VALUATION OF THE QUANTITATIVE STATE OF GROUNDWATER. EBRO RIVER BASIN (SPAIN)

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Introduction

As in the rest of the Spanish areas, the Ministry of Environment, by the Ebro River Basin Authority, builds, maintains, and works with a net to do the follow up of the standing levels of the aquifers of its territorial area.

The Ministry publishes a standing level almanac (Ministry of Environment, 2005) as an answer to the National Statistic Plan, which includes amongst other operations the statistics that refer to the quantitative state of groundwater.

Based on previous heritance, in a way due to the Instituto Geológico y Minero de España, the Ministry of Environment defined the design bases of a general control net of groundwater that intended to cover qualitative and quantitative aspects (SGOPU, 1992). From that moment on, several authorities of the river basin carried out the implementation and construction projects. Nowadays, those projects are being built (photo 1) with the purpose of having the nets completely implemented by December 2006.

In Spain, before the adoption of the Water Framework Directive 2000/60/CE (from now on WFD), the basic management element in groundwater was the “hydro-geological unity”, understood as the merger of one or several aquifers grouped in order to achieve a rational and efficient water administration. The definition of the hydro geological units is made in the hydrological plans of the basin in 1998.

Photo 1. Building site of one of the drains of the standing level net of the Ebro basin. Deza, Saragossa.

With the progressive implementation of the WFD, the concept of hydro geological unity is updated with that of groundwater body (WFD, Art. 2.12), the first definition of which is presented as an answer to the 2005 report requested to comply with the obligations of character marked in article 5 of the mentioned directive.

In the case of the Ebro basin, the land was qualified in 72 hydro geological units (Arqued *et al.*, 2000). Now they count 105 groundwater bodies distributed in two superposed horizons, 103 on the upper and 2 on the lower (Confederación Hidrográfica del Ebro, 2005).

The quantitative research that is now shown, in reference to the year 2004, still shows their analysis and results by the hydro geological units. Obviously, from the new formal definition of groundwater bodies, the survey should use these new profiles. However, the methodology used is applicable to two kinds of places, it can also be considered appropriate for groundwater bodies, because these should offer homogeneity for their labelling, although it is not strictly requested in the definition of the hydro geological units.

Control net

The Ebro river basin is located in the northeast area of the Iberian Peninsula, the southwestern part of Europe. It borders on the Pyrenees to the north, including the Basque and Cantabrian mountains, on the Iberian chain to the southeast and on the Coast-Catalonian chain to the east. Its territorial area covers an extension of 85.566 km^2, of which 39.965 km^2 (54% of the whole) are occupied by the 72 hydro geological units now defined. This definition answers to the update foreseen in article 7 of the Hydrological Plan of the Ebro basin, presented to the Water Council of the basin. Most of the units are carbonated aquifers (49 hydro geological units), but the big aquifers of detrital aquifers developed at alluvial and mountain-based streams (16 hydro geological units) are also remarkable.

The basic net of standing level control is constituted, at the end of 2004, by 180 points, so it has been possible to register levels at 50 hydro geological units. The highest density area for observation is located in the alluvial unit of Oja, with one point for every 37 km^2; the average density is one point for every 222 km^2 of surface attached to the defined hydro geological units. The measurements have been carried out monthly. Nearly all of the points that build this net are previously controlled, in some cases since the 70's and most of them since the 80's. Some points of late construction have been included, a trend that we wish to keep in the future.

Most of the parts occupied by the hydro geological units do not have a big exploitation. These concentrate in certain areas of some units and they are specially intense in the hydro geological units of Campo de Cariñena and del Bajo Ebro. Now, we include the table no.1 that shows a list of the hydro geological units of the Ebro area indicating, with other information, the number of observation points that have been included in this basic net.

Table no. 1. List of the hydro geological units of the Ebro district.

KEY	NAME	SURFACE (km^2)	CHARGE (hm^3/año)	MAIN LITHOLOGY	NO. OF POINTS
1.01	Fontibre	133	35	Carbonate	0
1.02	Páramos de Sédano y La Lora	744	147	Carbonate	3
1.03	Sinclinal de Villarcayo	997	147	Carbonate	2
1.04	Montes Obarenes	575	25	Carbonate	6
1.05	Sinclinal de Treviño	842	25	Mixt	4
1.06	Calizas de Subijana	224	56	Carbonate	4
1.07	Aluvial de Vitoria	112	46	Detrital	0
1.08	Sierra de Cantabria	214	35	Carbonate	4
1.09	Sierra de Lóquiz	427	136	Carbonate	3
1.10	Sierra de Urbasa	648	394	Carbonate	3
1.11	Basaburua - Ulzama	149	---	Carbonate	1

KEY	NAME	SURFACE (km^2)	CHARGE (hm^3/año)	MAIN LITHOLOGY	NO. OF POINTS
1.21	Gorbea	34	20	Carbonate	0
1.22	Aizkorri	134	77	Carbonate	0
1.23	Sierra de Aralar	140	163	Carbonate	2
1.24	Bureba	84	---	Carbonate	3
1.25	Calizas de Losa	231	10	Carbonate	3
2.01	Alto Iratí	832	122	Carbonate	1
2.02	Sierra de Alaiz	278	14	Carbonate	0
2.03	Sierra de Leyre	491	43	Carbonate	2
2.04	Peña Ezcaurri - Peña Telera	390	112	Carbonate	0
2.05	Tendeñera - Monte Perdido	553	217	Carbonate	0
2.06	Sto. Domingo - Guara	838	104	Carbonate	4
2.21	Larra	70	119	Carbonate	0
3.01	Alto Ésera - Valle de Arán	397	248	Carbonate	0
3.02	Cotiella - Turbón	827	236	Carbonate	1
3.03	Tremp - Isona	1.598	260	Carbonate	5
3.04	Litera Alta	905	50	Carbonate	4
3.05	Sierras marginales catalanas	762	45	Carbonate	2
3.06	Cerdaña	253	49	Mixt	2
3.21	Cadí - Port del Compte	394	68	Carbonate	0
4.01	Aluvial del Oca	72	---	Detrital	0
4.02	Aluvial del Tirón	31	---	Detrital	0
4.03	Aluvial del Oja	148	---	Detrital	4
4.04	Aluvial del Ebro: Cenicero - Lodosa	301	35	Detrital	1
4.05	Aluvial del Ebro: Lodosa - Tudela	632	135	Detrital	1
4.06	Aluvial del Ebro: Tudela - Gelsa	1.276	337	Detrital	5
4.07	Arga medio	30		Detrital	0
4.08	Aluvial del Cidacos	32		Detrital	0
4.09	Arbas	390	12	Detrital	0
4.10	Aluvial del Gállego	272	104	Detrital	2
4.11	Hoya de Huesca	110	16	Detrital	0
4.12	Aluvial del Cinca	270	31	Detrital	0
4.13	Aluvial del Segre	182	48	Detrital	0
4.14	Aluvial de Urgell	273	80	Detrital	0
4.15	Calizas de Tárrega	795	3	Carbonate	2
5.01	Pradoluengo - Anguiano	249	32	Carbonate	5
5.02	Fitero - Arnedillo	222	12	Carbonate	2
5.03	Mansilla - Neila	199	38	Carbonate	3
6.01	Añavieja - Valdegutur	416	19	Carbonate	3
6.02	Somontano del Moncayo	1.316	90	Carbonate	15
6.03	Campo de Cariñena	1.255	40	Mixt	14
6.04	Campo de Belchite	1.452	12	Carbonate	2
6.05	Depresión de Calatayud	1.925	75	Detrital	1
6.06	Oriche - Anadón	162	9	Carbonate	2
6.21	Araviana - Vozmediano	207	34	Carbonate	3
6.22	Borobia - Aranda de Moncayo	115	14	Carbonate	2
7.01	Sierra de Miñana	209	11	Carbonate	2
7.02	Páramos del alto Jalón	2.220	130	Carbonate	4
7.03	Gallocanta	300	22	Mixt	5
7.04	Alto Jiloca	1.558	135	Mixt	10

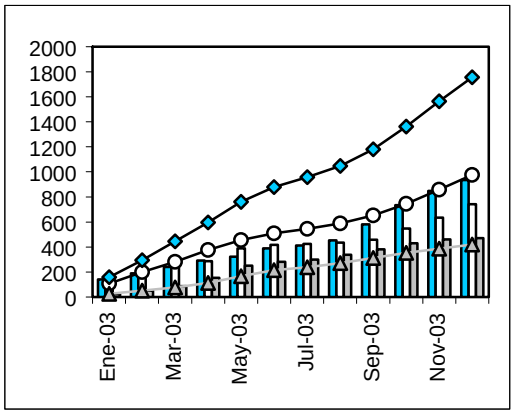
KEY	NAME	SURFACE (km^2)	CHARGE (hm^3/año)	MAIN LITHOLOGY	NO. OF POINTS
7.21	Cella - Molina de Aragón	82	104	Carbonate	4
7.22	Campo de Visiedo	125	38	Carbonate	0
8.01	Cubeta de Oliete	1.354	70	Carbonate	8
8.02	Aliaga - Calanda	1.915	252	Carbonate	3
8.03	Pitarque	552	46	Carbonate	1
8.04	Puertos de Beceite	1.093	135	Carbonate	4
8.05	Fosa de Mora	530	25	Mixt	2
8.06	Priorato	269	2	Mixt	0
8.07	Montsant	342	12	Carbonate	0
8.08	Puig Moreno	509	---	Carbonate	3
8.21	Bajo Ebro - Montsiá	1.287	385	Mixt	7
8.22	Alto Maestrazgo	1.011	---	Carbonate	1

Map no. 1 shown in the next page, shows the location of these units in the territorial area of the Ebro and the situation of the points that build the present net.

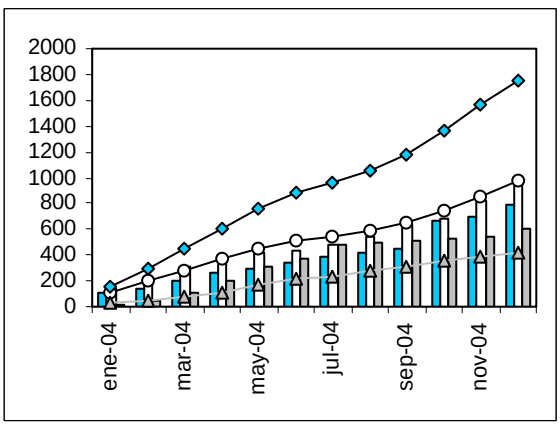
Level evolution

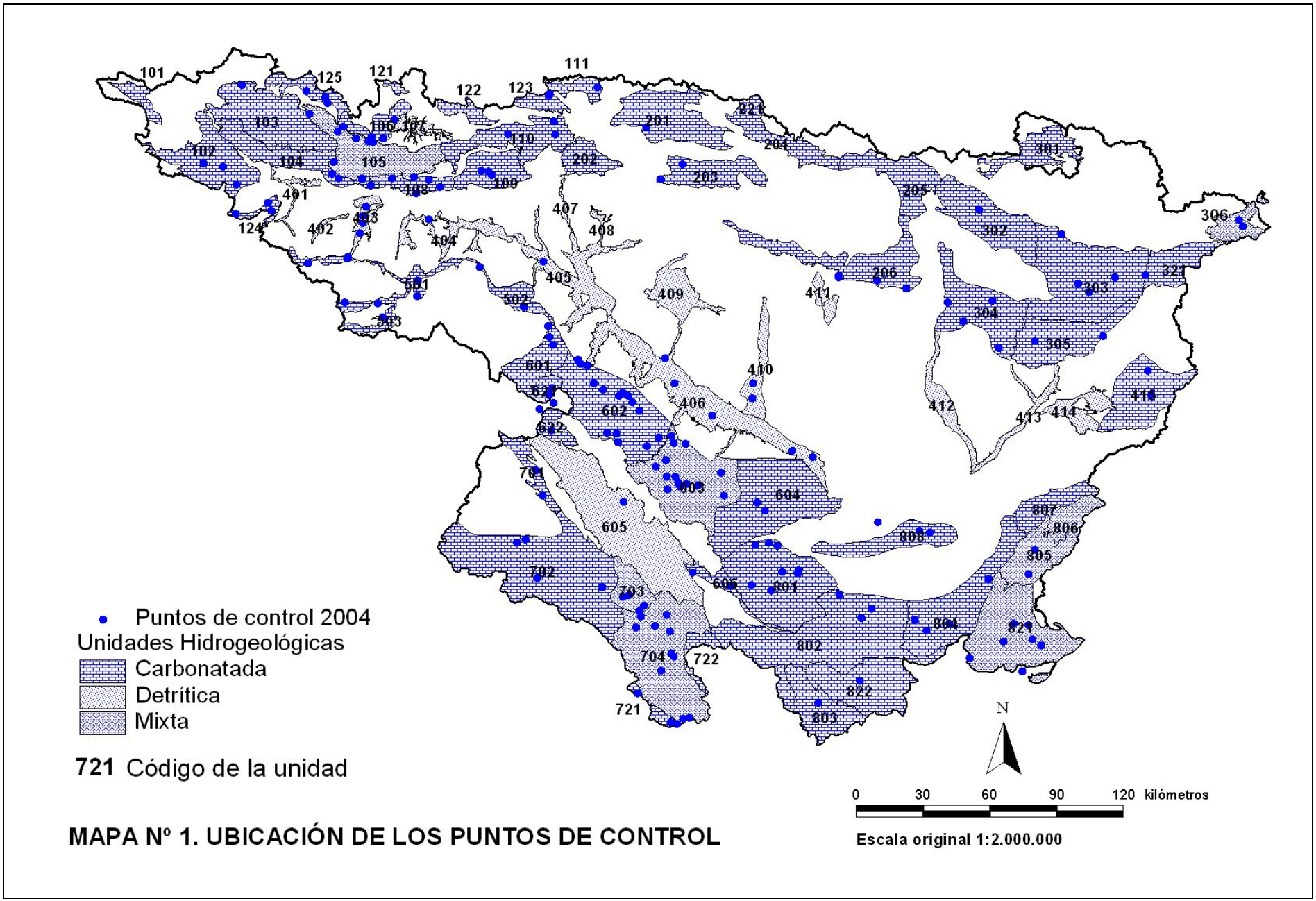
The isopluvial map of the Ebro basin is amounted in 660 mm, a slightly higher value than that registered in 2004, of 647 mm according to the INM. It can be concluded that during 2004 there was a continuance in the recovery of the rainwaters registered in 2003 in comparison to the previous years. Maps 1.a. and 1.b. show the hydrographs of the monthly accumulated values, belonging to the years 2003 and 2004, of three pluviometric stations of the SAIH (Automatic System for Hydrological Information) net expressing the general evolution registered in the basin. They are the stations of Canfranc (Central Pyrenees), Urrúnaga (North of Vitoria) and Gallipuén (Central Iberian). They also include the average accumulated rain registered during the period of measures that have taken place in the stations.

Map. 1.a. Monthly rain accumulated belonging to the year 2003 (bars) and to the average year of the stations of the series (lines and symbols), for the stations of Canfranc (blue and diamond, Urrúnaga (white and circle) and to the dam of Gallipuén (grey and triangle). Values in mm.



Map. 1.b. Monthly rain accumulated belonging to the year 2004 (bars) and to the average year of the stations of the series (lines and symbols), for the stations of Canfranc (blue and diamond, Urrúnaga (white and circle) and to the dam of Gallipuén (grey and triangle). Values in mm.

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MAPA Nº 1. UBICACIÓN DE LOS PUNTOS DE CONTROL
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Rain in 2004 was more frequent in the first semester, and was particularly high in the right margin of the basin. During the second semester, there was an acute pluviometric reduction.

The distribution and intensity of the rain were translated into the evolution registered by the standing level. In picture no. 2, we represent eight hygrograms that belong to the same number of standing levels. We represent the values registered during the last two years and the extreme maximum and minimum values of all the series of each month. The charts are placed from top to bottom from the header to the lower part of the basin, to the right of the right margin and to the left of the left margin of the Ebro.

The point 2107-6-25 is located in the area of Alava (Basque Country) and shows a strong recovery during the springtime that reaches values close to the month's maximum and then decrease to the average values at the end of the year.

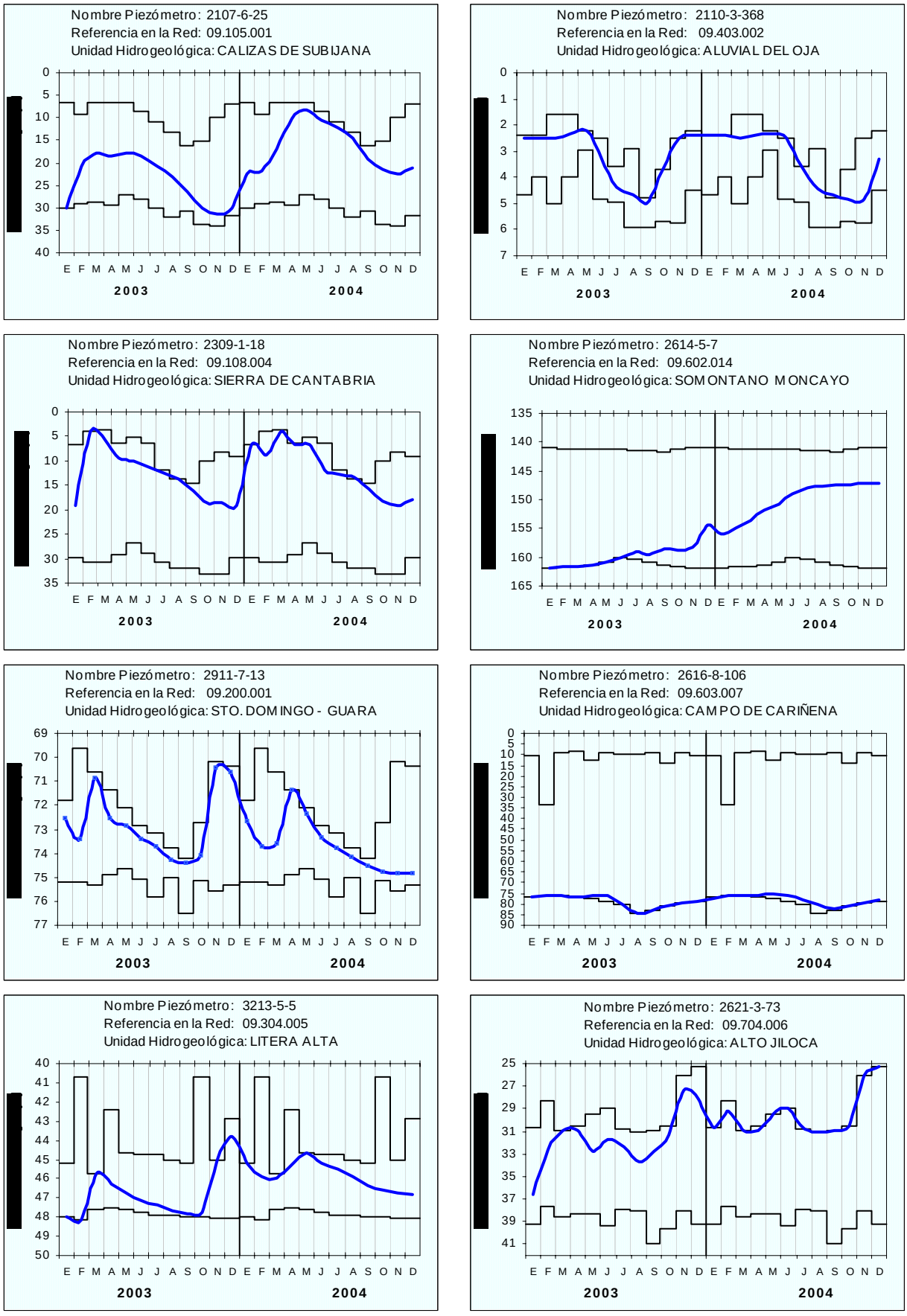
The point 2309-1-18, which is located in the Cantabrian Mountains shows, in general, very high values at the beginning of the year, with a historical maximum in March, and then it reaches the average value at the end of the year.

For the high part of the right margin, we present the point 2110-3-368, located in the rain aquifer of the Oja River. Its level still shows the cyclical character of this aquifer, but with higher registers at the beginning of the year and average values at the end.

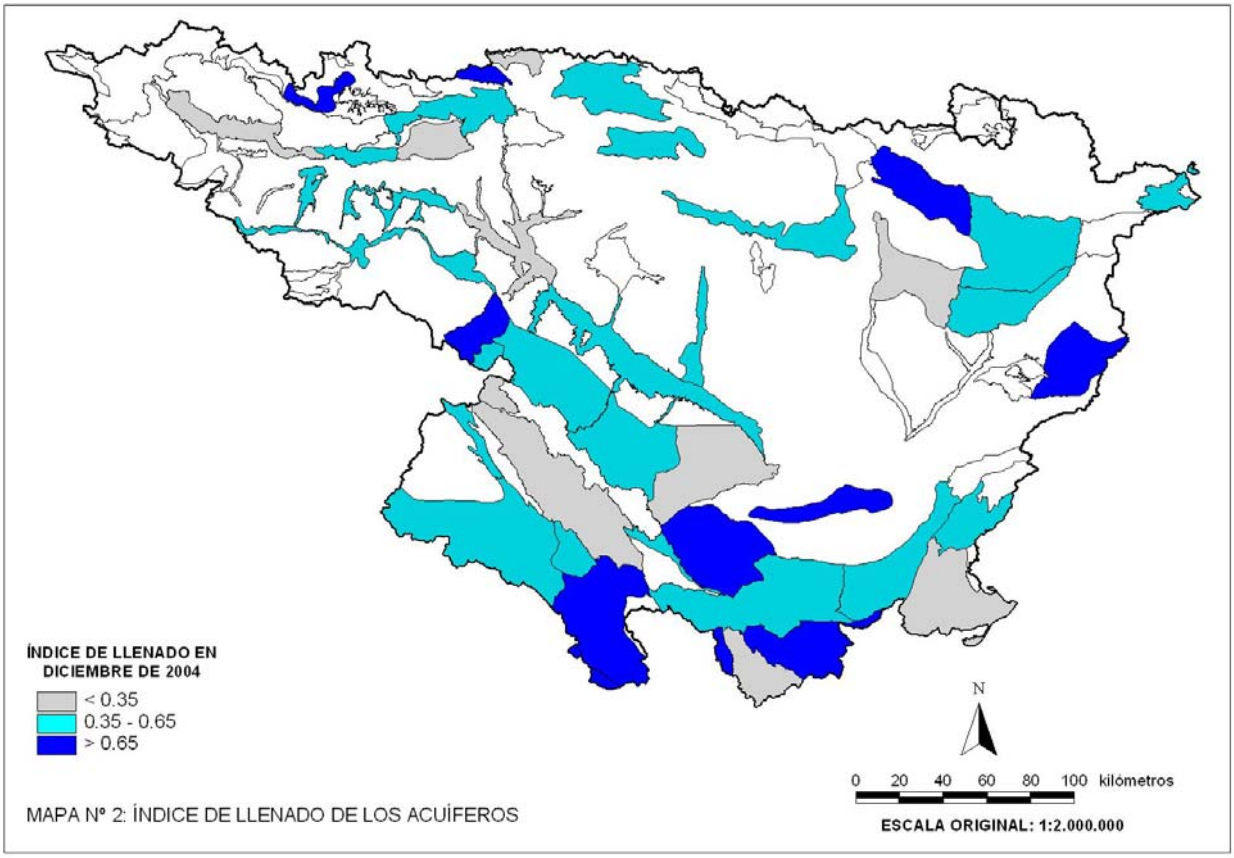
In the central area of the right margin of the basin, the levels are still in the situation of historical minimums already stated in 2003, due to the intense exploitation of the ground resources. This is specially highlighted in point 2616-8-106 which registers the level of the detrital tertiary aquifer of Campo de Cariñena of hard exploitation, despite the fact that it shows a slight increase from May to September. Point 2614-5-7, located in Moncayo, registers a clear trend to recovery from the mid 2003 as an answer to the rain of the winter and spring.

The left margin in Aragon is represented by point 2911-7-13, located under Sierra de Guara, in the preceding part of the Pyrenees. In this case, after the recovery of the levels shown in 2003 and during the spring of 2004, we have registered a continuous decrease until the end of the year. In the eastern part of the left margin the recharge took place during the spring of 2004 and standing levels like 3213-5-5, located in Ribagorza, have registered a continuous decrease from April to the end of the year.

Finally, the eastern part of the right margin is represented by point 2621-3-73, located in the high part of Jiloca, after a progressive recovery during the year 2003 has registered historical maximums during 2004.



Picture. 2. Charts of standing level evolution in some significant points of the net. The measure of the month is marked in blue and the maximum and minimum value of each month, in black, considering the registers during the whole series of measures.



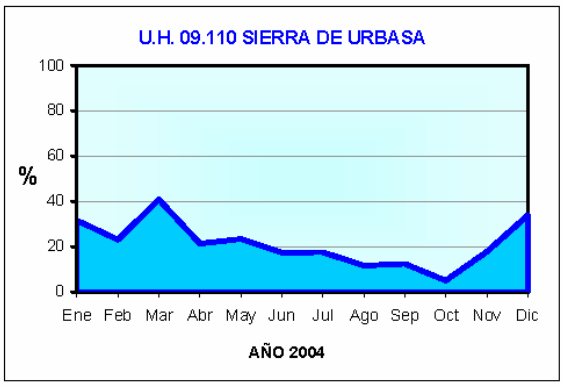
MAPA Nº 2: ÍNDICE DE LLENADO DE LOS ACUÍFEROS

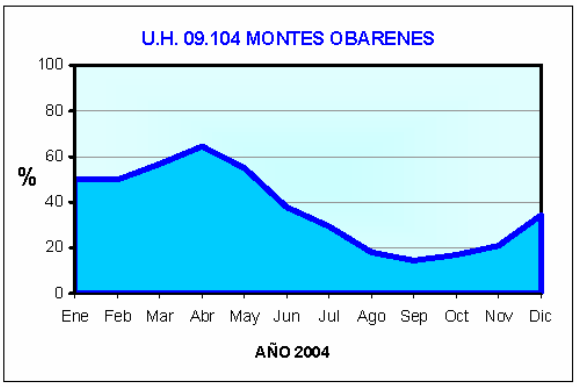
Filling index of aquifers

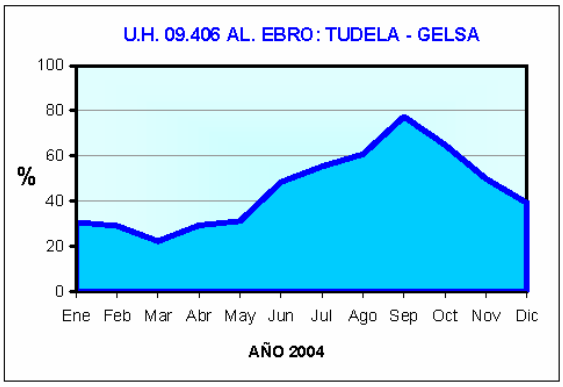
It was possible to do this index (Fidalgo *et al.*, 2002) for 44 hydro geological units, which mean 61% of the total units defined in the Ebro basin. The calculus percentage may seem low, but in any case, it has been taken into account in all the units that suffer a clear exploitation, and also in those that act more as an example of the general hydrologic behaviour of the basin. The results of the calculus made are shown in map number 2 and in picture 3. For the preparation of the map, each hydro geological unit has been valued by its more important or representative aquifer. When we had several points that pointed towards the same aquifer, we calculated the average. The colour categories shown in each unit represent the percentage of filling by December 2004, in comparison with the minimum and maximum registered in the whole series of measures.

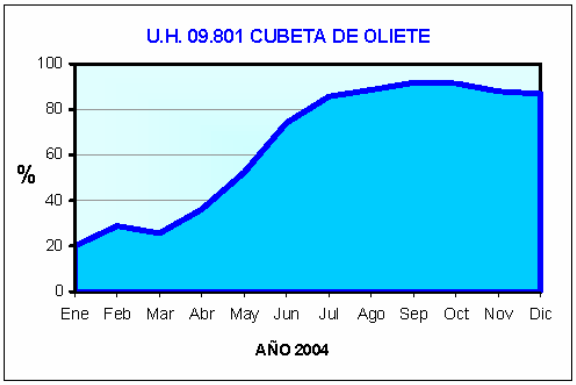
This information is completed with the charts shown on the next page (Picture 3). They show the evolution of the filling index during the year in some hydro geological units, different to those that hold the standing levels shown in picture 2, and that are also representative of the general behaviour of the basin. The presentation is organised as in the previous case, from header to end and separating the right margin from the left.

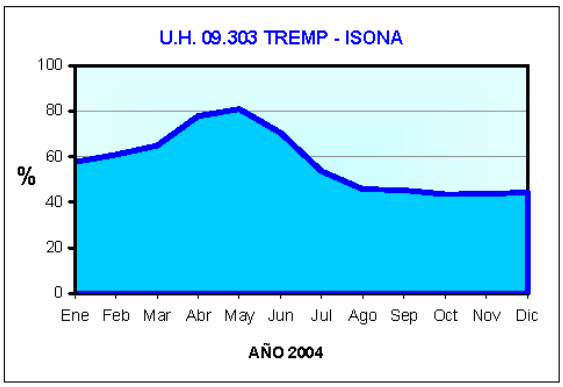
With all this, we consider that the general situation in which the groundwater reserves are in the basin of the Ebro at the end of the year 2004 is between medium and high level.

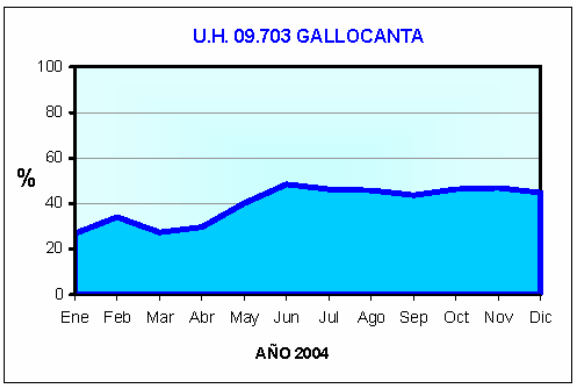


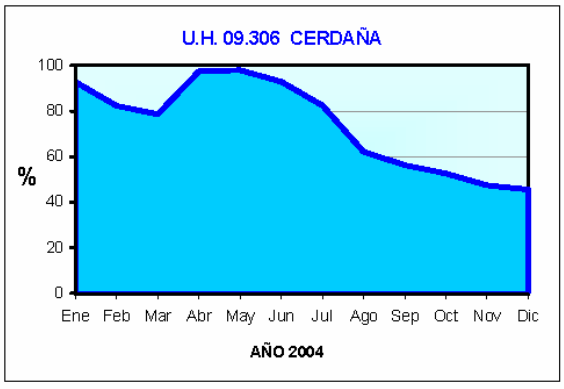


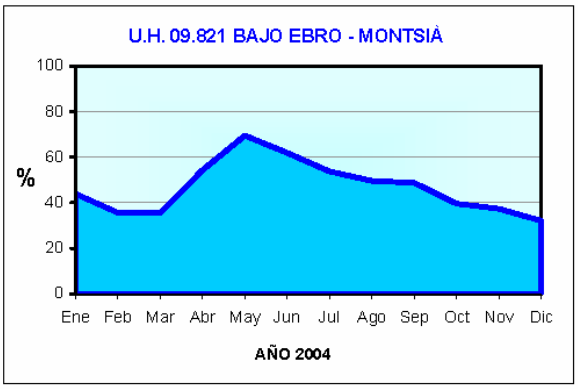












Picture. 3. Charts that show the evolution of the filling index of some hydro geological units, example of the behaviour registered by the aquifers of the Ebro basin during the year 2004.

The filling indexes are amounted, in 40% of the cases, beyond 50%, passing over 70% in 15 % of the analysed units of the Ebro basin. This means a significant increase of the ground reserved in comparison with the last two years, because of the amount of rain that conditioned the general level recovery during the winter of 2003, and winter and spring 2004.

Even if there are no clear steps, in general the lower filling indexes were registered in the aquifers located in hydro geological units of the left margin, in the western areas of the Pyrenees and in the Basque and Cantabrian areas.

We do find that the higher filling levels are shown in those units with the advantage of the recharge of the southern and eastern part of the basin, with some exceptions: Borobia, Pitarque, Campo de Belchite, la Depresión de Calatayud and Bajo Ebro have registered the low filling indexes. In these cases it is very important the extraordinarily changing nature of some karstic means (such as Pitarque o Borobia), the representation of the standing levels (Depresión de Calatayud) or the long series of historical data (Campo de Belchite).

Difference in the stored volumes

This change is registered in map no. 3, where there is a comparison of the situation of the hydro geological units at the end of the year 2004 with the situation they showed at the end of the year 2003. The calculus made compares the difference of level between the levels that correspond to the months of December in both years.

As it is shown in the map, the general situation is of slightly equal levels or higher to those of December 2003.

The rain registered during the last months of the year 2003 and during the spring of 2004 meant a significant increase of the levels especially remarkable in the Iberian hydro geological units.

We should also highlight that this recovery has also influenced some units of the central Iberian sector (Campo de Cariñena) which, however, still register filling indexes relatively low as a consequence of the progressive ending of the reserves.

The information system

The data of the standing levels register, this is, the data of depth of the water inside the observation radar, is noted in a database operated by the Organismo de Cuenca, known as IPA (Latre *et al*, 2004), acronym of Inventario de Puntos de Agua (Water Points Control). The information kept includes data of the points, both special as relative to their nature and source of the information, and data relative to the perforation, cover, lithologic column, hydrometry, hydrochemistry, etc. All this information is kept in an Oracle that efficiently manages the data and the static or dynamic restrictions established. The information of the database is accessible and kept by an application developed in Java. The client's application of the IPA is also in charge of establishing the mechanisms of communication coordinated with a GIS tool in which the aspects relative to the geological information of the stock are shown and edited. The system is completed with an information server that is in charge of creating those reports that need interaction with the database automatically or semi-automatically; amongst them the

analysis of the standing levels that are shown in this article.

The implementation of the WFD means new challenges about the general hydrologic information management and, in particular, the hydro geological. These practices lead to the creation of a special data infrastructure, which is able not only to comply with the requirements of the WFD, but also with the principles and targets of the proposal of new Guideline INSPIRE (*INfrastructure for SPatial InfoRmation in Europe*).

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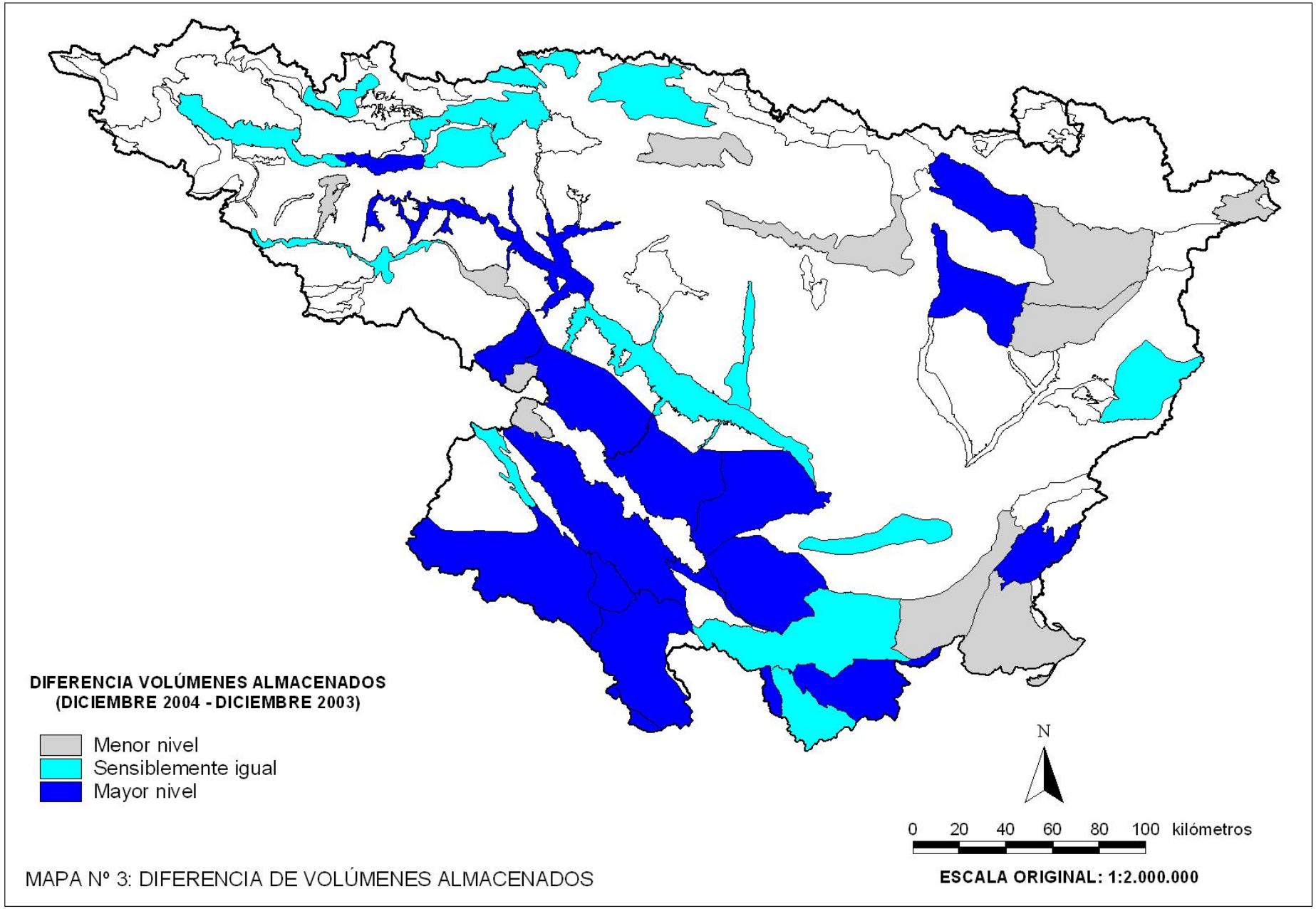

MAPA Nº 3: DIFERENCIA DE VOLÚMENES ALMACENADOS