculation of the annual mean discharge and the mean period discharge. The annual mean discharge is a weighted mean value derived from the ranked daily discharges for selected periods. The mean discharge of the period is estimated by arithmetic mean of years for which annual mean discharges are available.
      Ab) Calculation of the annual mean EC and the mean period EC.

Ab1) Significant correlation exists between EC and discharge. The annual mean EC is calculated by substituting the corresponding ranked discharges in the power equation. The mean EC of the period is obtained by calculating a mean EC weighted by discharge of the years for which data exist.

Ab2) No significant correlation exists between EC and discharge. The mean EC of the period is estimated by arithmetic mean of the existing data.

B) There are no daily discharge data.

Ba) There are data (from 25 to >100 records) of instantaneous discharge when the sample is collected. The mean discharge of the period is obtained by arithmetic mean of the instantaneous discharges. For sampling stations with less than 25 records of discharge, the mean discharges have been calculated either comparatively from adjacent sampling stations or indirectly through estimations of precipitation and runoff in the catchment.

Bb) For sampling stations with more than 25 records of EC, the mean EC of the hydrological period is obtained: a) by weighted mean, when there is correlation between EC and discharge, or, b) by arithmetic mean when there is no such correlation. For sampling stations with less than 25 records, the mean EC of the period is obtained as an arithmetic mean.

3) Establishment of linear regressions between the selected ion ($meql^{-1}$) most representative of gypsum and EC (μScm^{-1}) (Table 3).

4) Estimation of the value of the selected ion ($meql^{-1}$) after substituting the mean EC of the period (calculated according to item 2) into the preceding equation (Table 4).

5) Conversion of the value of the selected ion ($meql^{-1}$) in gypsum (gl^{-1}) by multipliyng it by the 0.08598 factor.

6) Multiplication of the gypsum concentration by the mean annual discharge of the period. In this way, the mean load of gypsum (in t $year^{-1}$) for the period 1970-85 in each sampling station is obtained (Table 4).

Load computation is associated with four different levels of accuracy (based on the quantity and reliability of data) at individual stations, which are indicated in Table 4 by asterixes.

As a synthesis of the gypsum transport in the Ebro river basin, Table 5 summarizes the contributions (from tributaries of both banks and non-point sources) and abstractions (from canals and non-point sinks) of gypsum, expressed either as absolute or percentage values. To obtain an overall picture, this data can be completed with those of water contributions and abstractions summarized in Table 6. From the results obtained the following conclusions can be drawn (see Tables 5 and 6):

The left bank tributaries are those of major discharge, and among them the rivers Cinca, Segre, Aragón and Arga supply $10.57.10^9$ m^3 (69 % of total volume water from the rivers), but a gypsum load of only $1.36.10^6$ t (59% of the gypsum load from the rivers) is transported by them. In this respect, the Aragón river is the one that in percentage terms supplies the major water amount (16%), with the least gypsum (6%). On the other hand, the right bank tributaries are those which supply the least water with the major amount of gypsum. Thus for example, the rivers Tirón, Jalón, Martín and Guadalope contribute 4% of the total water from the rivers, but the gypsum load supplied rises to 12 %. Among these, the Martín river carries most gypsum (1.3%) for the least volume of water (0.13%).

It is clear that non-point sources, including surface and subsurface flows and groundwaters, make an important contribution to gypsum transport in the Ebro basin. However, also among the non-point sources it is necessary to include some ungauged rivers, mostly situated on the Ebros' left bank, and generally having low discharge. Gypsum concentration in non-point sources is higher than that in sinks. This seems a reasonable finding since most of these sources are surface and subsurface runoff that are located in reaches fed very largely from areas of gypsum outcrop.

In the reaches Mendavia-Castejón, Zaragoza-Sástago and Mequinenza-Ascó, non-point sources of gypsum are associated with water abstractions. Gypsum non-point sources are more important in the last two reaches in which large reservoirs are situated. As a result of evaporation, these resorvoirs can act as water sinks especially if they are sited in zones with high potential evaporation, and also if their ratio of surface area to pondage is high, this produces an increase in the gypsum concentration. On the other hand, in the Sastago-Mequinenza reach, an important gypsum sink is associated with a water source. This is probably related to the storing of good quality waters during the high flow seasons, and has a dilution effect producing a consequent decrease in the gypsum concentration.

Connection between the presence of gypsiferous lithofacies and the estimated gypsum load

The estimated gypsum loads in individual reaches of the Ebro, can be compared with the extent of the drainage area occupied by gypsiferous formations. The area of the gypsiferous lithofacies in each catchment above the sampling stations in the Ebro river network has been measured by planimeter from a geological map (NAVAS 1983). These data are summarized in Table 7 which also expresses them as a percentage of total area in each catchment and lists the corresponding percentage of gypsum in the total dissolved solids load.

In order to establish a relationship between gypsum load and the surface area occupied by the gypsiferous lithofacies, a formula between gypsum percentage in the total salinity (y) and surface percentage of gypsiferous formations in the catchments (x) was established. The equation obtained is: $y = 29.13 + 0.38x$, where $n = 68$, the correlation coefficient is 0.35 and the statistical significance is 99.95%.

However since gypsum is transported in solution, the gypsum load should be directly related to the water supply in each catchment. To test this influence, the following multiple linear regression has been established: $y = -26369 + 66x + 130z$, where y = gypsum load in tons $year^{-1}$, x = gypsiferous surface area in km^2, and z = water volume in $m^3.10^6$.

The high correlation obtained ($r=0.99$) confirms the close relationship between these variables. Therefore it can be concluded that for the whole of the sampling stations in the Ebro river basin, the total gypsum load supplied by each catchment depends directly on the surface area occupied by the gypsiferous lithofacies and on the volume of water supplied.

Nevertheless, cartographic synthesis of the gypsiferous lithofacies in the Ebro river basin (NAVAS 1983) showed a large number of discrepancies in current geological literature, regarding the presence or absence of gypsum, the mapping of outcrops and the nature of the gypsiferous deposits.

To test the accuracy of the estimated gypsum load, the analysis of anomalies between the gypsum supplies and the presence of gypsiferous lithofacies found in some sampling stations is required. Therefore, two types of checks must be made. The first is to confirm that the sampling stations in which sulphate and calcium are correlated, i.e. dissolved solids, largely supplied from a gypsum source, effectively correspond to the presence of gypsiferous lithofacies in their catchments. The second check is concerned with the absence of correlation between these two ions and whether this is due either to the absence of gypsum in the respective catchment, or to other causes.

The first verification has been effectively confirmed in 52 of the 68 sampling stations of the Ebro river network, where strong correlations between sulphate and calcium always imply the presence of gypsiferous lithofacies. Hence, in each of them the gypsum load depends on the gypsiferous surface area and on the volume of water supplied. With regard to the second verification, in 7 sampling stations without gypsiferous lithofacies in their catchments (Table 7), no correlation was discovered between the sulphate and calcium ions. Nevertheless in 9 other sampling stations (identified by • in Table 7) no correlation was discovered either, although gypsum is present in their catchments. The reasons for the lack of correlation despite the presence of gypsiferous lithofacies are mainly as follows:

1) The small percentage of surface area covered by gypsum in each catchment. This is the case in the sampling stations identified by * in Table 7.

2) An insufficient amount of data. This occurs at Guatizalema (32) and Alcanadre (33) at Peralta de Alcofea, where only 6 readings were taken. In these cases the relative surface area occupied by gypsum in their catchments is also small, representing only 11% and 6.5% respectively.

3) The possibility of cartographic mistakes. This is the case for the catchment of the Matarraña at Maella (176) where gypsum occurs in the Caspe Formation. This formation extends over an area of 442 km^2 representing 35% of the total surface, but in it the gypsum is a minor and irregularly distributed component. Also the incidence of gypsum compared with sodium and magnesium sulphate is low. In the catchment of the Isuela at Pompenillo (218), the Keuper's gypsum represents 39.6% of the total surface area. However, the area of gypsum is probably overestimated and its contribution to the salinity is disguised due to the existence of sodium sulphate.

Larger scale anomalies can exist in the relationship between the percentage surface area of the gypsiferous lithofacies in the catchments and the percentage of gypsum in the total salinity, due to two possible situations:

a) Catchments without gypsiferous lithofacies or with a small percentage surface area (less than 6%) occupied by them, where gypsum represents a relatively high percentage in the total salinity. This is the case in the sampling stations identified by ** in Table 7. In these, inconsistencies are mainly due to cartographic mistakes, but they could also arise through the existence of a yet unknown mechanism or specific conditions that accelerate the incorporation of gypsum into surface waters.

b) Catchments with a large gypsiferous surface area in which the relative participation of gypsum in the total salinity is small. This occurs in some catchments with a percentage gypsiferous surface area greater than 30%. However, contrary to what is expected, gypsum participation in the total salinity is lower than this value. This situation indicates the existence of a large number of local sources of salinity (natural or anthropic) that hide the actual gypsum contribution. The sampling stations where this occurs are identified by *** in Table 7. In the rivers Arba at Gallur (60), Gállego at Zaragoza (89), Gállego at Anzánigo (123), Isuela at Pompenillo (218), salinity originates from industrial sources and domestic waste, whilst in Matarraña at Maella (176) and Clamor Amarga at Zaidín (225) the sources of salinity are natural.

CONCLUSIONS

It can be concluded that a general increasing trend of gypsum load (reaching 2.95 million tons year^{-1} at the mouth of the basin) exists along the whole Ebro river course, due either to tributary contributions or from non-point sources, the latter being of greater significance. With regard to the tributary contribution, the majority of the supply comes from those on the Ebros' left bank, since they drain a larger surface area of the basin (58% of the total drainage area), and receive higher precipitation. Likewise, most of the irrigated areas in the basin are also situated on the Ebros' left bank, and as a result the gypsum supplies from these areas are more plentiful than those coming from soils in natural conditions. In general terms, a good agreement between the gypsum load in each catchment and the surface area occupied by gypsiferous lithofacies has been found.

RESUMEN

Se ha realizado una cuantificación de la carga de yeso transportada por las aguas superficiales en las estaciones de muestreo de la red hidrográfica del Ebro durante el periodo hidrológico 1970-1985. La masa de yeso ha sido calculada a partir de las series de datos disponibles para cada una de las 68 estaciones de muestreo de la red COCA. En cada una de ellas, se ha medido la superficie ocupada por las litofacies yesíferas en las correspondientes cuencas de drenaje. En términos generales, puede afirmarse que el aporte de yesos en cada cuenca se relaciona directamente con el área ocupada por los yesos y con el volumen de agua suministrado.

REFERENCES

Alberto,F. y Navas,A. (1986). La participación de los yesos en la salinización de las aguas superficiales de la Cuenca del Ebro. I. Cartografía de síntesis de las formaciones con yesos. **Anales de Aula Dei** 18: 7-18.

Brandt, A., S. Kempe, M.Seeger & F. Vladi (1976). Geochemie, Hydrographie und Morphogenese des Gipskarstgebietes von Düna/Südharz. **Geol. Jb.** C 15:3-55, Hannover.

Kempe, S., A. Brandt, M.Seeger & F. Vladi (1976). Fünf Aspekte der Entwicklung der Gipshöhlen im Hainholz/Südharz. **Mitt. Verb. dt. Höhlen- u. Karstforscher** 22 (1):1-10, München.

Magaritz, M., A. Nadler, U.Kafri & A.Arad (1984). Hydrogeo chemis try of continental brackish water in the southern Coastal Plain, Israel.**Chemical Geology** 42: 159-176.

MOPU (1970-1978): Aforos 9. Cuenca del Ebro: Período 1970-71 a 1977-78. Servicio de Publicaciones. Dirección General de Obras Hidráulicas. Madrid.

MOPU (1972-1985): Análisis de calidad de aguas. Red Oficial del MOPU. Servicio de Publicaciones. Dirección General de Obras Hidráulicas. Madrid.

Navas, A. (1983). Las litofacies yesíferas de la Cuenca del Ebro. Síntesis cartográfica y consideraciones sobre su papel en la Planificación Territorial. Tesis de Master. IAMZ. Zaragoza. 239 pp.

Navas, A. (1989). La participación de los yesos en la salinización de las aguas superficiales de la Cuenca del Ebro. III. Metodología de cuantificación.**An. Aula Dei** 19 (3-4): 345-359.

Riley, J.P., D.J.Jr. Chadwick, L.S. Dixon; L.D. James & W.J. Grenney (1982). Salt uptake in natural channels traversing Mancos shales in the Price Basin, Utah.**Water Resources Planning Series**, UWRL/P-82/02. 194 pp.

Table 1.- Power regression equations between electrical conductivity (μScm^{-1} at 25°C) and discharge (m^{3}s^{-1}) at the sampling stations of the Ebro river network.

River	Sampling Station	No.	n	Electrical conductivity – discharge				
				r	a	b	F	S
Ebro	Miranda	1	155	-0.197	507.9	-0.051	6.2	***
Ebro	Castejón	2	155	-0.804	2669.4	-0.268	280.1	***
Ega	Andosilla	3	146	-0.709	1701.8	-0.261	146.2	***
Arga	Peralta	4	151	-0.531	1842.7	-0.183	58.6	***
Aragón	Caparroso	5	152	-0.434	477.1	-0.077	34.8	***
Jalón	Huérmeda	9	149	-0.660	1949.4	-0.260	113.6	***
Ebro	Zaragoza	11	155	-0.861	8634.2	-0.427	439.0	***
Martín	Hijar	14	118	-0.662	1987.3	-0.176	90.9	***
Guadalope	Alcañiz	15	154	-0.646	1085.1	-0.201	109.1	***
Cinca	Fraga	17	128	-0.289	1145.0	-0.110	11.6	***
Aragón	Jaca	18	151	-0.158	223.1	-0.036	3.8	
Valira	Seo de Urgel	22	72	-0.446	181.0	-0.115	17.4	***
Segre	Seo de Urgel	23	105	-0.697	275.6	-0.180	97.3	***
Segre	Lérida	24	117	-0.517	1020.8	-0.183	42.1	***
Segre	Serós	25	154	-0.529	996.6	-0.151	59.2	***
Ebro	Tortosa	27	145	-0.370	1905.1	-0.152	22.7	***
Ebro	Mequinenza	29	105	-0.286	1382.3	-0.095	9.2	***
Guatizalema	Peralta de Alcofea	32	47	-0.577	468.9	-0.082	22.6	***
Alcanadre	Peralta de Alcofea	33	41	-0.424	365.7	-0.025	8.6	***
Iregua	Islallana	36	107	-0.714	466.0	-0.305	109.6	***
Najerilla	Torremontalvo	38	113	-0.857	743.6	-0.348	311.1	***
Jiloca	Calamocha	42	151	-0.223	921.3	-0.045	7.9	***
Tirón	Cuzcurita	50	103	-0.331	1185.7	-0.084	12.5	***
Arba	Gallur	60	128	-0.746	4246.7	-0.438	159.4	***
Irati	Liédena	65	107	-0.492	351.3	-0.055	33.6	***
Arga	Echauri	69	127	-0.652	1318.1	-0.232	92.8	***
Ega	Estella	71	118	-0.853	1101.7	-0.255	310.5	***
Zadorra	Arce	74	156	-0.355	603.4	-0.063	22.3	***
Jalón	Grisén	87	125	-0.044	979.2	-0.009	0.3	
Gállego	Zaragoza	89	55	-0.645	2188.3	-0.263	38.4	***
Nela	Trespaderne	92	118	-0.749	566.0	-0.201	148.8	***
Oca	Oña	93	117	-0.577	967.7	-0.081	57.6	***
Segre	Balaguer	96	142	-0.668	786.6	-0.160	114.2	***
N. Ribagorzana	La Piñana	97	148	-0.627	615.6	-0.150	95.0	***
Aragón	Yesa	101	153	0.044	274.0	0.010	0.4	
Huerva	Mezalocha	105	102	-0.504	536.2	-0.031	34.2	***
Ebro	Sástago	112	154	-0.868	10863.3	-0.444	466.6	***
Segre	Pons	114	115	-0.601	497.0	-0.163	64.1	***
Ebro	Mendavia	120	156	-0.622	1899.2	-0.242	97.0	***
Ebro	Flix	121	70	-0.371	1561.4	-0.115	10.9	***
Gállego	Anzánigo	123	153	0.031	252.8	0.009	0.2	
Arga	Huarte	159	64	0.214	250.3	0.032	3.0	
Ebro	Palazuelos	161	117	-0.000	306.5	-0.003	0.0	
Ebro	Pignatelli	162	110	-0.789	1973.8	-0.203	179.2	***
Ebro	Ascó	163	23	-0.389	1780.8	-0.126	3.8	
Bayas	Miranda	165	110	-0.615	533.6	-0.122	66.0	***
Jerea	Palazuelos	166	115	-0.313	410.4	-0.021	12.3	***
N. Pallaresa	Camarasa	169	114	0.032	240.3	0.009	0.2	
Matarraña	Maella	176	92	-0.249	466.0	-0.025	6.0	**
Zadorra	Vitoria	179	19	-0.426	641.8	-0.097	3.8	
Zadorra	Durana	180	18	0.411	350.3	0.075	3.2	
Aragón	Sangüesa	205	104	-0.490	386.1	-0.061	32.4	***
Segre	Pla de San Tirs	206	67	-0.668	408.8	-0.246	52.6	***
Segre	Termens	207	89	-0.627	763.4	-0.158	56.5	***
Ebro	Conchas de Haro	208	107	-0.449	712.6	-0.097	26.5	***
Gállego	Zuera	209	38	-0.785	9221.5	-0.637	57.9	***
Ebro	Ribarroja	210	117	-0.349	2000.7	-0.159	16.0	***
Ebro	Presa de Pina	211	34	-0.911	9666.1	-0.420	156.6	***
Ebro	Cherta	212	61	-0.311	1438.6	-0.102	6.3	**
Cidacos	Calahorra	213	4	-0.988	1517.8	-249.00	90.2	***
Alhama	Alfaro	214	96	-0.288	1017.3	-0.075	8.5	***
Huerva	Zaragoza	216	105	-0.465	992.7	-0.131	28.6	***
Arga	Ororbia	217	28	-0.750	1292.5	-0.268	33.5	***
Isuela	Pompenillo	218	0					
Segre	Torres de Segre	219	0					
Clamor Amarga	Zaidín	225	4	-0.963	10559.4	-1.320	25.6	***
Alcanadre	Ontiñena	226	0					
Flumen	Sariñena	227	0					
Cinca	Monzón	228	0					

Statistical significance: ***≥99.99%, **≥99.975%.

Table 2.- Annual mean values of discharge and electrical conductivity for the hydrological period 1970-85 in the sampling stations of the Ebro river network.

River	Sampling Station	No.	Discharge m^3s^{-1}		Electrical conductivity μScm^{-1}	
Ebro	Miranda	1	69.87	+	416.4	Q
Ebro	Castejón	2	287.06	+	673.6	Q
Ega	Andosilla	3	14.42	+	1014.0	Q
Arga	Peralta	4	65.47	+	947.3	Q
Aragón	Caparroso	5	76.01	+	356.4	Q
Jalón	Huérmeda	9	11.57	+	1073.1	Q
Ebro	Zaragoza	11	279.03	+	1007.1	Q
Martín	Hijar	14	0.68	+	2228.7	Q
Guadalope	Alcañiz	15	4.77	+	829.0	Q
Cinca	Fraga	17	92.38	+	710.8	Q
Aragón	Jaca	18	6.77	+	223.6	o
Valira	Seo de Urgel	22	15.20	+	143.7	Q
Segre	Seo de Urgel	23	17.10	+	175.1	Q
Segre	Lérida	24	93.34	+	459.6	Q
Segre	Serós	25	100.85	+	514.6	Q
Ebro	Tortosa	27	441.54	+	792.9	Q
Ebro	Mequinenza	29	274.61	+	847.8	Q
Guatizalema	Peralta de Alcofea	32	0.74	+	503.4	Q
Alcanadre	Peralta de Alcofea	33	4.85	+	357.7	Q
Iregua	Islallana	36	7.28	+	289.4	Q
Najerilla	Torremontalvo	38	14.55	+	339.3	Q
Jiloca	Calamocha	42	3.19	+	875.0	Q
Tirón	Cuzcurita	50	6.03	+	1073.4	Q
Arba	Gallur	60	13.63	+	1530.3	Q
Irati	Liédena	65	37.37	+	298.8	Q
Arga	Echauri	69	53.55	+	643.6	Q
Ega	Estella	71	13.13	+	662.0	Q
Zadorra	Arce	74	14.31	+	529.0	Q
Jalón	Grisén	87	7.58	+	1005.0	o
Gállego	Zaragoza	89	14.69	+	1442.9	Q
Nela	Trespaderne	92	22.65	+	362.4	Q
Oca	Oña	93	6.78	+	861.2	Q
Segre	Balaguer	96	33.73	+	497.5	Q
N. Ribagorzana	La Piñana	97	19.97	+	401.7	Q
Aragón	Yesa	101	28.95	+	285.8	o
Huerva	Mezalocha	105	1.11	+	546.7	Q
Ebro	Sástago	112	285.03	+	1124.2	Q
Segre	Pons	114	33.10	+	296.8	Q
Ebro	Mendavia	120	135.07	+	630.5	Q
Gállego	Anzánigo	123	29.80	+	264.8	o
Arga	Huarte	159	7.61	+	249.3	o
Ebro	Palazuelos	161	59.15	+	309.6	o
Ebro	Pignatelli	162	255.68	+	734.1	Q
Ebro	Ascó	163	451.70	o	884.2	o
Bayas	Miranda	165	5.55	o	382.6	#
Jerea	Palazuelos	166	7.53	+	403.0	Q
N. Pallaresa	Camarasa	169	35.60	o	254.0	o
Matarraña	Maella	176	1.39	+	468.5	Q
Zadorra	Vitoria	179	4.83	o	549.5	o
Zadorra	Durana	180	1.86	o	355.3	o
Aragón	Sangüesa	205	55.32	$	286.7	#
Segre	Pla de San Tirs	206	27.10	$	164.5	#
Segre	Termens	207	30.86	$	394.4	#
Ebro	Conchas de Haro	208	83.97	$	462.3	#
Gállego	Zuera	209	12.44	$	1000.0	#
Ebro	Ribarroja	210	425.27	+	769.3	#
Ebro	Presa de Pina	211	243.85	$	672.2	#
Ebro	Cherta	212	475.54	o	764.8	#
Cidacos	Calahorra	213	1.98	o	1253.4	o
Alhama	Alfaro	214	1.08	o	1276.0	#
Huerva	Zaragoza	216	4.17	+	904.0	Q
Arga	Ororbia	217	15.70	o	562.1	#
Isuela	Pompenillo	218		-	844.5	o
Segre	Torres de Segre	219	95.55	$	740.6	o
Clamor Amarga	Zaidín	225	3.71	o	2223.5	o
Alcanadre	Ontiñena	226		-	1167.5	o
Flumen	Sariñena	227		-	1432.9	o
Cinca	Monzón	228		-	531.4	o

Calculation: Discharge: + = weighted mean from the ranked daily discharges, o = arithmetic mean, $ = comparison from adjacent sampling stations, - = relationship precipitation – runoff.
EC: Q = weighted mean from the ranked discharges, o = arithmetic mean, # = weighted mean.

Table 3.- Linear regressions between the selected ion ($meql^{-1}$) most representative of gypsum and electrical conductivity (μScm^{-1}), and values of the conversion factors (c. f.) in the sampling stations of the Ebro river network.

River	Sampling Station	No.	Selected ion	Selected ion – electrical conductivity				
				r	S	b	a	c.f.
Ebro	Miranda	1	Ca	0.671	***	0.0031	-0.206	
Ebro	Castejón	2	Ca	0.756	***	0.0020	0.480	
Ega	Andosilla	3	Ca	0.874	***	0.0023	0.516	
Arga	Peralta	4	SO_4	0.916	***	0.0013	0.118	
Aragón	Caparroso	5	SO_4	0.469	**	0.0022	-0.085	
Jalón	Huérmeda	9	Ca	0.650	***	0.0030	-0.238	
Ebro	Zaragoza	11	Ca	0.836	***	0.0019	0.603	
Martín	Hijar	14	Ca	0.909	***	0.0075	0.228	
Guadalope	Alcañiz	15	Ca	0.980	***	0.0071	-1.290	
Cinca	Fraga	17	Ca	0.495	**	0.0013	0.833	
Aragón	Jaca	18	SO_4					0.0010
Valira	Seo de Urgel	22	SO_4					0.0016
Segre	Seo de Urgel	23	SO_4	0.399	*	0.0010	0.123	
Segre	Lérida	24	Ca	0.918	***	0.0040	-0.222	
Segre	Serós	25	Ca	0.922	***	0.0036	0.123	
Ebro	Tortosa	27	Ca	0.845	***	0.0028	0.250	
Ebro	Mequinenza	29	Ca	0.814	***	0.0028	0.203	
Guatizalema	Peralta de Alcofea	32	Ca					0.0013
Alcanadre	Peralta de Alcofea	33	Ca					0.0018
Iregua	Islallana	36	Ca	0.806	***	0.0044	-0.011	
Najerilla	Torremontalvo	38	SO_4	0.787	***	0.0046	-0.276	
Jiloca	Calamocha	42	Ca	0.665	***	0.0028	1.990	
Tirón	Cuzcurita	50	Ca					0.0064
Arba	Gallur	60	Ca	0.643	***	0.0012	0.997	
Irati	Liédena	65	SO_4	0.539	*	0.0016	-0.161	
Arga	Echauri	69	SO_4					0.0011
Ega	Estella	71	SO_4	0.915	***	0.0027	-0.548	
Zadorra	Arce	74	SO_4					0.0021
Jalón	Grisén	87	Ca					0.0032
Gállego	Zaragoza	89	Ca	0.761	***	0.0025	0.160	
Nela	Trespaderne	92	SO_4	0.857	***	0.0023	-0.249	
Oca	Oña	93	Ca					0.0045
Segre	Balaguer	96	Ca	0.861	***	0.0046	-0.361	
N. Ribagorzana	La Piñana	97	SO_4	0.648	***	0.0043	0.016	
Aragón	Yesa	101	SO_4					0.0011
Huerva	Mezalocha	105	Ca	0.785	***	0.0041	-0.534	
Ebro	Sástago	112	Ca	0.965	***	0.0026	0.577	
Segre	Pons	114	SO_4	0.699	***	0.0023	0.112	
Ebro	Mendavia	120	SO_4	0.765	***	0.0030	-0.047	
Gállego	Anzánigo	123	SO_4					0.0019
Arga	Huarte	159	SO_4	0.619	***	0.0015	-0.035	
Ebro	Palazuelos	161	Ca	0.859	***	0.0040	-0.400	
Ebro	Pignatelli	162	Ca	0.698	***	0.0011	1.160	
Ebro	Ascó	163	Ca	0.804	***	0.0026	0.398	
Bayas	Miranda	165	Ca	0.829	***	0.0053	-0.889	
Jerea	Palazuelos	166	SO_4					0.0013
N. Pallaresa	Camarasa	169	SO_4	0.842	***	0.0041	-0.331	
Matarraña	Maella	176	Ca	0.592	**	0.0037	-1.570	
Zadorra	Vitoria	179	SO_4					0.0020
Zadorra	Durana	180	SO_4					0.0014
Aragón	Sangüesa	205	SO_4	0.878	***	0.0036	-0.640	
Segre	Pla de San Tirs	206	SO_4	0.545	*	0.0011	0.077	
Segre	Termens	207	Ca	0.937	***	0.0046	-0.377	
Ebro	Conchas de Haro	208	Ca	0.461	***	0.0025	-0.027	
Gállego	Zuera	209	Ca	0.975	***	0.0027	0.027	
Ebro	Ribarroja	210	Ca	0.893	***	0.0034	-0.406	
Ebro	Presa de Pina	211	Ca	0.957	***	0.0026	0.340	
Ebro	Cherta	212	Ca	0.816	***	0.0024	0.574	
Cidacos	Calahorra	213	Ca	0.711	***	0.0027	-0.048	
Alhama	Alfaro	214	Ca	0.946	***	0.0054	-2.150	
Huerva	Zaragoza	216	Ca	0.620	***	0.0025	1.070	
Arga	Ororbia	217	SO_4					0.0014
Isuela	Pompenillo	218	Ca					0.0018
Segre	Torres de Segre	219	Ca	0.934	***	0.0033	-0.069	
Clamor Amarga	Zaidín	225	Ca	0.973	***	0.0043	-1.250	
Alcanadre	Ontiñena	226	Ca	0.790	***	0.0015	1.810	
Flumen	Sariñena	227	Ca	0.973	***	0.0019	1.610	
Cinca	Monzón	228	SO_4	0.798	***	0.0020	0.096	

Statistical significance: *** ≥99.99%, ** ≥99.975%, * ≥99.95%.

Table 4.- Mean concentrations of sulphate and/or calcium derived from the dissolution of gypsum, and annual mean gypsum load (calculated either from the sulphate or calcium, or through the arithmetic mean of both) in the sampling stations of the Ebro river network for the hydrological period 1970-85.

				SO_4	Ca	Gypsum $t\ year^{-1}$		
River	Sampling Station	No.		$meql^{-1}$		SO_4	Ca	Mean
Ebro	Miranda	1	***	0.99	1.09	187435.2	205076.2	196255.7
Ebro	Castejón	2	***		1.83		1423189.8	
Ega	Andosilla	3	***		2.85		111479.9	
Arga	Peralta	4	***	1.35	1.69	239658.3	299572.9	269615.6
Aragón	Caparroso	5	***	0.70		143898.6		
Jalón	Huérmeda	9	***		2.98		93514.2	
Ebro	Zaragoza	11	***		2.52		1902048.5	
Martín	Hijar	14	**		16.94		31383.8	
Guadalope	Alcañiz	15	***		4.60		59463.3	
Cinca	Fraga	17	**		1.76		440189.2	
Aragón	Jaca	18	***	0.22		4056.5		
Valira	Seo de Urgel	22	**	0.23		9596.2		
Segre	Seo de Urgel	23	**	0.30		14032.2		
Segre	Lérida	24	***		1.62		409445.4	
Segre	Serós	25	***		1.98		541052.2	
Ebro	Tortosa	27	***		2.47		2953963.5	
Ebro	Mequinenza	29	***		2.58		1923872.0	
Guatizalema	Peralta de Alcofea	32	**		0.65		1302.0	
Alcanadre	Peralta de Alcofea	33	**	0.54	0.64	7037.5	8414.5	7726.0
Iregua	Islallana	36	***	1.12	1.26	22289.8	25041.7	23665.8
Najerilla	Torremontalvo	38	**	1.29		50502.1		
Jiloca	Calamocha	42	***		4.44		38471.2	
Tirón	Cuzcurita	50	***		6.87		112496.9	
Arba	Gallur	60	**		2.83		104907.8	
Irati	Liédena	65	***	0.32		31836.5		
Arga	Echauri	69	**	0.68		99705.3		
Ega	Estella	71	***	1.24		44353.6		
Zadorra	Arce	74	***	1.11		43369.0		
Jalón	Grisén	87	***		3.21		65980.6	
Gállego	Zaragoza	89	**		3.77		150268.0	
Nela	Trespaderne	92	***	0.59		35736.0		
Oca	Oña	93	***	3.96	3.88	73001.3	71288.6	72145.0
Segre	Balaguer	96	***		1.93		176698.7	
N. Ribagorzana	La Piñana	97	***	1.74		94555.5		
Aragón	Yesa	101	***	0.31		24658.6		
Huerva	Mezalocha	105	***		1.71		5137.7	
Ebro	Sástago	112	***		3.50		2707504.0	
Segre	Pons	114	**	0.80		71030.8		
Ebro	Mendavia	120	***	1.84		677807.5		
Gállego	Anzánigo	123	***	0.50		40432.9		
Arga	Huarte	159	***	0.34		6963.2		
Ebro	Palazuelos	161	***		0.84		134426.9	
Ebro	Pignatelli	162	***		1.97		1363647.5	
Ebro	Ascó	163	*		2.71		3306164.4	
Bayas	Miranda	165	*		1.12		16924.4	
Jerea	Palazuelos	166	***	0.52		10699.7		
N. Pallaresa	Camarasa	169	*	0.71		68557.7		
Matarraña	Maella	176	**		0.15		524.5	
Zadorra	Vitoria	179	*	1.10		14394.2		
Zadorra	Durana	180	*	0.50		2504.4		
Aragón	Sangüesa	205	*	0.39	0.32	60021.1	47306.2	
Segre	Pla de San Tirs	206	*	0.25		18719.5		
Segre	Termens	207	*		1.45		121737.5	
Ebro	Conchas de Haro	208	*		1.11		253967.2	
Gállego	Zuera	209	*		2.71		90999.7	
Ebro	Ribarroja	210	**		2.21		2548149.8	
Ebro	Presa de Pina	211	*		2.08		1377485.6	
Ebro	Cherta	212	*		2.39		3089305.8	
Cidacos	Calahorra	213	-		3.35		17982.7	
Alhama	Alfaro	214	*		4.74		13858.4	
Huerva	Zaragoza	216	**		3.30		37343.2	
Arga	Ororbia	217	-	0.79		33667.5		
Isuela	Pompenillo	218	-		1.52		1815.7	
Segre	Torres de Segre	219	*		2.34		605858.2	
Clamor Amarga	Zaidín	225	-		8.20		82594.9	
Alcanadre	Ontiñena	226	-		3.55		407644.7	
Flumen	Sariñena	227	-		4.33		141073.6	
Cinca	Monzón	228	-	1.16	1.11	105594.9	101354.2	103474.6

Level of accuracy: *** = high, ** = medium, * = low, - = approximate.

Table 5.- Supplies and abstractions of gypsum in the Ebro river network.

GYPSUM ($t.10^6$):

LOAD FROM RIVERS: 2.31

TRIBUTARIES OF THE EBRO RIVER

Right bank			Left bank		
Oca	0.07	3.03%	Nela	0.04	1.73%
Tirón	0.11	4.76%	Jerea	0.01	0.43%
Najerilla	0.05	2.16%	Bayas	0.02	0.87%
Iregua	0.02	0.87%	Zadorra	0.04	1.73%
Cidacos	0.02	0.87%	Ega	0.11	4.76%
Alhama	0.01	0.43%	Arga	0.24	10.39%
Jalón	0.07	3.03%	Aragón	0.14	6.06%
Huerva	0.04	1.73%	Arba	0.10	4.33%
Martín	0.03	1.30%	Gállego	0.15	6.49%
Guadalope	0.06	2.60%	Cinca	0.44	19.05%
Matarraña	0.0005	0.02%	Segre	0.54	23.38%
	0.48	20.78%		1.83	79.22%

LOAD FROM NON-POINT SOURCES: 1.90

REACHES

Palazuelos (161)	- Miranda (1)	0.06	3.16%
Miranda (1)	- Mendavia (120)	0.23	12.11%
Mendavia (120)	- Castejón (2)	0.22	11.58%
Pignatelli (162)	- Zaragoza (11)	0.37	19.47%
Zaragoza (11)	- Sástago (112)	0.62	32.63%
Mequinenza (29)	- Ascó (163)	0.40	21.05%
		1.90	

Total load through Tortosa: 2.95
Total abstraction: 1.28

SINKS:

REACHES

Castejón (2)	- Pignatelli (162)	0.06	4.69%
Sástago (112)	- Mequinenza (29)	0.87	67.97%
Ascó (163)	- Tortosa (27)	0.35	27.34%
		1.28	

Canal abstraction: 0.41
Reservoir abstraction: 0.87

Table 6.- Supplies and abstractions of water in the Ebro river network.

WATER ($m^3.10^9$):

DISCHARGE FROM RIVERS: 15.26

TRIBUTARIES OF THE EBRO RIVER

Right bank			Left bank		
Oca	0.21	1.38%	Nela	0.71	4.65%
Tirón	0.19	1.25%	Jerea	0.24	1.57%
Najerilla	0.46	3.01%	Bayas	0.18	1.18%
Iregua	0.23	1.51%	Zadorra	0.45	2.95%
Cidacos	0.06	0.39%	Ega	0.46	3.01%
Alhama	0.03	0.20%	Arga	2.07	13.56%
Jalón	0.24	1.57%	Aragón	2.40	15.73%
Huerva	0.13	0.85%	Arba	0.43	2.82%
Martín	0.02	0.13%	Gállego	0.46	3.01%
Guadalope	0.15	0.98%	Cinca	2.92	19.13%
Matarraña	0.04	0.26%	Segre	3.18	20.84%
	1.76	11.53%		13.50	88.47%

DISCHARGE FROM NON-POINT SOURCES: 0.96

REACHES

Palazuelos (161)	-	Miranda	(1)	0.34	35.42%
Miranda (1)	-	Mendavia	(120)	0.55	57.29%
Pignatelli (162)	-	Zaragoza	(11)	0.07	7.29%
				0.96	

Total discharge through Tortosa: 13.93
Total abstraction: 3.00

SINKS:

REACHES

Mendavia (120)	-	Castejón	(2)	0.22	7.33%
Castejón (2)	-	Pignatelli	(162)	0.99	33.00%
Zaragoza (11)	-	Sástago	(112)	0.41	13.67%
Sástago (112)	-	Mequinenza	(29)	0.50	16.67%
Mequinenza (29)	-	Ascó	(163)	0.56	18.67%
Ascó (163)	-	Tortosa	(27)	0.32	10.67%
				3.00	

Canal abstraction: 1.53
Reservoir abstraction: 1.47

Table 7.- Data of surface area, surface area occupied by gypsum, percentage of this of the total surface area and percentage of gypsum in the total salinity for the catchments of the sampling stations in the Ebro river network.

				Surface area	Gypsum surface area		% of gypsum in the total salinity		
River	Sampling Station	No.		Km^2	Km^2	%	SO_4	Ca	Mean
Ebro	Miranda	1	**	5481	300.00	5.50	33	36	34
Ebro	Castejón	2		25194	4698.50	18.70		36	
Ega	Andosilla	3		1445	502.90	35.00		38	
Arga	Peralta	4		2704	609.96	22.55	20	25	22
Aragón	Caparroso	5		5469	861.60	15.70	27		
Jalón	Huérmeda	9		7164	1008.20	14.10		34	
Ebro	Zaragoza	11		40434	8248.50	20.40		33	
Martín	Hijar	14		1419	496.50	40.00		73	
Guadalope	Alcañiz	15		3476	669.90	19.30		65	
Cinca	Fraga	17		9612	1682.80	17.50		31	
Aragón	Jaca	18		238			13		
Valira	Seo de Urgel	22		559			22		
Segre	Seo de Urgel	23 •	**	1233	23.30	1.90	24		
Segre	Lérida	24		11369	1309.70	11.50		47	
Segre	Serós	25		12782	1505.50	11.80		50	
Ebro	Tortosa	27		84230	18967.31	22.50		43	
Ebro	Mequinenza	29		57444	14290.91	24.90		40	
Guatizalema	Peralta de Alcofea	32 •		362	40.00	11.10		17	
Alcanadre	Peralta de Alcofea	33 •		765	50.00	6.50	20	24	22
Iregua	Islallana	36		573	90.20	15.70	49	55	52
Najerilla	Torremontalvo	38	**	1090	58.30	5.40	49		
Jiloca	Calamocha	42	**	1498	35.00	2.30		67	
Tirón	Cuzcurita	50		698	458.30	65.70		73	
Arba	Gallur *	60	***	2249	756.00	33.60		25	
Irati	Liédena	65		1546			15		
Arga	Echauri	69 •	*	1756	78.30	4.46	15		
Ega	Estella	71		943	203.20	21.50	26		
Zadorra	Arce	74	**	1357	10.00	0.74	28		
Jalón	Grisén	87		9694	1744.40	18.00		40	
Gállego	Zaragoza	89	***	4009	1628.01	40.60		37	
Nela	Trespaderne	92		1093	40.00	3.70	21		
Oca	Oña	93		1051	120.00	11.40	61	60	60
Segre	Balaguer	96	**	7796	416.60	5.30		52	
N. Ribagorzana	La Piñana	97		1757	513.30	29.20	60		
Aragón	Yesa	101		2191	343.30	15.70	15		
Huerva	Mezalocha	105	**	620	13.30	2.20		40	
Ebro	Sástago	112		48974	11686.21	23.90		42	
Segre	Pons	114		3320	33.00	1.00	35		
Ebro	Mendavia	120		12010	1536.60	12.80	39		
Gállego	Anzánigo	123	***	1391	463.30	33.30	27		
Arga	Huarte	159		178			19		
Ebro	Palazuelos	161		4514	253.20	5.60		35	
Ebro	Pignatelli	162		26427	4883.40	18.50		36	
Ebro	Ascó	163		82458	18400.71	22.30		41	
Bayas	Miranda	165		317	46.60	14.70		39	
Jerea	Palazuelos	166		290			17		
N. Pallaresa	Camarasa	169		2820	231.20	8.20	39		
Matarraña	Maella	176 •	***	1260	441.60	35.10		4	
Zadorra	Vitoria	179		682			27		
Zadorra	Durana	180		460			19		
Aragón	Sangüesa	205 •	*	4153	343.30	8.30	20	15	
Segre	Pla de San Tirs	206 •	*	1841	34.10	1.85	19		
Segre	Termens	207	**	8493	483.20	5.70		48	
Ebro	Conchas de Haro	208	**	7323	396.60	5.40		32	
Gállego	Zuera	209		3267	1051.40	32.20		38	
Ebro	Ribarroja	210		81914	18324.11	22.40		39	
Ebro	Presa de Pina	211		46062	10439.71	22.70		41	
Ebro	Cherta	212		84009	18937.31	22.50		42	
Cidacos	Calahorra	213		689	83.30	12.10		36	
Alhama	Alfaro	214		1245	166.50	13.40		48	
Huerva	Zaragoza	216		1017	253.30	25.00		45	
Arga	Ororbia	217 •	*	882	28.30	3.20	20		
Isuela	Pompenillo	218 •	***	84	33.30	39.60		24	
Segre	Torres de Segre	219		12288	1395.50	11.40		41	
Clamor Amarga	Zaidín	225	***	786	426.60	54.30		42	
Alcanadre	Ontiñena	226	**	8486	456.40	5.40		38	
Flumen	Sariñena	227		2528	283.10	11.20		13	
Cinca	Monzón	228		4387	723.20	16.50	29	28	29