DRAFT

GROUNDWTER ISSUES IN SOUTHERN EU MEMBER STATES
SPAIN COUNTRY REPORT[1]

Nuria Hernández-Mora (Fundación Nueva Cultura del Agua)
Luis Martínez Cortina (Instituto Geológico y Minero de España)
M. Ramón Llamas Madurga (Universidad Complutense de Madrid)
Emilio Custodio (Universidad Politécnica de Cataluña)

Madrid, April 19th 2007

1. INTRODUCTION

Spain is globally the most arid country in the European Union, especially in the center and eastern half. Therefore, it is logic that the problems in relation to water use and management are relevant. Spain is a classical case of the recent and pervasive phenomenon of the intensive groundwater use silent revolution (Fornés *et al.* 2005; Llamas and Martinez-Santos, 2005). Groundwater use in Spain has increased dramatically over the last several decades, with the total volume pumped growing from 2,000 Mm^3/year in 1960 to more than 6,500 Mm^3/year in 2000. These developments were for the most part the result of the initiative of thousands of individual users and small municipalities, with scarce public planning or oversight. Today, groundwater provides between 15-20% of all water used in the country, although it may approach 100% in some areas and islands.

The intensive development of groundwater resources has brought about significant social and economic benefits, but their unplanned nature has also resulted in negative environmental, legal and socioeconomic consequences. This situation is not exclusive of Spain. With different hues it is similar in most arid and semiarid countries, as emphasized in the Alicante Declaration approved at the International Symposium on Groundwater Sustainability (Ragone *et al*. 2007). In order to deal with these problems in Spain, the 1985 Water Act radically transformed the institutional context for the management of groundwater resources in Spain. Most significantly, it publicized groundwater ownership, allowing existing users to remain in the private property regime if they so wished, but requiring administrative permits for any new uses. It also regulated the concept of aquifer overexploitation, giving water authorities broad powers to regulate groundwater use in aquifers that were declared overexploited. While this declaration should be accompanied by strict regulatory measures, they have most often not been successfully implemented, and a situation of chaos still persists in many of these aquifers.

Groundwater use in Spain has significant socioeconomic importance, both as a factor of production in agriculture and industry, and as a source of drinking water for over 12 million people (almost one third of the total population). Existing data on groundwater use and its associated economic value points to the higher productivity of groundwater irrigation compared with irrigation using surface water. Given the importance of irrigation as a water user, and in the context of increased competition for limited water resources, recent efforts to

---

[1] This is the draft of the Report on Spain for the General Report on Groundwater Issues in the Southern EU Member States. This general report is being prepared by a working group appointed by the Europèan Academies of Sciences Advisory Council (EASAC). The group is chaired by prof. M.R. Llamas of the Spanish Royal Academy of Sciences. This draft was presented in the second meeting of the working group held on April 19, 2007 in the headquarters of the ARECES Foundation in Madrid. This draft with minor changes will be soon published in a scientific magazine, Observations on this draft can be sent to M. Ramon Llamas mrllamas@geo.ucm.es or to Nuria Hernandez-Mora nhernandezmora@yahoo.com

improve the quality of data on groundwater use and its economic importance in the context of the Water Framework Directive requirements, are crucial to inform water policy decisions in the future.

This paper presents an overview of the situation of intensive groundwater use in Spain, with an emphasis on economic and institutional aspects. After a review of available data on groundwater use and a brief discussion of some regions where groundwater is used intensively, we look at the economic parameters associated with this use, focusing on irrigation. We then go on to evaluate the institutional framework for the management of groundwater resources that has evolved from the 1985 Water Code, its 1999 and 2003 reforms, and the current reform proposals.

2. SCOPE

This paper is mainly an updated version of an article by Hernandez-Mora *et al.* (2003), which was presented in an International symposium on Groundwater Intensive Use held in Madrid in December 2001. The outlook of the article is still generally valid but in the last six years the approval and beginning of the implementation of the EU Water Framework Directive (WFD) has transformed water management objectives and contributed new data on water resources, water uses and water economics.

The interest in groundwater has increased significantly in the last year and not only in Spain, but in almost all the arid and semiarid countries where irrigation plays a relevant role in the use of water. A few examples of such interest are: a) the report of the World Bank on India's water (Briscoe, 2005); where the spectacular increase of groundwater use for irrigation is defined as a "quiet" revolution; b) The special theme issue of the Hydrogeology Journal (February, 2006) devoted to the economic and institutional aspects of groundwater management; c) the International Symposium on Groundwater Sustainability, held in January 2006 in Alicante (Spain) (Ragone *et al.* 2007); and the recent book on the "groundwater irrigation revolution" published by the IMWI-CGIAR (Giordano and Villholth 2007).

The role of groundwater in twenty Mediterranean countries is being studied by the European Union Water Initiative (EUWI). A final report on this topic has been released in October 2006 (EUWI, 2006). This report provides important data on the groundwater use in all these twenty countries but its emphasis on the economic, institutional, and legal aspects is rather scarce.

The goal of this manuscript is to provide basic data for the preparation of the REPORT ON THE ROLE OF GROUNDWATER IN THE WATER POLICY OF THE SOUTHERN EUROPEAN UNION MEMBER STATES. This report for the EU Commission and Parliament is an activity of the European Academies of Sciences Advisory Council (EASAC). This report will contribute to the European Union Water Initiative for the Mediterranean countries. In this manuscript we have tried to incorporate the new data that the Spanish Government is obtaining in order to enforce the requirements of the WFD. However, the availability of these data is still scarce due to several causes. Perhaps most importantly, the fact that many of the WFD's guiding objectives, such as ecological conservation, cost recovery, information transparency and public participation, are a significant novelty for Spain's water management field is presenting significant challenges in the government's efforts to meet the WFD's requirements and deadlines.. But the lack of information on groundwater uses can also be explained as the result of the general "hydroschizophrenia" or lack of interest of most water decision-makers in groundwater issues (Ragone *et al.* 2007; Llamas and Martinez-Santos 2005)

3. GROUNDWATER RESOURCES

Spain is a well-endowed country in terms of aquifer formations widely distributed throughout the country. This distribution is uneven spatially, depending on the geological characteristics of each region. Traditionally only sedimentary, carbonated or volcanic formations of higher permeability were officially considered aquifers. This meant that official estimates calculated that aquifer formations were found in about 180,000 km^2, or one third of the country's surface area. Aquifer formations were divided into 411 hydrogeological units, a concept that was defined for the first time in the 1985 Water Act, often following more administrative than hydrogeological criteria. However, this concept excluded many areas with small low permeability aquifer formations, that while containing limited resources were of strategic importance at the local level.

The WFD introduced the concept of water bodies as the new unit of reference. The spirit of the Directive indicates that water bodies should be considered as subunits of river basins that are coherent from a management standpoint in order to achieve the environmental objectives of the Directive. These objectives will be compared in each water body with the current status, which must be described in sufficient detail (EC, 2003).

The existing demarcation of hydrogeological units was a starting point for the characterization of groundwater bodies. Areas that were previously classified as having "no aquifers" have now been included following the criteria established by the WFD, such as the need to characterize as water bodies those that serve as a drinking water source for more than 50 people or that supply over 10 m^3/day.

Under the new classification, 699 groundwater bodies have been identified, covering an area of over 350,000 km^2, practically 70% of Spain's surface area (MMA 2006). The size of groundwater bodies varies greatly: from less than 2,5 km^2 of the Guernika groundwater body, in the Basque Internal River Basins (*Cuencas Internas del País Vasco*), to the more than 20,000 km^2 of the Esla-Valderaduey groundwater body, in the Duero River basin. The average size is about 500 km^2. Figure 1 show the distribution of groundwater bodies in Spain and Table 1 shows a summary of existing groundwater bodies for each River Basin District, as well as their areal extent and the percentage of the total territory of the basin that they cover.

This classification was developed in order to comply with the requirements of articles 5 and 6 of the WFD. It is currently being revised and updated for the elaboration of the Basin Management plans, which need to be published before 22/12/2009 and submitted for public review one year before that. The work done so far indicates that the number of groundwater bodies will increase significantly after the review.

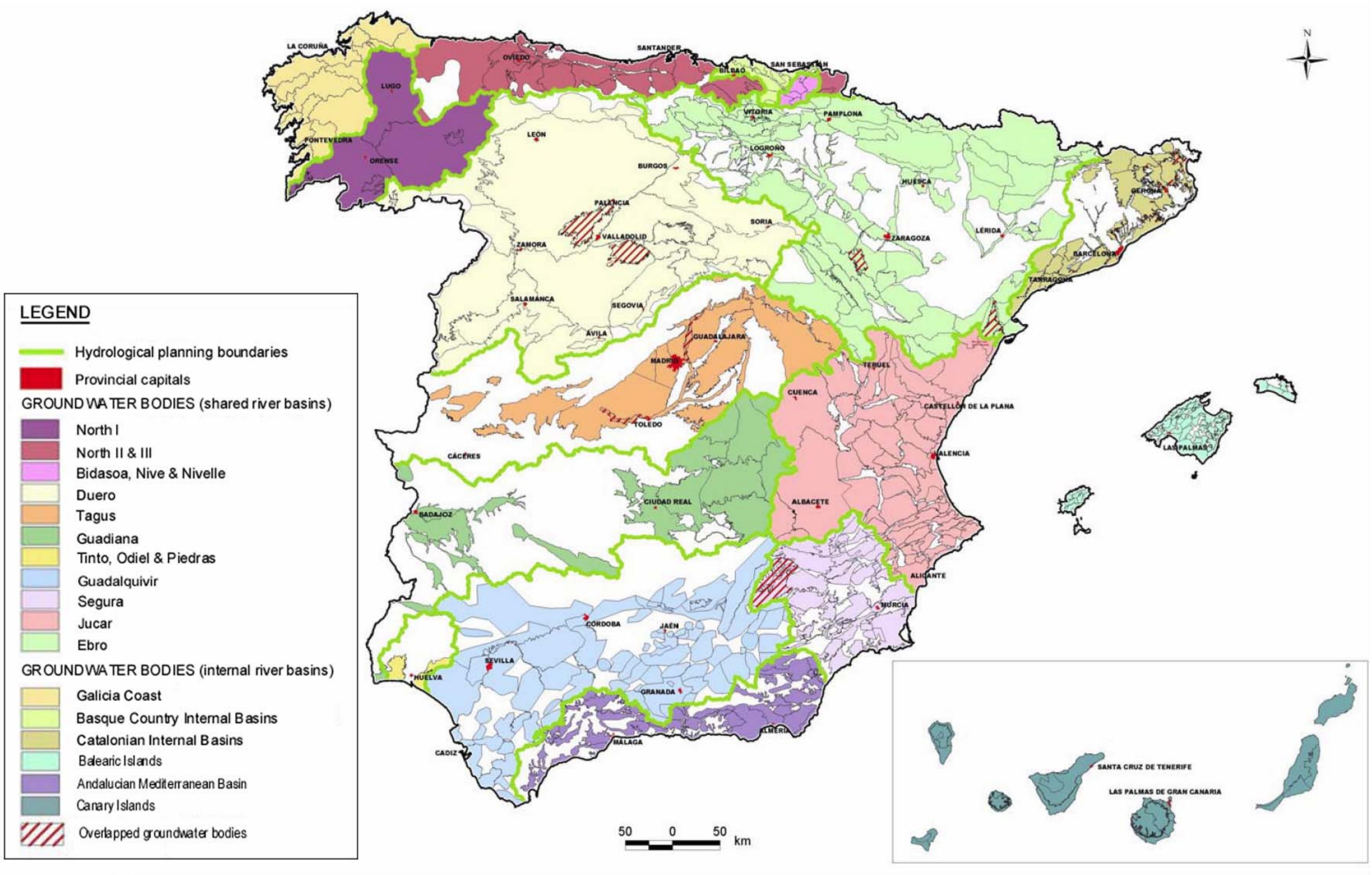

Figure 1. Groundwater bodies in Spain. (MMA 2006)

Table 1. Summary of groundwater bodies (MMA 2006)

River Basin District		Number of groundwater bodies	Total surface area (km^2)	% of the basin's area
SHARED RIVER BASINS	Norte I	6	17.600	100 %
	Norte II y III	34	16.400	82 %
	Bidasoa, Nive y Nivelle	2	800	94 %
	Duero	31	74.700	95 %
	Tajo	24	21.900	39 %
	Guadiana	20	22.100	40 %
	Tinto, Odiel y Piedras (1)	4	1.000	22 %
	Guadalquivir	71	40.600	61 %
	Segura	63	15.000	73 %
	Júcar	79	40.600	94 %
	Ebro	105	54.800	63 %
INTERNAL RIVER BASINS	Galicia Costa	18	13.100	100 %
	Cuencas Internas del País Vasco	14	2.300	100 %
	Cuencas Internas de Cataluña	39	11.100	65 %
	Cuenca Mediterránea Andaluza	67	10400	58 %
	Baleares	90	4.200	84 %
	Canarias	32	7.400	100 %
	TOTAL	699	354.000	69 %

(1) These two river basins are now within the Andalusian Internal River Basins (*Cuencas Internas Andaluzas)* planning district.

A precise estimate of the total volume of water stored in Spain's aquifers would not be easy to calculate. Depending on the study, estimates vary between 150,000 Mm^3 and 300,000 Mm^3. However, actual reserves are probably much higher, since the existing calculations only take into account the volume stored to 100–200 m depth and do not consider *unofficial* hydrogeological units (Llamas *et al.*, 2001), which now are clearly included in the new definition of groundwater bodies, and whose reserves can be significant. In any case, groundwater reserves present a much higher storage than surface water infrastructures, whose full capacity is about 53,000 Mm^3, of which on average only 37,425 Mm^3 are annually available for use (MMA 2007a).

The storage of many aquifers usually exceeds the natural rate of recharge by one or two orders of magnitude. This feature has practical implications that are particularly important for a country like Spain, where evapotranspiration is high and droughts are frequent. However, groundwater planning and management has traditionally not been adequately considered by the Administration.

From a practical point of view, knowing how much water can be extracted from an aquifer is more important than the aquifer's total reserves. This is usually a difficult volume to quantify, as it is difficult to calculate and is conditioned by changing technical, social, economic and environmental factors. An aquifer's renewable resource, sometimes termed net recharge, is the difference between aquifer recharge and phreatic evapotranspiration. This is interesting to know in order to assess the effects of groundwater abstraction on the aquifer's water balance.

A mathematical model was developed to estimate Spain's renewable groundwater resources for the White Book of Water (MMA 2000). This model calculates that total renewable resources amount to about 30,000 Mm^3/yr, significantly above previous estimates of 20,000 Mm^3/yr. Even the 30,000 Mm^3/yr figure is probably an underestimation since simulations are carried out under natural conditions, certain low permeability areas are ignored, and the model grid (1 km side) is not able to consider in detail the real behaviour of groundwater (Cruces 1999). In any case, what these global estimates make apparent is that groundwater is a key resource in Spain.

From a management standpoint however, and given the climatic and hydrogeological diversity of Spain, what is important is to develop accurate local estimations of stored and renewable groundwater resources. This is happening with the work being done for the elaboration of the River Basin Management Plans.

4. GROUNDWATER USE IN SPAIN

Existing information on groundwater uses in Spain is very heterogeneous and often scarce. This is due to several causes. On one hand, water management responsibilities in Spain are divided between different levels of government: River Basin Management Agencies that depend of the central government's Ministry of the Environment for shared river basins; Water Management Agencies that depend of autonomous regional governments for river basins that are entirely within one autonomous region; local governments in issues pertaining to public water supply; and irrigator associations for management and distribution of irrigation water among their members. On the other hand, most official statistics about water use for irrigation do not differentiate between surface and groundwater sources. This is primarily due to the fact that, until 1986, there were no inventories of existing groundwater uses and no administrative permits were required to abstract groundwater. Additionally, very often surface and groundwater sources are used conjunctively and the data does not distinguish between one and the other. This makes it increasingly difficult to make a global estimation of groundwater uses for the entire country.

Table 2. Groundwater use in Spain

Use	Total water used (Mm^3/year) (1)	Groundwater used (Mm^3/year)	Percentage of total use supplied by groundwater
Domestic supply	5,500 (≈ 15%)	1,000 – 1,500 (≈ 20%) (1)	≈ 20 %
Agriculture	24,500 (≈ 65%)	4,000 – 5,000 (≈ 75%)	≈ 20 %
Industry	1,500 (≈ 4%)	300 – 400 (≈ 5%)	≈ 20-25 %
Electrical energy production	6,000 (≈ 16%)	–	–
Total	37,500 (100%)	5,500 – 6,500 (100%)	15 –20 %

Source: Elaborated with data from MMA (2007b) (1), MMA (2000), MOPTMA-MINER (1994), and ITGE (1995).

Table 2 presents estimations of groundwater uses in Spain using data from the 1990s and indicates that overall groundwater use ranges from 5,500 to 6,500 Mm^3/year, representing between 15% and 20% of total water uses in Spain. However, this percentages vary widely from region to region so that, for instance, in Mediterranean basins, groundwater can represent up to 75% of all resources used (MMA 2007a). The volume of groundwater use also increases significantly in times of drought, when surface water resources are less available.

It is worth pointing out the limited use of groundwater resources in Spain for domestic purposes. According to the European Environmental Agency (EEA 1999), in European countries with sufficient aquifer potential, over 75% of domestic water supply comes from groundwater. In comparison to other European countries and with the exception of Norway, which has very little aquifer potential, in 1999 Spain had the lowest percentage of groundwater used for urban supply, 19% according to MMA (2007b). However, groundwater as a source of domestic water supply is more important in some particularly arid river basins (51% in the Andalusian Mediterranean Basins, 49% in the Canary Islands or 43% in the Júcar River Basin, and even more in the Balearic Islands). These are low percentages for a country with the hydrogeological potential and the meteorological characteristics of Spain, and where groundwater could play a major role in guaranteeing water supply to cities during droughts. Nevertheless, roughly 12 million people (or about the 35% of total population) use groundwater as their main source of drinking water. In communities of less than 20,000 inhabitants, approximately 70% of water comes from groundwater sources, whereas the figure is 22% in larger cities (MMA 2000).

The principal use of groundwater is for irrigation, as is the case in most arid and semiarid countries. The dramatic increase in groundwater development in Spain has been primarily undertaken by thousands of individual farmers in different regions with very limited public involvement. In some regions (Castilla-La Mancha, Murcia, Valencia), groundwater is the primary source of water for irrigation. In the Balearic and Canary islands, groundwater is often the only available resource.

Approximately 75% of groundwater abstracted in Spain is used for irrigation. Groundwater irrigates around one million hectares, about 30% of the total irrigated area, although frequently both surface and groundwater sources are used conjunctively to irrigate crops. Groundwater resources allows farmers to guarantee their crops in drought years when surface water resources are not available.

To sum up, groundwater provides 20% of all water used to irrigate 30% of the total irrigated area. That is, groundwater irrigation is significantly more efficient than surface water irrigation in Spain (Llamas *et al*., 2001). The reasons that may help explain this greater efficiency will be discussed later.

5. THE ECONOMIC ASPECTS OF GROUNDWATER USE IN SPAIN

Until the approval of the WFD there was little data on the economic importance of water use in Spain. This problem was even more acute in the case of groundwater, since the overwhelming private character of groundwater uses resulted in little administrative attention to this resource. The few economic studies that did exist were constrained to particular regions or sectors, and for the most part did not differentiate between surface and groundwater sources.

This situation has started to change with the new obligations that derive from the WFD. The obligation of member states to apply the full cost recovery principle by 2010 has resulted in the need to undertake an economic analysis of each water use. In order to undertake this challenge the Ministry of the Environment of Spain created the Economics Analysis Group (*Grupo de Análisis Económico)*, an internal working group that has been coordinating and guiding the work of the different Basin and Water Management Agencies in what pertains to the economic aspects of water use. Recently, the group has published two reports (MMA 2007a and 2007b) that summarize the content of the work undertaken by the Management Agencies to comply with WFD Article 5 and Annex II and III reporting obligations. The content of these reports is currently being presented in a series of eight public meetings being held in different cities throughout Spain that will end in November 2007. The reports, as well as the presentations, debates and conclusions of each of these meetings, can be found at the website of the Fundación Biodiversidad of the Ministry of the Environment, which is organizing these public meetings (http://www.fundacion-biodiversidad.es/opencms/export/fundacion-biodiversidad/envios/portal_debate07.html). Even though the reports have been elaborated with limited and inconsistent economic data, as a result of this work it is possible, for the first time, to have a more clear understanding of the economics of water use in Spain.

However, the information presented in the reports for the most part still fails to distinguish between surface or groundwater sources so that, in what pertains to the economics of groundwater use specifically, the information is still quite limited. Also, the reports use information primarily from official government sources, and fail to incorporate information from many other sources (regional governments, academics and others) that could have allowed for more sophisticated analysis. Finally, a lot of work remains to be done on non-traditional economic analysis, such as resource and environmental costs, or more detailed analysis of other sectors that while less significant in volume of water used, could be significant from an economic or environmental perspective.

5.1. Costs of groundwater use

In general terms, it can be stated that in Spain, as in most countries around the world, groundwater is used intensively because the direct benefits that users obtain from a certain level of abstraction greatly outweigh the direct costs of obtaining that water, even when these are very high. But the associated indirect or external costs, which could make some levels of abstraction economically or socially inefficient, do not accrue directly to the users. Rather, they are spread over space and time and are borne by other users or by society at large. As a result, the overall costs of intensive groundwater use do not motivate changes toward more economically and socially efficient abstraction regimes.

It is precisely in order to deal with this discrepancy that the WFD requires the calculation of both the direct water service costs as well as environmental and resource costs. In Spain the work done so far has focused on the estimation of the direct service costs. In line with the WFD reporting obligations, the Ministry of the Environment published in 2003 a study evaluating the extraction costs associated with groundwater use for irrigation and urban water supply in Spain (MMA 2003). This work calculates groundwater costs as the costs of well drilling and construction, the replacement value of the infrastructure needed for water abstraction, and the costs of the energy or fuel needed for pumping. No estimation is yet available of the environmental or resource costs, which can be significant. Work by other authors has also focused on these direct service costs. What follows is a review of some of the data that can be gathered from these sources.

5.1.1. Service or direct costs

In Spain, pumping costs are a function of the yield of the well, the characteristics of the terrain, the pumping technology used, depth to water and energy costs. The 2003 Ministry of the Environment study (MMA 2003) estimated the average groundwater abstraction costs to be 0.08 €/m^3 for urban water supply and 0.12 €/m^3 for irrigation. However, values vary greatly from one hydrogeological unit to another. Costs of groundwater use for urban water supply range from as little as 0.03 €/m^3 in some aquifers of the Guadiana river basin to as high as 0.37 €/m^3 in the North basin. In the case of irrigation values range from 0.04 €/m^3, again in the Guadiana, to as high as 0.74 €/m^3 in the Segura river basin. As Llamas and Garrido (2007) point out, this assessment was done without specific field surveys and therefore it should be considered only as a preliminary approach. Additionally, these values estimate the costs of extraction at the well. Other direct service costs, such the cost of construction and maintenance of irrigation infrastructures and distribution networks have not been calculated specifically for groundwater uses, and therefore are not included in these calculations. However, more regionally specific and field based information discussed below indicates similar cost ranges.

Historically, public subsidies have been granted for the conversion of dryland agriculture to irrigation. Regional governments and the national Ministry of Agriculture continue to give economic assistance for the modernization of irrigation infrastructures in order to increase water use efficiency. However, most often, Spanish farmers pay for all direct costs associated with groundwater irrigation. Table 3 presents some estimates of the costs involved in well construction in some regions where aquifers are used intensively. Total costs are per well and include the costs of drilling the well and installing the necessary mechanical and electrical equipment.

Table 3. Pumping infrastructure construction costs in different regions in Spain

		La Mancha	Planas levantinas	Campo de Dalías (Almería)	Llano de Palma (Mallorca)
Depth of well (m)	Min	100	60	150	30
	Max	200	160	400	70
Pumping capacity (L/s)		50	60	100	10
Total cost (10^3 €)	Min	50	25	94,2	13,9
	Max	79,8	51,4	218,8	18,4

Source: Modified from Llamas *et al.* (2001) with data from Ballester and Fernández Sánchez (2000).

In the case of groundwater used for irrigation, in addition to well construction other important costs are those of the irrigation infrastructure, which will depend on the technology used (pivot, sprinkler, drop or gravity irrigation) and the type of crop, and the costs of energy consumption. In Spain there is no public support or subsidy for energy use by irrigators. Therefore, the relative importance of this cost component to the farmers is directly related to the depth of groundwater levels and the profitability of the crops.

Existing data indicate that, even where piezometric levels are very low, the costs of energy consumption only represent a small portion of farmer's income and therefore are not a deterrent for lower levels of abstraction. In the case of the La Mancha region in south central Spain, Llamas *et al.* (2001) estimate that the energy cost of irrigating one hectare, pumping water from a depth of 100 m, is about 84 euros/ha/year, which only represents about 5% of an "average" farmer's gross income. Therefore, increasing energy costs resulting from increasing pumping depths will hardly discourage farmers from continuing existing pumping patterns. Similar conclusions result from looking at other intensively used aquifers where pumping depths are greater and energy costs are therefore higher. For instance in the Crevillente aquifer, a small (100 km^2) karst aquifer in the Júcar river basin in southeastern Spain, water is pumped from depths of up to 500 m to irrigate highly profitable grapes for export. Pumping costs have increased to 0.29 €/m^3, but with crop values ranging between 15,000 €/ha to 25,000

€/ha, pumping costs still represent less than 10% of total crop value (Garrido *et al.* 2006). Additionally, as these authors point out, "as land without water is valueless, farmers will not be deterred by such productivity erosion" (p.346).

A final set of costs associated with groundwater use for irrigation are the distribution costs that occur when various users share a well so that pumped water is distributed among them using networks that can be very complex. These types of well or irrigator associations are very common in coastal eastern and southeastern Spain. Pipelines are expanded as new users join the well association and it becomes necessary to service their land. The design of these networks can therefore be very inefficient both from an economic and a resource use perspective. The costs involved in this category are the building and maintenance of the networks, as well as the construction of holding ponds to regulate water distribution in some cases.

In some regions, irrigator or well associations charge all pumping and distribution costs to their members using a tariff system that usually has a fixed component, proportional to the area with irrigation rights, and a variable component that is proportional to the amount of water used. Carles *et al.* (2001a) calculated the direct or service costs that irrigator associations charge their members for their use of water in the Valencia Autonomous region (coastal eastern Spain). Table 4 shows some of their results. For comparative purposes, we have included the price paid by members in the same area for surface water or a mixture of surface and groundwater. Three significant conclusions can be drawn from the table: (1) there is a great variability in costs throughout the region; (2) groundwater users pay a higher price for water than surface water users since they pay for all direct costs; (3) users never pay for environmental or resource costs of groundwater use. Therefore there is no relationship between resource scarcity and cost of the resource, except when that scarcity requires the deepening of existing wells or the drilling of new ones.

Table 4. Average cost of irrigation water in the Valencia region

Groundwater management areas	Source of water	Crop	Average cost [1] (€/m^3)
Mijares- Plana de Castellón	Surface	Citrus	0.05
	Groundwater	Citrus	0.15
Palancia - los Valles	Mixed	Citrus	0.12
	Groundwater	Citrus	0.13
Alarcón-Contreras	Surface	Citrus	0.02
	Mixed	Citrus	0.07
	Groundwater	Citrus	0.10
Serpis	Surface water	Citrus	0.05
	Groundwater	Citrus	0.15
Vinalopó - Alacantí –Vega Baja	Surface water	Various	0.08
	Groundwater (2)	Grapes	0.29
		Various	0.26

[1] Average values of all irrigator associations in each region weighed by the areas irrigated by each.
[2] Rico and Olcina (2001) found that groundwater costs in the region in 1999 were 0.51 €/m^3
Source: Modified from Carles *et al* (2001a)

Data refers to abstraction and distribution costs, and does no consider water quality, mainly water salinity. Salinity may affect crop yield and/or the needed irrigation depth and frequency. Also an inadequate use of relatively saline water may enhance soil salinisation and alkalinisation rate, a serious problem in many irrigated areas in Spain. Data on the involved costs, that include reduced yield or quality of crop, incremental use of water, improved drainage facilities and loss of soil fertility, are seldom considered. Economic figures are lacking, and often the effects are passed as unaccounted changes to future users and society.

In some cases, farmers have begun to pay attention to these facts and price water of various salinity and chemical composition differently, and sometimes select the best water for irrigation and the worst to be released for human consumption, as has been the case in the Canary Islands, especially for slightly brackish sodium bicarbonate water from deep wells and galleries. Currently some farmers, aware of the salinity problems, pre-treat irrigation water by low pressure reverse osmosis, which adds to the true direct water cost.

For town or rural water supply excess hardness, and even excess salinity or nitrate content, has to be corrected before distribution to public fountains and households. In some cases desalination plants have been installed for this purpose. But more often poor quality of groundwater has enhanced the use of bottled water, at least for direct drinking and cooking. Figures on the involved incremented cost are not available.

5.1.2. *Environmental and resource costs*

In addition to the direct service costs, groundwater use results in environmental and resource or scarcity costs that need to be evaluated both to comply with WFD requirements as well as to accurately assess the economic viability and social desirability of different pumping regimes. Intensive and uncontrolled groundwater use can have various negative consequences such as aquifer salinization or contamination; decreased groundwater discharges to dependant aquatic ecosystems (wetlands, rivers and streams); land subsidence; and impact on the rights of other surface or groundwater users.

There are still no estimates of the environmental and resource costs associated with groundwater use in Spain. Environmental costs will be calculated as the cost of applying the corrective measures to achieve the environmental goals of the WFD (MMA 2007b). In any case, it is apparent that if the full cost recovery principle is applied to intensively used aquifers, many existing uses would not be economically viable. As it currently stands, the individualist nature of groundwater abstractions together with the inadequate enforcement of existing rules and regulations, as will be discussed in a later section, has resulted in the elimination of the value of scarcity and made it difficult to guarantee existing rights, thus making it difficult to achieve the goals of the WFD and resulting in unsustainable extraction regimes in many intensively used aquifers.

5.2. Benefits of groundwater use

Groundwater is an essential economic and social resource both as a production factor in agriculture and industry, as well as a source of drinking water. These are the extractive values of groundwater. But groundwater also performs other services for society that are harder to quantify and are generated simply by maintaining certain water levels in the aquifer. An important service provided by groundwater when used in conjunction with surface water resources, is the supply guarantee or regulation value, which is particularly relevant in areas subject to droughts. This value comes from the increase in total resources available to users when both surface and groundwater are used in conjunction, as well as from the increase in the average amount of water available to users in any year, and the decrease in uncertainty. The regulation value of groundwater can represent up to 80% of all extractive values (National Research Council (1997) as cited in Llamas *et al.* 2001).

5.3. Economic aspects of groundwater use in Spain

Until the implementation of the WFD and the work of the Economic Analysis Group, there was little data in Spain on the economic importance of water use. The studies that did exist were constrained to particular regions or sectors and often did not distinguish between surface and groundwater sources. In spite of these limitations, Llamas *et al.* (2001) and Hernández-Mora *et al.* (2001) developed a rough estimate of the economic value of groundwater use in Spain using data from different sources. Table 5 presents an updated version of that work, using more current information where it is available. The information on irrigation has not been updated because no more current information is available specific to the productivity of irrigation using groundwater sources.

Table 5. Economic valuation of groundwater uses in Spain

	Total volume used[2] (Mm^3/año)	Range of average values (€/m^3)	Total economic value (10^6 €)
Irrigation	4000-5000	1.08 – 2.16 [3]	4,508 – 10,518
Water supply	1000	0.8 – 2.06 [4]	800 – 2,060
Bottled waters	5.9	-	1122 [6]
Industrial use[1]	300-400	100 [5]	30,000 – 40,000

[1] Uses not connected to urban infrastructures.

[2] Data from table 5.16 in Llamas *et al* (2001).

[3] Data from table 7.6 in Llamas *et al.* (2001) and from Corominas (2001), both for Andalusia. Both values refer to gross productivity, that is, average production per average price paid to farmers.

[4] Data from MMA (2007a). The economic value is estimated as the price paid by domestic users in 2004 since these serve as indicator of the gross revenue of water supply companies. On average, these prices represent only 80% of total costs of providing urban water supply services.

[5] Average apparent productivity of water in industrial uses in Spain for 2001 (MMA 2007b).

[6] Total gross revenue for the bottled water sector in 2005 (MMA 2007a).

The table does not include environmental or social benefits that have no direct monetary value. Although methodologies have been developed to value these benefits, few studies have applied them to Spain and they are therefore not included here. In spite of the clear limitations of the data presented, the magnitude of the economic contribution of groundwater is apparent. Given the overwhelming weight of groundwater use for irrigation and public water supply, we will limit our discussion to these two sectors. The economic importance of groundwater in industrial uses is also significant, but there is very little available data on these uses.

5.3.1. Public water supply

Available data does not allow comparisons between the economics of public water supply using surface or groundwater. However, a few comments will serve to illustrate the situation of the water supply sector in Spain. From an economic perspective, the price of water in public water supply in Spain is nil. Users pay for the distribution costs, but do not pay for the resource itself or for external or opportunity costs (Pérez Zabaleta 2001). In 2004 home consumers in Spain paid an average tariff of 1.17 €/m^3. However tariffs paid in different regions vary widely, from the 0.80 €/m^3 paid by home consumers in Castilla-León or Castilla-Mancha (Duero and Guadiana River Basins respectively), to the 1.72 €/m^3 paid in the southeaster Mediterranean region of Murcia, in the Segura River Basin (MMA 2007a and b).

Often these tariffs cover only a portion of the distribution and sanitation costs, and they do not cover the costs of the necessary infrastructures associated with the service (dams, canals, etc.), which are usually paid for by general revenue of the national or local government responsible for providing the service. The Ministry of the Environment estimates that, in fact, the price for urban water supply paid for by consumers covers 80% of total costs of providing the service for the entire country, but this percentage ranges from as little as 57% in the Ebro River Basin in the northeast, to as much as 95% in the Guadalquivir River Basin in the south (MMA 2007a). However, it is worth pointing out that these calculations are still an approximation since the information on which they are based was limited and very heterogeneous.

In 2000, the White Book of Water in Spain (MMA 2000) estimated that the average tariff that resulted from dividing gross revenue of water supply companies by the volume of water actually metered was 0.43 €/m^3, much less than the resulting tariffs in other European countries such as Germany (1.41 €/m^3), France (1.03 €/m^3), or Belgium (1.12 €/m^3). The comparatively low tariffs that urban consumers pay in Spain do not encourage savings or good management. In addition, they do not encourage water supply companies to do the necessary maintenance and improvements in the distribution networks, so that often these are highly inefficient. However improvements are being introduced, especially when public supplies are large or are managed by technically prepared companies. Additionally, more current information (MMA 2007b) indicates that while there is some correlation between higher tariffs and lower water consumption rates by domestic users, total household expenditures on water supply services are so low (0.09 €/day for the 167 liters of water consumed by domestic users on average) that water fees are hardly an incentive for lower consumption. Often, public education and water conservation campaigns are much more effective in reducing household water consumption.

5.3.2. *Irrigation*

The primary economic contribution of groundwater in Spain is in irrigation. The recent reports on the economic analysis of the use of water (MMA 2007a and b) present updated information on the economics of irrigated agriculture, but for the most part fail to clearly distinguish between irrigation with surface and groundwater sources. However, some general conclusions are worth highlighting where inferences can be made on the importance of groundwater economics in agriculture:

(1) On average, gross productivity of irrigated agriculture is 4.4 times that of dryland agriculture. However, there are significant regional differences. In areas with profitable dryland crops (olives, grapes, or cherries) the ratio can be as little as 1.1. But in regions of southeastern Spain with intensive horticultural production under plastic which rely heavily or entirely on groundwater sources, net productivities for irrigated agriculture can be as much as 50 times higher than when using surface water and as high as 12 €/m^3.

(2) A large percentage of irrigated agriculture is closely tied to subsidies from the European Common Agricultural Policy (CAP), representing sometimes as much as 50% of farmer's income. But once again, in areas that rely on groundwater sources to produce highly profitable horticultural crops CAP subsidies represent as little as 1% of farmer's incomes.

(3) Costs of water services for the farmer vary greatly between surface water users that pay, on average, 106 €/ha/year, and groundwater users that pay on average 500 €/ha/year.

(4) 58% of water used in agriculture is to produce 5% of gross agricultural production, while 9% of water produces 75% of gross production. Once again this 9% concentrates primarily in river basins that rely heavily on groundwater sources (Júcar, Segura, Sur, and Canary Islands).

In the following paragraphs we present a more detailed discussion of the economic aspects of groundwater use in irrigation in some regions where it is used intensively and economic data specific to groundwater is available. These results help validate the general conclusions presented above.

The most comprehensive analysis of the economic contribution of irrigation using groundwater is the Irrigation Inventory for Andalusia (www.cap.junta-andalucia.es) originally done in 1996 and 1997 and updated in 2002. Using data from the original 1997 study, Llamas *et al.* (2001) show that, in Andalusia, irrigated agriculture using groundwater is economically over five times more productive and generates almost three times the employment than agriculture using surface water, per volume of water used. This difference can be attributed to several causes: the greater control and supply guarantee that groundwater provides, which in turn allows farmers to introduce more efficient irrigation techniques and more demanding and profitable crops; the greater dynamism that has characterized the farmer that has sought out his own sources of water and bears the full costs of drilling, pumping and distribution; and the fact that the higher financial costs farmers bear, motivates them to look for more profitable crops that will allow them to maximize their return on investments.

Table 6. Irrigation economic indicators in Andalusia for ground and surface water

	Groundwater	Surface water	Total
Irrigated area (ha)	244,190 (27%)	648,009 (73%)	893,009 (100%)
Average water consumption (m^3/ha)	3,900	5,000	4,700
Total production (10^6 €)	2,222	2,268	4,480
Production (€/ha)	9,100	3,500	5,100
Employment generated (number jobs/100 ha)	23.2	12.6	15.4
EU aid to income (% of production value)	5.6	20.8	13.4
Gross water productivity (€/m^3)	2.35	0.70	1.08
Total average water price to farmer (€/m^3)	7.2	3.3	3.9

Source: Vives (2003) with data from the CAP Irrigation Inventory (2002)

Using data from the 2002 update, Vives (2003) shows that groundwater irrigation only occupies 27.3% of all irrigated agricultural land and represents only 22.7 % of all water used for irrigation in Andalusia, it generates almost 50% of all agricultural output and 50% of employment (Table 6). Irrigation using groundwater is three times more productive than that using surface water, it is at least 20% more efficient in the use of water and generates twice as much employment per m^3 used. EU income aid to farmers using groundwater is only 5%, as opposed to 20% for surface water irrigators. Groundwater irrigators produce three times as much and they pay more than twice the cost for volume of water used than surface water irrigators. In comparing surface and groundwater productivities, Vives uses information on the volume of water used in the field, not the volume of water actually pumped or diverted from reservoirs. If the latter were used (as Llamas *et al.* did in 2001), the difference between surface and groundwater productivities would be even greater since a significant amount of surface water is lost in transportation channels.

The same set of data serves to highlight the economic importance of groundwater not only for its extractive value, which is in itself significant, but also for its stabilization value, discussed in section 3.2. The availability of groundwater supplies has allowed irrigation agriculture in Andalusia to survive during severe drought periods. Corominas (2000) shows how total agricultural output during dry sequences decreased by only 10%, while 60% of irrigated land received less than 25% of its average surface water allocations. The implications are that the decrease in water supplies was made up by relying on groundwater sources.

It could be argued that the difference in productivity between surface and groundwater irrigation in Andalusia is largely due to the influence of the Campo de Dalías aquifer region, located in the southeastern coast (see Figure 1). In this region, intensive groundwater development for irrigation has fueled a most remarkable economic and social transformation. The combination of ideal climatic conditions, abundant groundwater supplies, and the use of advanced irrigation techniques under plastic greenhouses for the production of highly profitable fruits and vegetables, has allowed the phenomenal economic growth of the region since the 1950s, when irrigation begun. Today, irrigation of over 20,000 ha of greenhouses generates, directly or indirectly, an estimated 1,200 million euros every year, and it is usual for farmers in the area to have gross revenues of 60,000 €/ha. This has allowed the population in the region to grow from 8,000 inhabitants in the 1950s to more than 120,000 in 1999 (Pulido *et al.* 2000). But the lack of any kind of planning or control of these developments by either the water authorities or the users themselves has resulted in social tensions from the inadequate integration of necessary immigrant labor, as well as problems of salt water contamination in some areas, and the need to deepen or relocate some wells. While the effects of the Campo de Dalías in Andalusian agriculture is apparent, the productive advantage of groundwater is also clear in the interior basins, where irrigation with groundwater is twice as productive as that using surface water.

Data from other regions in Spain serve to underscore the fact that the productive advantage of groundwater irrigation is not only the result of more advantageous climatic conditions. Arrojo (2001) shows that similar advantages are observed in the 8,000 irrigated hectares in the Alfamén-Cariñena region, another area of intensive groundwater use in the Ebro river basin in northern Spain (see Figure 1). According to his work, net water productivity in this region ranges between 0.15 and 0.50 €/m^3, depending on the type of crop (peach, apple, pear or cherry). Arrojo (2001) compares these results with the productivities of some large surface water irrigation networks in this semi–arid region, such as Bárdenas or Monegros, where he estimates productivity hovers around 0.03 euros/m^3. This author estimates that while irrigation with groundwater occupies 30% of the total irrigated area and consumes only 20% of all water used for irrigation in the entire Ebro river basin, it produces almost 50% of the total agricultural output of the basin. Once again, the advantage can be attributed to the supply guarantee that groundwater provides, which allows farmers to invest in more sensitive and water demanding crops that are at the same time more profitable, thus helping them defray the higher costs of searching for and obtaining their own water supplies.

Another regional example of interest in Spain is the Canary Islands (see Figure 1). It is significant both for its insularity and the resulting need to be self-sufficient in terms of water resources, as well as for the strategic importance that groundwater plays, providing almost 80% of all available water resources in the islands. The general scarcity of water resources has resulted in a unique water supply and use system that is characterized by three factors: the prominent role played by the private sector in the search, extraction and marketing of groundwater resources; the widespread use of water-efficient irrigation techniques; and the increasing use of alternative water sources, such as desalinated seawater brackish groundwater, and recycled water with salinity reduction. Water resources have historically been distributed in the islands through the functioning of largely unregulated and imperfect water markets where both the resource and the transportation canals are privately owned (Aguilera Klink 2001).

As is the case in peninsular Spain, the economic and social importance of agriculture in the Canary Islands has decreased significantly in the second half of the twentieth century, rapidly losing ground to industrial production and tourism. In 1998, it was responsible for only 3.8% of the islands' total economic output and provided 7.5% of all employment. These values are equivalent to those observed in the rest of the country. In spite of the decline in relative importance, total agricultural output has remained constant and agriculture continues to be the primary water user in the islands, consuming 276 Mm^3/year, or 60% of all water used.

Table 7. Water productivity in the Canary Islands

	Area (ha)[1]	Production (tm)[1]	Specific production (€/ha)[1]	Average consumption (m^3/ha) [2]	Water productivity (€/m^3) [2]
Bananas	8,923	362,313	15,867	14,960	1.06
Potatoes	5,643	56,063	3,877	3,595	1.07
Tomatoes	3,816	327,964	38,837	8,167	4.75
Ornamental	369	8,030	24,126	8,431	2.86
Flowers	334	6,830	9,073	8,431	1.07

[1] http://www,gobiernodeCanarias,org/agricultura/Estadistica/index,htm, Data for 1999.
[2] Average consumption values for the island of Tenerife, which cultivates 57% of all area dedicated to bananas, 73% of potatoes, and 47% of ornamentals and flowers.
Source: Irrigation Plan for Canarias (2000), Consejería de Agricultura, Pesca y Alimentación, Gobierno de Canarias.

Table 7 presents data on the economic value of the primary agricultural crops of the islands. No official data is available on the productivity of water, and no distinction is made between irrigation using surface and groundwater. However, the amount of surface water used for irrigation is very small and it is used jointly with groundwater. Some rough calculations have been made using consumption data for the island of Tenerife (where no surface water is available), and for different crops. These results are comparable to those obtained for groundwater irrigation in other regions of Spain.

6. PRESSURES, IMPACTS AND MEASURES TO ACHIEVE THE GOALS OF THE WATER FRAMEWORK DIRECTIVE

6.1. General considerations on the goals of the WFD

The main goal of the WFD is that by 2015 all water bodies (surface and groundwater bodies) achieve a good ecological status. The steps to achieve this ambitious goal are as follow:

a) Definition and characterization of the water bodies and their pristine state;
b) Identification of the various pressures on the water bodies because of human activities;
c) Evaluation of the impacts due to the pressures on the ecological health of the water bodies;

d) Proposal of the measures to be taken in order to recover, if necessary, by 2015 the good ecological health;
e) Perform cost/efficiency analyses of the different measures proposal;
f) If the economic or social costs are excessive, propose to the Commission a delay of 6 or 12 years (2021 or 2027) to implement the goal of good ecological status

These analyses and proposals should be completed and included in the Basin Hydrological Plans which are due in 2009 after a lengthy process of public and stakeholder participation.

The concept of sustainability in the WFD is mainly related to its ecological dimension. Attention to other dimensions of sustainability (social, economic, institutional, legal, political, and so on) is only secondary. In terms of defining good ecological status for groundwater bodies, the WFD focuses primarily on water quality and pollution sources. This outlook may prove challenging to implement when dealing with groundwater in arid or semi-arid Southern Mediterranean Member States where excessive groundwater abstraction with its potential impact on water quality degradation and hydrological impacts on stream flows and wetlands has been the primary concern. The WFD states that groundwater abstraction should not cause a significant impact on the connected surface water bodies. But if this provision is strictly enforced, many groundwater intensive developments in Spain may have to cease, while the social and economic sustainability of such a decision, and its political viability, is problematic.

Some have argued that the implementation of the WFD goals will be impossible in the Southern Mediterranean countries without a significant delay. There are several justifications for this concern: a) the absence of a long-standing tradition of public participation in policy decision-making; b) the fact that groundwater management processes are significantly slower than surface water ones; and c) the fact that, in the Southern Mediterranean countries, the consumptive use of water for irrigation usually represents about 80% of total consumptive uses, and dealing with thousands of individual farmers and small communities is always more complex than dealing with less numerous and usually more organized water supply companies, electric utilities or industries.

Nevertheless, we consider that the prudent enforcement of the provisions of the WFD in the Southern Mediterranean countries will be positive and beneficial. The WFD requires performing cost/efficiency analyses of the different measures proposal. Only if the economic or social costs are excessive will be possible to request a delay of 6 or 12 years (2021 or 2027) to implement the goal of good ecological status. It seems clear that Spain and probably other countries will have to apply for delays, but in any case clear and thorough information on the hydrological, economical and social situation of water resources, and active public participation will be necessary. Such an exercise of transparent information and stakeholders participation will provide a new and positive outlook on the role of groundwater in the water policy of these countries as well as help facilitate management processes. However, it is important to be aware that it will not be an easy task.

6.2. Pressures on Spanish groundwater bodies

The situation of many intensively used aquifers in Spain can help illustrate some of the difficulties to implement the WFD. In Spain the intensive development of groundwater resources over the past 50 years has brought about significant social and economic benefits, but their unplanned nature has resulted in negative environmental, legal and socioeconomic consequences. As described in more detail in section 8, the 1985 Water Act regulated the concept of aquifer overexploitation, giving water authorities broad powers to regulate groundwater use in aquifers that were declared overexploited. The Water Administration identified overexploitation or salinisation problems in 77 hydrogeologic units (MIMAM–ITGE 1997) in addition to 15 units in the Canary Islands and Catalonia, which have their own water administration. But the legal declaration of overexploitation was often embedded in intense political and social debate. While these declarations should be accompanied by strict regulatory measures, they have most often not been successfully implemented, and a situation of chaos still persists in many aquifers.

Management efforts in Spain have focused primarily on resource quantity, while water quality concerns have been secondary. There are 60 hydrogeological units where total pumping volumes exceed natural recharge rates. Although estimates have to be taken cautiously, given significant data uncertainties and the fact that terms such as natural recharge, overexploitation or water deficit are sometimes misused, estimates indicate that there is an overall groundwater storage deficit in these aquifers of approximately 665 Mm^3/year (MAPA 2001). Most of these aquifers are located in southeastern Spain and in the Balearic and Canary islands. But maybe the most emblematic case of intensive groundwater use where overdraft is most acute is the Western Mancha hydrogeological unit, in the Upper Guadiana River basin, where drops in the water tables have dramatically impacted the wetlands in the Mancha Húmeda Biosphere Reserve.

It what pertains to water quality, the primary issue of concern in Spain has historically been aquifer salinization. This process is usually due to seawater intrusion, dissolution of evaporitic materials or return of high salinity excess irrigation water. Table 8 shows the degree of salinization (chloride and sulphates) observed in stations of the groundwater monitoring network. In the case of chloride, the limit considered in the table is 100 mg/L while for sulphates is 150 mg/L. It is worth noting that these limits are naturally attained in some aquifers and spring in the arid and semi-arid areas.

Table 8. Groundwater monitoring stations classified as per chloride, sulphate and nitrate contents.

River Basin District	**No. stations with an annual average chloride**		**No. stations with an annual average sulphate**		**No. stations with a maximum 6-month period value of nitrate**		
	0–100 mg/L	**> 100 mg/L**	**0–150 mg/L**	**> 150 mg/L**	**0–25 mg/L**	**25–50 mg/L**	**> 50 mg/L**
North	20	0	20	0	20	0	0
Duero	96	15	102	9	93	13	5
Guadiana	87	34	79	42	29	51	41
Guadalquivir	86	34	89	31	79	19	21
Cuenca Mediterránea Andaluza	70	46	71	45	92	6	18
Segura	40	61	33	68	73	15	13
Júcar	25	15	N.A.	N.A.	11	11	18
Ebro	350	103	277	176	280	82	90
Total	**774**	**308**	**671**	**371**	**677**	**197**	**206**

Source: MIMAM Web Page (www.mma.es). Data from 2003.

Nitrate pollution is usually due to diffuse pollution from agricultural activities, and is another recurring issue of concern in regard to groundwater quality. This kind of contamination is produced by the infiltration of water (rain or irrigation), that dissolves and carries chemical fertilizers. The WFD establishes a 50 mg/L limit for nitrates. Table 8 shows that 20% of the control points yielded values in excess of this figure, the Guadiana and Júcar basins being the most affected. High nitrate values are found in many aquifers in Catalonia (up to more 500 mg/L in the Maresme), Murcia (Campo de Cartagena), Balearic Islands (Inca–Sa Pobla) o the Canaries (Telde, Vecindario, Guia–Gáldar, in Gran Canaria). According to the WFD, readings in excess of 25 mg/L, also abundant, oblige to systematic monitoring every four or eight years. Thus, contamination by nitrates is one of the main challenges faced by Spain in regard to groundwater quality.

6.3. Characterization and risk assessment of groundwater bodies

The WFD and Directive 2006/118/CE, about groundwater protection against contamination and water quality degradation, require a significant effort to evaluate pressures and impacts on groundwater bodies and to identify and adopt measures to obtain good ecological status by 2015. In order to comply with these requirements, the reports submitted to the European Commission by the Spanish government classify groundwater bodies according to three categories:

(1) Groundwater bodies *at risk (de riesgo)*, which will presumably not attain good status by 2015 and need further characterization.

(2) Groundwater bodies *at risk under evaluation (de riesgo en estudio)*, in which not enough information is available to make a clear diagnosis in what pertains to the achievement of good status. These require additional studies for the initial characterization.

(3) Groundwater bodies with *no risk* (*riesgo nulo)* that according to available data will attain good status.

The initial characterization identifies two types of pressures: chemical risk as a result of point and non-point or diffuse pollution, and seawater intrusion; and quantitative risk as a result of unsustainable extraction volumes. With few variations, the criteria used in the different river basin districts to evaluate risk has been to apply a matrix that relates pressures and resulting impacts on groundwater bodies.

Pressures considered include:

- those resulting from diffuse pollution, primarily nitrate pollution;
- those derived from point source pollution, with a wide variation in the quality of the information available in different river basin districts, very often limited and insufficient;
- pressures resulting from seawater intrusion, according to the studies available in each case;
- and pressures resulting from groundwater abstractions, which have been difficult to evaluate because of insufficient information on the volumes pumped and available resources estimated in the terms established by the WFD.

The evaluation of impacts has considered separately the chemical and quantitative aspects. In what pertains to the chemical aspects, several contaminants have been considered with different threshold levels for each river basin district and depending on the available information, but risk evaluation has been mainly determined by the 50 mg/L threshold for nitrates. In general, several issues have been considered simultaneously for the evaluation of the quantitative aspects: expert opinion; average decrease in piezometric levels; the legal declaration of overexploitation; the inclusion of the groundwater mass in the "Catalogue of aquifers with overexploitation or salinization problems" *(Catalogo de acuíferos con problemas de sobreexplotación o salinización)* (MIMAM-ITGE 1997); or the impact on associated aquatic ecosystems (MMA 2006).

Table 9. Risk assessment classification of groundwater bodies (MMA 2006)

River basin district		Number of GWB	GWB at risk				Total characterized		
			Chemical			Quantitative	At risk	Under evaluation	No risk
			P	D	I	E			
SHARED RIVER BASINS	Norte I	6	0	0	0	0	0	6	0
	Norte II y III	34	0	0	0	0	0	12	22
	Bidasoa, Nive y Nivelle	2	0	0	0	0	0	1	1
	Duero	31	0	3	0	1	3	28	0
	Tajo	24	NE	1	0	NE	1	18	5
	Guadiana	20	0	9	1	6	11	9	0
	Tinto, Odiel y Piedras (1)	4	0	3	1	0	3	1	0
	Guadalquivir	71	1	21	1	19	35	29	7
	Segura	63	NE	1	2	25	25	33	5
	Júcar	79	0	13	8	23	29	26	24
	Ebro	105	11	29	0	1	35	7	63
INTERNAL RIVER BASINS	Galicia Costa	18	0	0	0	0	0	15	3
	Cuencas Internas País Vasco	14	2	0	0	0	2	0	12
	Cuencas Internas Cataluña	39	23		10	10	25	0	14
	Cuenca Mediterránea Andaluza	67	1	20	11	23	29	23	15
	Baleares	90	42	36	30	41	42	35	13
	Canarias	32	NE	8	8	15	19	13	0
TOTAL *		699	80	167	72	164	259	256	184

P: point source; D: diffuse; I: intrusion; E: extraction; GWB: Groundwater Bodies; NE: not evaluated

* Some groundwater bodies are at risk for more than one reason. Therefore the sum of each individual risk is larger than the total for both types of risk.

(1) These two river basins are now within the Andalusian Internal River Basins (*Cuencas Internas Andaluzas)* planning district.

Table 9 presents the results of applying the methodology described above (MMA 2006). It shows a summary of the risk assessment of groundwater bodies (GWB) in all the river basin management districts in Spain. The table shows that, of the 699 groundwater bodies (GWB) characterized, 259 (37%) have been classified as being *at risk* of not achieving good status by 2015; 184 (26%) have been classified as having *no risk*; and for the remaining 256 groundwater bodies (37% of the total) not enough information is available, so they have been classified as being *at risk under evaluation*. The most frequent causes of risk classification are a result of diffuse or non-point source pollution (167 GWB or 24% of those characterized) and quantitative risk (164 or 23%). In terms of saltwater intrusion, the risk results from a degradation of water quality resulting from inadequate pumping patterns. The problem has been identified in 71 GWB in all coastal regions except the northern coast.

Figure 2 (MMA 2006) shows the distribution of identified groundwater bodies highlighting the three categories described. A GWB is marked as being at risk as a result of any of the possible causes described above.

6.5. Measures to achieve the WFD goals and cost/efficiency analyses

For groundwater bodies at risk of not achieving the environmental goals by 2015, the WFD requires an additional characterization that provides information on the hydrogeological and hydrogeochemical aspects and evaluates the impact of human activities on the state of groundwater resources. The Spanish Ministry of the Environment (MMA) and the Geological Institute of Spain (IGME) have developed a methodological guide to guide, support and homogenenize the additional characterization work of Basin Management Agencies. The central component of this guide is an GWB characterization form that compiles all the required information required for the additional characterization, the status diagnosis, the design of measures to revert deterioration trends, and the proposals to apply the exceptions contemplated by the WFD. The form includes sections such as: GWB identification, general geological characteristics; hydrogeological characteristics; unsaturated zone; piezometric levels and variations in storage; associated and independent surface ecosystems; recharge; artificial recharge; groundwater abstraction regimes; chemical characterization; description of pollution trends; land uses; significant pollutions sources; and other pressures.

There is only preliminary work on this issue so far, some of it available in the websites of Basin Management Agencies. It is important to keep in mind that the proposed measures will have to be specified in the proposals of the Basin Hydrological Plans after a period of public debate. Final proposals need to be available by 2009.

It is important to be aware that the design and implementation of the measures will not be an easy task. For example, in July 2001 the Spanish parliament asked the Government to prepare an Special Hydrological Plan for the Sustainable development of the Upper Guadiana Basin. This Plan should be presented to the Parliament within one year. Six year later the Government has not sent yet to the Parliament such Plan. Just one month ago the Government submitted a proposal of Plan for debate and general consideration. After receiving the suggestions from the different stakeholders the Government will approve or modify the Plan and will be sent to the Parliament. And this is only one case in Spain that concerns a basin of only 18,000 km^2.

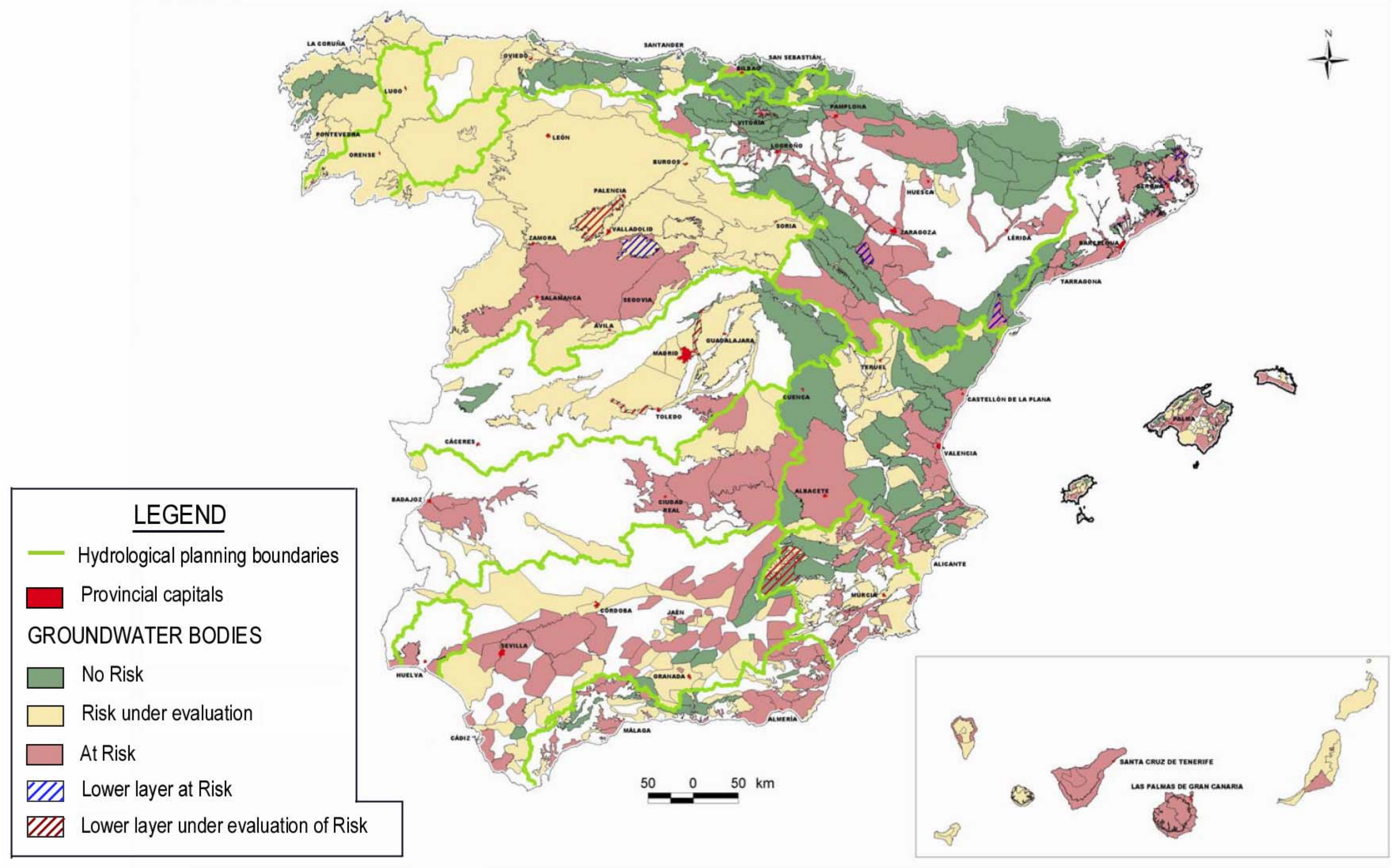

Figura 2. Classification of groundwater bodies according to the degree or risk of not attaining environmental objectives by 2015 (MMA 2006)

8. INSTITUTIONS FOR GROUNDWATER GOVERNANCE

Spain has experimented with different solutions for the management of groundwater resources: from the liberal approach that characterized private property of groundwater resources under the 1879 Water Act, to the more government-controlled approach of the 1985 Water Act, responding to more intensive groundwater use. A review of the characteristics and evolution of Spanish water law and water administration might shed some light on the challenges encountered when trying to manage groundwater resources sustainably.

8.1. Intensive groundwater use in Spain and the 1985 Water Act

The 1985 Water Act transformed the institutional context for groundwater management in Spain. Three innovations are particularly relevant. First, groundwater was declared a part of the public domain, as surface water resources had been since the first Water Act of 1866. As a result Basin Management Agencies acquired, at least on paper, a relevant role in the management of public groundwater resources and were responsible for granting permits for any uses that started after 1985. The Act created a registry system for public water use permits or concessions for both surface and groundwater rights, the Registry of Public Waters (*Registro de Aguas Públicas*). Uses existing prior to 1986 had the option of remaining in the private property regime by registering the use in the Catalogue of Private Waters (*Catálogo de Aguas Privadas*).

As was discussed earlier, the Act also gave river Basin Agencies broad powers for the management of aquifers declared overexploited in accordance with the law. When an aquifer is declared legally overexploited, Agencies have to draw up a management plan and determine annual pumping regimes. Restrictions apply to users in both the public and private property regimes. No new pumping permits can be granted. All users in the aquifer are required to organize themselves into Groundwater User Associations, and a General User Association that encompasses all associations in one aquifer system has to be formed. The goal of these measures is to foster user participation in the management of the resource. These associations can represent the interests of the users and cooperate with Basin Agencies in the design and implementation of management plans. However, the practical implementation of these measures has not always been easy. User organizations have only been created in five of the 16 aquifers that have been declared overexploited over the past 20 years, and management plans have only been drawn up in three of them.

The third relevant change was the legal reaffirmation of the concept of user participation in water management. Historically, user participation in Spain was understood as the right of irrigators to organize self-governing institutions for the management of surface water irrigation systems. Since the creation of the original river basin authorities in the 1920s, representatives of these irrigator associations (*Comunidades de Regantes*) were an integral part of their governing and management bodies. However, the 1985 Act expanded the concept of users to groundwater users and representatives of other interests and uses beyond irrigators. It established user participation quotas in the different participatory boards of the Basin Agencies: Governing Board, participatory management bodies (User Assembly, Public Works Board, Aquifer Management Boards, and Dam Management Boards), and in the basins' planning body, the Water Council.

The changes introduced by the 1985 Water Act were necessary to deal with the challenges resulting from the more intensive use of groundwater resources. However its implementation has encountered difficulties which in some ways continue to this day. Two are worth highlighting. On one hand, Basin Agencies, who lacked any experience in groundwater management, have consistently lacked sufficient human and financial resources to deal with their newly acquired responsibilities. They have also had difficulty shifting their focus from their traditional water infrastructure development and management responsibilities to their new broader water management goals. Staff at Basin Agencies has been historically dominated by Civil Engineers, and they have lacked expertise in other areas (economics, ecology, hydrogeology, geography, education, etc.) necessary to address their new responsibilities. This limitation has only been accentuated with the requirements of the implementation of the WFD, and although it has started to be remedied, Basin Agencies have consistently had to rely on outside consultants to do much of their work.

The second significant difficulty is the absence of updated groundwater rights records. More than twenty years after the Water Act came into effect, both the Registry of Public Waters and the Catalogue of Private Waters are still incomplete. There is no up-to-date record of existing groundwater uses and total extraction volumes, which makes effective management difficult. In spite of significant efforts and specific programs launched by the Ministry of the Environment at considerable expense, the White Book on Water in Spain (MMA 2000) estimated that of the 500,000 operational wells existing in Spain only 50% had been declared and less than 25% had actually been registered, and the situation today is still not resolved.

8.2. The 1999 reform of the Water Law and the 2001 and 2005 National Hydrologic Plans: Reinforcing the framework

There have been several reforms and more have been proposed to adapt the 1985 Water Act to new challenges and transpose the content of the WFD into national law. The first major reform came in 1999. In what pertains to groundwater management it attempted to address some of the problems mentioned above and reinforce the institutional framework for the management of groundwater resources, particularly in the areas of aquifer overexploitation and user participation. Two issues are worth highlighting.

First, the 1999 reform required Basin Management Agencies to approve an aquifer management plan within two years of the legal declaration of overexploitation in order to avoid situations in which declarations of overexploitation remain in the books but no action to mitigate the problems is taken. Second, the reform allowed Basin Management Agencies to temporarily assign the responsibilities of the user communities in overexploited aquifers to an appointed board representing all stakeholders in the aquifer until a user community could be established. It also explicitly allowed basin agencies to subscribe cooperation protocols that could include technical as well as financial support, something that was possible before but seldom done. These reforms have had almost no practical results.

The next significant landmark in Spanish water law was the approval of the **National Hydrologic Plan** (Law 10/2001) after more than a decade of intense political debate. The Plan was a legal requirement of the 1985 Water Act and the basic framework to guide water resources management in the country. It meant to coordinate basin hydrologic plans and compensate for the uneven geographical distribution of water resources through inter-basin water transfers. Most significantly, the Plan enabled the transfer of 1,050 Mm^3/year from the Ebro river basin to northern and southern areas along the Mediterranean coast partly in order to replace excessive pumping in overexploited aquifers along the coast. The Plan tried to reinforce the existing groundwater management framework by requiring the declaration of overexploitation of receiving aquifers and the approval of the corresponding management regimes prior to use (Sánchez 2003). It required users in the receiving aquifers to be organized in user associations and established that the user communities would hold the title to the transferred water and made them responsible for reducing user pumping rights proportionally to the volume of transferred water received, until total abstractions were reduced to sustainable levels. In essence the Hydrologic Plans put users for the first time in charge of allocating and limiting water rights, thus making them responsible for aquifer management decisions together with basin management agencies.

In 2001, the 1985 Water Act, its subsequent partial reforms and the 1999 reform, the National Hydrologic Plan, and other specific water related laws, were integrated into Legislative Decree 1/2001 of July 20 Combined Text of the Water Act (*Texto Refundido de la Ley de Aguas*).

However, the Ebro basin transfer proposal was very controversial and received intense criticism from academics, environmental organizations, other public interest groups and much of the population in the Ebro basin, for its environmental, economic and social impacts. Massive demonstrations in Zaragoza, Madrid and Brussels were held against it. In March 2003 the Socialist Party won the country's presidential elections, ousting the Popular Party after eight years in power. In his inauguration speech, the incoming President announced a new era for water policy and management in Spain and the cancellation of the Ebro River transfer plan. Instead, the new government presented the **A.G.U.A. Program** (Actuaciones para la Gestión y Utilización del Agua), a multifaceted program that aimed to increase available resources in coastal Mediterranean river basins through water efficiency and saving measures, increased use of recycled waters and the building of desalination plans along the coastline, in order to address water shortages. The plan was enacted in 2005 through Law 11/2005 of June 2005, which modified the 2001 National Hydrologic Plan and legally cancelled the Ebro river transfer.

8.3. Water management organizations: River Basin Authorities and water user associations

Water administration in Spain is in the hands of River Basin Management Agencies (*Organismos de Cuenca* or *Confederaciones Hidrográficas*) created by the 1985 Water Act by consolidating the old Water Commissioner offices (*Comisarías de Aguas*) and the Hydrographic Confederations (*Confederaciones Hidrográficas*). When the river basin runs through more than one Autonomous Region, the River Basin Authority is affiliated to the Central Administration and is called *Confederación Hidrográfica*. Where the river basin lies within a single Autonomous Region, it is managed by the regional government through the Water Administration of the Autonomous Community. There are currently 11 interregional river basin agencies and 6 autonomous water administrations (see Figure 1 for a distribution of basin management regions). These numbers will probably change when the definition of water management planning units under the WFD is completed. However, whether the administration is inter- or intra-regional, the management unit is the river basin and management is integral (that is, dealing with both surface and groundwater resources), multi-sector and participative, with financing shared between the users and the State (Varela and Hernández-Mora, *in press*).

A second key players in water administration are water user associations. Spain has a long-standing tradition of participation of irrigators in water management activities. Irrigator associations have existed from as far back as the 11th century. These traditional associations were originally organized around irrigation networks in order to build and maintain the canals, distribute the water among the different members, and resolve water-use related conflicts that could arise between them. Given this tradition, it seemed logical that the 1985 Water Act would encourage a similar participatory management structure for groundwater resources. However, it is questionable whether the system has transferred successfully.

Today, there are thousands of irrigator associations in Spain. This includes approximately 1,400 groundwater user associations that are registered as public entities in accordance to the 1985 Water Code, and hundreds others that are organized as private corporations under private law and of which there is no official count. These *private* irrigator associations predominate in Eastern and Southeastern Spain, where groundwater for irrigation is for the most part managed collectively and privately.

There exists great variability among groundwater user associations. Their size and organizational complexity varies from a few members using the same well for domestic or agricultural use, to General User Communities that include thousands of individual irrigators, municipalities and irrigator associations in one aquifer. In spite of these differences, all groundwater user associations, whether of private or public nature, can be classified into two categories, according to their goals and objectives. One category would include those associations whose objective is the common exploitation of a well or group of wells. In the terminology used by Carles *et al.* (2001b), these could be called *associations for the collective management of irrigation networks*. To a large extent, they operate like surface water irrigation associations, dedicated primarily to the distribution of water among their members. But in contrast to those, they typically pay for all drilling, installation, operation and maintenance costs.

The second and more interesting group includes those user communities that comprise all or a majority of users within one aquifer. In addition to pursuing their own interests, that is, maximizing the private utility in the exploitation of the resource, they also contribute to its conservation, that is, they also serve a social goal. They could be called the *associations for the collective management of the aquifers*. In terms of the tenets of the law, it is the associations included in this second group that can play a significant role in the management of groundwater resources. However, of the thousands of existing groundwater user associations, only six can be truly included in this group, and only two (Comunidad General de Usuarios del Acuífero 23 and the Comunidad de Regantes de Aguas Privadas del Campo de Montiel, in the Western Mancha and Campo de Montiel aquifers, respectively) were created in response to a declaration of overexploitation.

A particularly interesting example of successful groundwater user communities are the Associations of Water Users of the Low Llobregat and Cubeta de Sant Andreu, both located in Barcelona, Catalonia. These are two linked civil organizations created before the 1985 Water Act, when groundwater was a private property. Their members are primarily industrial users and public water supply companies, but also include some farmer associations. Affiliation to the associations is compulsory for all users in the aquifers. They represent successful organizations that not only control wells and groundwater abstraction, but also carry but monitoring, artificial recharge and restoration programs, and either manage or significantly influence public water management projects. They have a considerable technical staff that has increased over time. Currently they share a detailed flow and salinity transport model with the Catalan Water Administration (*Agència Catalana de l'Aigua*) in order to facilitate decision-making on joint aquifer and river water use, groundwater recharge operations, and on seawater intrusion control. To some extent these user communities are unique in that industrial and water supply uses dominate, as opposed to farming interests, which are predominant in most other intensively used aquifers in Spain.

The Spanish Water Administration has not succeeded in creating similarly effective organizations in the other aquifers that are *legally* overexploited. . One of the problems derive from the poor definition of the term overexploitation (Custodio, 2002). Given the challenges encountered by river basin management agencies to create operative user associations in intensively used aquifers, it may be useful to enumerate some common keys to the success of those associations in acting as true resource managers. In this context, we understand success as the ability of the user associations to articulate common goals and objectives and establish mutually accepted rules regarding resource access and use, in order to guarantee the long-term sustainability of the resource and dependant uses. Some of these keys are:

- The appearance of crisis situations through which a collective understanding develops on the part of all aquifer users about the negative effects of uncontrolled patterns of use.

- Adequate knowledge and common understanding by all users and affected parties of the boundaries and hydrogeological characteristics of the aquifer.

- A sufficiently large area of influence and sufficient resources to be able to articulate effective solutions to the existing problems.
- The ability to articulate common interests and goals, which becomes more difficult as the geographic area increases or when more than one administrative or political jurisdiction are involved.

- The number and type of users. In this sense, the participation of users or stakeholders with economic means or technical know-how can facilitate the creation and effective operation of user associations.

- The influence of leaders that understand the problems associated with anarchic and uncontrolled resource use, feel the need to organize users in order to limit access and use, and are able to communicate their vision of a successful user community and motivate others to cooperate with their efforts.

- The existing social capital in the communities where the user associations are created. When there is a tradition of association or there exist close ties among users, it is easier to articulate common interests and goals.

- The existence of external motivating factors that favor the creation of user associations. Examples would be the need to organize in order to receive and manage water from future surface water transfers, or to manage and receive the public subsidies.

- The attitude of the Water Authority toward the users and the resulting relationship that develops between them.

The framework for the management of intensively used aquifers that resulted from the 1985 Water Act and its reforms calls for active user participation through groundwater user associations. While there exist some excellent examples of user associations that act as effective resource managers, they are still few. Current regulatory reform proposals may help advance in this road.

8.4. The transposition of the WFD into Spanish law

The transposition of the WFD into Spanish law is still an ongoing process. It is proceeding in parallel to the work being carried out by the different Basin Management Agencies, autonomous water administrations and other water research and management institutions under the supervision and coordination of the Spanish Ministry of the Environment to comply with the WFD requirements and deadlines. Some of this work relevant to groundwater management has been discussed in other sections of this paper.

From a legal standpoint, the first reform came in 2003 through Law 62/2003 of December 30th, which introduced some of the key concepts and language of the WFD into Spanish law. However, this reform has been critiqued by environmentalists and academics as inadequately transposing the WFD, and has proven to be insufficient. Many have also argued that the 1985 Water Act has been subject to recurrent piecemeal reform efforts and that a new law is necessary to adequately transpose the WFD into law. In order to address these very real concerns, the current administration appointed working groups on some key topics (water economics, water administration, management of droughts and extreme events, floodplain and shoreland management, and groundwater management) to draw up reform proposals that would allow for the management of water resources in the framework set by the WFD.

The groundwater working group (*Grupo de Trabajo de Aguas Subterráneas*) (http://www.uam.es/proyectosinv/aguasubt/) was appointed by the Ministry of the Environment in 2004, with the goal of conducting a public consultation process to identify the major deficits and needs in groundwater management and make reform proposals. It was made up of academics, and representatives of groundwater users, water administration and research institutions. After a series of six public meetings in 2005 a legislative reform proposal was presented to the public in December 2005 and focused on three key areas:

- Reinforce the role of groundwater user associations as co-managers of groundwater resources.
- Strengthen groundwater protection measures in line with the WFD requirements as well as those of the Directive on the Protection of Groundwater Resources.
- Simplify administrative processes for the management of groundwater resources and involve regional autonomous administrations in these processes.

In March 2007 the Ministry of the Environment presented a proposed reform to the 2001 Combined Text of the Water Act which included many of these proposals and therefore continue to advance in the strengthening of the institutional framework for groundwater management. However, the proposal has been stalled primarily due to the lack of an agreement between the Central and Autonomous governments about the distribution of water management responsibilities in the reformed water administration, and will probably not be taken to Parliament in time for discussion and approval before the next general elections in March 2008.

8. CONCLUSIONS

Intensive groundwater development in many regions of Spain, primarily since the 1970s, has brought about significant social and economic benefits. But the unplanned nature of these developments has also resulted in unwanted social and environmental consequences, which in agreement with the WFD, should be corrected by 2015. If this is not considered feasible or possible, the Spanish government has to request for specific exceptions or a deadline extension to 2021 or 2029. However these requests have to be well documented and be subject to public participation processes.

Groundwater is an important economic resource in Spain. Existing data for irrigated agriculture show that, in terms of its extractive value, groundwater is more productive than surface water resources. Some of the reasons that explain this higher productivity are the greater supply guarantee groundwater provides, which allows investment in better irrigation technologies; and the fact that users bear all private costs, thus paying a higher price per volume of water used than irrigators using surface water, and motivating them to look for more profitable crops and use water more efficiently.

Available data indicate that the economics of intensive groundwater use are such that the direct benefits obtained from a certain level of abstraction greatly exceed the costs of obtaining that water, even when these are very high. This is true even in areas where intensive aquifer use has resulted in dramatic drops in the water table, saltwater intrusion, wetland degradation, and significant social conflict. These environmental and social costs are spread over space and time and do not accrue to the direct user, but to society at large. Therefore there is no economic incentive to modify pumping patterns that would be socially and economically inefficient if both direct and indirect benefits and costs were considered. Changes need to be achieved through a transformation of the institutional arrangements (both formal and informal) in place for the management of groundwater resources.

In order to deal with the problems associated with intensive and unplanned use, the 1985 Water Act transformed the institutional context for the management of groundwater resources in Spain. By making groundwater part of the public domain, the Act gave basin management agencies the power to limit access to and use of the resource. Following a well established Spanish tradition of user participation in water management, the Act created the figure of groundwater user associations, giving them a prominent role in the management of groundwater resources. While hundreds of user associations exist throughout the country, a vast majority act as mere water distributors among their members, and very few can be considered true resource managers. The few successful ones have been able to articulate common goals and objectives and establish mutually accepted rules regarding resource access and use, in order to guarantee the long-term sustainability of the resource and dependant uses. The variety of circumstances under which these successful user associations operate; their ability to bring together thousands of independent users and sometimes manage large and complex aquifer systems, and the way in which some are working cooperatively with water authorities to establish sustainable management regimes, are all promising developments. The fact that many of these associations were created, not as a result of the statutory requirements of the 1985 Act, but because of a combination of user initiative and administrative support, points to the limitations of searching for a general solution through regulatory means.

The regulatory measures contained in the 1985 Act and its reforms have so far proved to be insufficient to solve the problems resulting from intensive groundwater use. We expect that current reform proposals and, more importantly, the requirements of transparency and participation that are required to comply with the WFD or to demand exceptions to the good ecological status goals by the 2015 deadline will contribute significantly to improve the situation of groundwater management in Spain.

REFERENCES

Aguilera Klink, F. (2001) *El papel económico de las aguas subterráneas en Canarias.* (The economic role of groundwater in the Canary Islands). In: “La economía del agua subterránea y su gestión colectiva”. Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid, pp. 269-280.

Arrojo, P. (2001). *Valoración de las aguas subterráneas en el marco económico general de la gestión de aguas en España.* In: “La economía del agua subterránea y su gestión colectiva”. Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid: 3-39.

Ballester, A. and Fernández Sánchez, J.A. (2000*). Coste de obtención del agua subterránea en España.* Industria y Minería, Madrid, 341: xxxx.

Briscoe, 2005

Carles, J., García, M. and Avellá, Ll. (2001a). *Aspectos económicos y sociales de la utilización de las aguas subterráneas en la Comunidad Valenciana.* In: “La economía del agua subterránea y su gestión colectiva”. Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid: 153-173.

Carles, J., García, M. and Vega, V. (2001b). *Gestión colectiva de las aguas subterráneas en la Comunidad Valenciana.* In: “La economía del agua subterránea y su gestión colectiva”. Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid: 291-321.

CAP Irrigation Inventory (2002) *Inventario y caracterización del regadío en Andalucía. (*Inventory and Characterization of Irrigation in Andalucía). Andalucía: Ministry of Agriculture and Fishing of Andalucía (http://www.cap.junta-andalucia.es).

Corominas, J. (2001). *El papel económico de las aguas subterráneas en Andalucía.* In: “La economía del agua subterránea y su gestión colectiva”. Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid: 111-139.

Corominas, J. (2000). *Las aguas subterráneas en la gestión de sequías en España. Andalucía.* Revista de la Real Academia de Ciencias Exactas, Físicas y Naturales. Monográfico: “Aguas subterráneas y sequías”. Madrid 94 (2).

Cruces, J. (1999) *Evaluación de los recursos subterráneos en el Libro Blanco del Agua en España* [Estimation of groundwater resources in the White Book of Water in Spain]. In: *Jornadas sobre las Aguas Subterráneas en el Libro Blanco del Agua en España* [Symposium on groundwater in the White Book of Water in Spain]. International Association of Hydrogeologists – Spanish Group. May 1999, Madrid: 11–22.

Custodio, E. (2002). Aquifer exploitation, what does it mean?. Hydrogeology Journal, 10(2): 254–277.

EC (2003). *Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance Document No 2: Identification of Water Bodies*. European Commission, European Communities: 1–23.

EEA (1999). *Sustainable water use in Europe – Part 1: Sectoral use of water*. European Environment Agency. Environmental assessment report, No 1. Office for official publications of the European Communities. Luxembourg: 1–91.

EUWI (2006)

Fornés, J.M., Hera, A. de la, Llamas, M.R. (2005) “The Silent Revolution in Groundwater Intensive Use and its Influence in Spain”, Water Policy, Vol. 7, No. 3, pp. 253-268. ISSN: 1366-7017.

Garrido, A., P. Martínez-Santos and M.R. Llamas. (2006) *Groundwater irrigation and its implications for water policy in semiarid countries: the Spanish experience.* Hydrogeology Journal, vol.14, 3: 340-349.

Giordano and Villroth (2007) *The Agricultural Groundwater Revolution: Opportunities and Threats to Development*. Giordano and Villholth (eds), 2007. CAB International, Wallingford, UK.

Hernández-Mora, N.; Martínez Cortina, L. and Fornés, J. (2003). Intensive groundwater use in Spain. In: *Intensive use of groundwater. Challenges and opportunities*. Editors: M.R. Llamas and E. Custodio. Balkema, the Netherlands: 387–414.

Hernández-Mora, N., Llamas, M. R. and Martínez Cortina, L. (2001). Misconceptions in aquifer over-exploitation. Implications for water policy in Southern Europe. In: "Agricultural use of groundwater: Towards integration between agricultural policy and water resources management". Ed. C. Dosi. Kluwer Academic Publishers. Dordrecht, The Netherlands, pp. 107 - 125.

ITGE (1995). *Identificación de Unidades Hidrogeológicas donde establecer reservas para abastecimiento urbano en el territorio peninsular*. Instituto Tecnológico GeoMinero de España. (Internal report)

Llamas, M.R. and Martínez-Santos, P. (2005) “Intensive Groundwater Use: Silent Revolution and Potential Source of Social Conflicts”. Journal of Water Resources Planning and Management, American Society of Civil Engineers, September/October 2005, pp. 337-341

Llamas, M.R. and Garrido, A. (2007) Lessons from intensive groundwater use in Spain: Economic and social benefits and conflicts. In: *The Agricultural Groundwater Revolution: Opportunities and Threats to Development*. Giordano and Villholth (eds), 2007. CAB International, Wallingford, UK: 266-295.

Llamas, M.R.; Fornés, J.; Hernández-Mora, N. and Martínez Cortina, L. (2001). *Aguas subterráneas: retos y oportunidades* [Groundwater: challenges and opportunities]. Mundi-Prensa and Fundación Marcelino Botín, Madrid, Spain: 1–529.

MAPA (2001). *Plan Nacional de Regadíos. Horizonte 2008*. Ministerio de Agricultura, Pesca y Alimentación, Madrid, Spain: 1–360.

MMA (2007a) *Precios y Costes de los Servicios del Agua en España: Informe Integrado de recuperación de costes de los servicios de agua en España*. Articulo 5 y Anejo III de la Directiva Marco de Agua. Working Document. Madrid, *Ministerio de Medio Ambiente*, Spanish Ministry of Environment (http://www.fundacion-biodiversidad.info/ciclodelagua/production/Precios%20y%20Costes%20de%20los%20Servicios%20de%20Agua.pdf)

MMA (2007b) *El Agua en la economía española: situación y perspectivas (Water in Spanish economy: situation and perspectives)*. Working Document. Madrid. (internal)

MMA (2006). *Síntesis de la información remitida por España para dar cumplimiento a los Artículos 5 y 6 de la Directiva Marco del Agua, en materia de aguas subterráneas. Memoria*. Dirección General del Agua, Ministerio de Medio Ambiente. Madrid: 1–85.

MMA (2003) Valoración del coste de uso del agua subterránea en España (Valuation of the costs of groundwater use in Spain). Madrid. (Internal report)

MMA (2000). *Libro Blanco del Agua en España* [White Book of Water in Spain]. Secretaría de Estado de Aguas y Costas, Dirección General de Obras Hidráulicas y Calidad de las Aguas. Madrid: 1–637.

MIMAM–ITGE (1997). *Catalogo de acuíferos con problemas de sobreexplotación o salinización*. Ministerio de Medio Ambiente [Spanish Ministry of Environment] and Instituto Tecnológico Geominero de España [Geological Survey of Spain], Madrid: 1–43 + Appendix.

MOPTMA–MINER (1994). *Libro blanco de las aguas subterráneas.* Serie Monografías. Ministerio de Obras Públicas, Transportes y Medio Ambiente, y Ministerio de Industria y Energía, Madrid: 1–135

National Research Council (1997). *Valuing groundwater. Economic concepts and approaches.* National Academy Press, Washington D.C.: 1–189.

Pérez Zabaleta, A. (2001). *La oferta de aguas subterráneas para abastecimientos urbanos*. In: "La economía del agua subterránea y su gestión colectiva". Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid: 75-96.

Pulido, A., Molina, L., Vallejos, A. and Pulido, P. (2000). *El Campo de Dalías: paradigma de uso intensivo*. Papeles del Proyecto Aguas Subterráneas. Fundación Marcelino Botín. Serie A, Nº 4, Madrid: 1–54.

Ragone, S., Hernández-Mora, N., de la Hera, A., Bergkamp, G. and J. McKay (eds.) (2007) *The global importance of groundwater in the 21st Century: Proceedings of the International Symposium on Groundwater Sustainability*. National Groundwater Association Press, Ohio, USA. (In press)

Rico Amorós, A.M. and Olcina, J. (2001). *La gestión colectiva de aguas subterráneas en tierras alicantinas.* . In: "La economía del agua subterránea y su gestión colectiva". Eds: N. Hernández-Mora and M.R. Llamas. Mundi-Prensa and Fundación Marcelino Botín, Madrid: 475-533.

Sánchez, A. (2003) *Major challenges to future groundwater policy in Spain.* Water International, 28(3): 321-325.

Varela, C. and N. Hernández-Mora. (2008) *Institutions and institutional reform in the Spanish water sector: A historical perspective*. In: "Water Policy in Spain." Garrido, A. and M.R. Llamas (eds). Resources for the Future. (In press)

Vives, R. (2003) *Economic and social profitability of water use for irrigation in Andalucía.* Water International, 28(3): 326-333.

RELEVANT WEBSITES

CEH–CEDEX (Centre for Water Studies of the Centre for Public Works Studies and Experimentation): http://www.cedex.es/hidrograficos/presentacion.html
Eurostat (EU Bureau of Statistics): http://epp.eurostat.cec.eu.int
Hispagua (Spain's water information system): http://hispagua.cedex.es
IGME (Instituto Geológico y Minero de España) [Spanish Geological Survey]: http://www.igme.es
INE (Instituto Nacional de Estadística) [National Bureau of Statistics]: http://www.ine.es
INM (Instituto Nacional de Meteorología) [National Weather Institute]: http://www.inm.es
MMA (Ministerio de Medio Ambiente) [Ministry of the Environment]: http://www.mma.es

River Basin Authorities:

Ebro → http://www.chebro.es
Duero → http://www.chduero.es
Tajo → http://www.chtajo.es
Guadiana → http://www.chguadiana.es
Júcar → http://www.chj.es
Guadalquivir → http://www.chguadalquivir.es
Catalonian Water Agency → http://www.gencat.net/aca
Andalusian Water Agency → htpp://www.agenciaandaluzadelagua.com