CHAPTER 14

Issues related to intensive groundwater use[1]

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1 INTRODUCTION

Groundwater use in Spain has increased dramatically over the last decades, with total volume pumped growing from 2,000 Mm^3/year (million m^3 per year) in 1960 to more than 6,500 Mm^3/year in 2006. Today, groundwater provides between 15–20% of all water used in Spain, although the proportion may approach 100% in some peninsular areas and the islands. This development is mostly the result of the initiative of thousands of individual users and small municipalities, with scarce public planning and oversight. The result has been intensive rates of groundwater use, in what has been called a silent revolution (Fornés *et al*., 2005; Llamas, 2005).

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 fourth of the total population. Given the importance of irrigation water demand, and in the context of increased competition among the different water demand sectors for limited water resources, recent efforts to improve the quality of data on groundwater use and its economic importance are crucial to inform future water policy decisions. This better knowledge is also needed to meet the environmental requirements of the Water Framework Directive (WFD, 2000, see Chapter 16) and the *daughter* Groundwater Directive (GWD, 2006) of the European Union.

The intensive development of groundwater has brought significant social and economic benefits, although their unplanned nature has also resulted in negative environmental, legal and socioeconomic consequences. While the drivers and conditions may vary, the situation in Spain is

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similar to what happens in most arid and semiarid countries, both developed and developing ones, as emphasized in the Alicante/Alacant Declaration approved at the International Symposium on Groundwater Sustainability (Ragone *et al*., 2007).

This chapter presents a critical overview of intensive groundwater use in Spain, with emphasis on economic and institutional aspects. After a review of available data on groundwater use and a brief discussion of the situation in some regions where groundwater is used intensively, the economic parameters associated with this use are considered, focusing on irrigation. After that, the institutional framework for the management of groundwater resources that has evolved from the 1985 Water Act and its later reforms are evaluated. This chapter builds on Chapters 10 and 11, which present and discuss the legal framework of Spain's water sector, and on Chapter 12 which reviews water institutions in Spain with a historical perspective. It provides the technical, economic and political bases for the in-depth discussion of groundwater institutions of Chapter 15.

2 GROUNDWATER RESOURCES IN SPAIN

Spain is well endowed with aquifer formations, which tend to be small and widely spread around the country. Traditionally, only sedimentary, carbonated or volcanic formations of quite high permeability were officially considered aquifers. This meant an aquifer surface area of about 180,000 km^2, or one third of the country's surface area. Aquifer formations were divided into 411 hydrogeological units. This concept was defined for the first time in the 1985 Water Act, often following administrative rather than hydrogeological criteria. However, many areas with low permeability aquifer formations containing limited water resources were excluded, although they were strategically importance resources 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. This is 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 given 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 WFD criteria, that 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 to more than 20,000 km^2, with an average groundwater body size of about 500 km^2. A classification was developed in 2005 in order to comply with the requirements of articles 5 and 6 of the WFD and is currently being revised and updated for the elaboration of the new Basin Management plans to be published before the end of 2009 after an extensive public consultation process.

Estimates of the total volume of water stored in Spain's aquifers vary between 150,000 and 300,000 Mm^3, depending on the study. However, actual reserves are probably much higher, since the existing calculations (done under the previous definition of hydrogeological units) only take into account the volume stored in the 100–200 m depth range and do not consider smaller aquifer formations (Llamas *et al*., 2001)—now included in the new definition of groundwater bodies—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 only 37,425 Mm^3 are annually available for use (MMA, 2007).

From a management standpoint, two hydrogeological concepts are significant: aquifer storage, annual rate of recharge or renewable groundwater resources. The storage of many aquifers usually exceeds the annual natural rate of recharge by one or two orders of magnitude. This has practical implications, particularly important for a country like Spain where evapotranspiration is high and droughts are frequent, and where these reserves can be important to guarantee supply during drought periods.

A mathematical distributed model (SIMPA) was developed to estimate Spain's renewable groundwater resources for the White Book of Water (MMA, 2000). Results show that total renewable resources amount to about 30,000 Mm^3/yr. This amount probably underestimates total resources, since simulations are carried out under natural conditions, certain low permeability areas are ignored, and the model is not able to consider in detail the real behaviour of groundwater (Cruces 1999). Recently, aquifer recharge rates on peninsular Spain have been recalculated through the atmospheric chloride deposition balance (Alcalá & Custodio, 2007). Ultimately, usable groundwater resources are less than renewable water resources due to environmental restrictions, seawater intrusion limitations in coastal areas and islands, and interference with already committed surface water resources.

In spite of their quantitative and strategic importance, groundwater resources have traditionally not been adequately taken into consideration by the Spanish Water Administrations, which has emphasized surface water development, although the situation is improving. From a management standpoint, 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 being done for the elaboration of the River Basin Management Plans, required by the WFD and to be completed within 2009 after extensive public consultation processes.

3 GROUNDWATER USE IN SPAIN

Existing information on groundwater uses in Spain is very heterogeneous and often scarce. This is due to two main causes. On one hand, water management responsibilities in Spain are divided between local, regional and national government levels. River Basin Authorities that depend of the national government's Ministry of the Environment, Rural and Marine Affairs (Ministerio de Medio Ambiente, Rural y Marino or MMARM) for the management of shared river basins (those that flow through more than two autonomous regions); Water Management Agencies that depend of Regional Governments for river basins that flow entirely within that region, as is the case in Catalonia, Andalusia, Galicia and the Basque Country in peninsular Spain, and in the Balearic and Canary archipelagos; Regional Governments for the management of protected natural areas and environmental policies; municipalities in issues relative to public water supply and sanitation; and irrigators associations for management and distribution of water among their members. On the other hand, most official statistics about water use for irrigation and urban supply 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 other than drilling ones were required to abstract groundwater. This lack of detailed information makes it difficult to make a global estimation of groundwater uses for the entire country.

Table 1 presents an estimation of groundwater use in Spain using data from the 1990s. It indicates that overall groundwater use ranges from 5500 to 6500 Mm^3/year, or between 15% and 20%

Table 1. Estimations of groundwater use in Spain.

	T, Total water		G, Groundwater		
Use	Mm^3/year	%	Mm^3/year	%	G/T
Domestic supply	5500	15	1000–1500	20	0.20
Irrigation	24500	65	4000–5000	75	0.20
Industry	1500	4	300–400	5	0.20–0.25
Hydroelectricity	6000	16	–	–	–
Total	37500	100	5500–6500	100	0.15–0.20

Source: Elaborated with data from MIMAM (internal reports of 2007), MIMAM (2000), MOPTMA-MINER (1994).

of total water use in Spain. However, these percentages vary widely from region to region. For instance, in the Mediterranean basins groundwater can represent up to 75% of all water resources used (MMA, 2007). The volume of groundwater use also increases significantly in times of drought, when surface water resources dwindle (López Geta, 2006).

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: only 19% according to 2007 data from the Ministry of the Environment. This national average is low for a country with the hydrogeological potential and the meteorological characteristics of Spain, where groundwater could play a major role in guaranteeing urban water supply during droughts. 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 (accounting for desalinization contribution) or 43% in the Júcar (Xúquer) River Basin, and even more in the Balearic Islands. 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 in Spain 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 of around one million hectares, about 30% of the total irrigated area. However both surface and groundwater sources are often used conjunctively to irrigate crops. Groundwater resources allow farmers to guarantee their crops in drought years when surface water resources are not available. Groundwater provides 20% of all water used to irrigate 30% of the total irrigated area.

While seawater, brackish groundwater and waste water desalination and salinity reduction currently contribute to water resources in the islands and the Mediterranean area of the peninsula, it does not significantly change previous figures. Recently, advanced treatment of brackish and polluted groundwater, including membrane technology (reverse osmosis and reversible electrodialysis) are augmenting groundwater use and the reclamation of waste water, a part of which was originally groundwater. Most of this water is for urban water supply, which can pay their relative high production cost, or for highly productive crops, such as those under greenhouses.

When groundwater quality is poor it may be applied to some urban uses, such as gardening, street cleaning and ornamental fountains. In urban areas prone to high water-table problems, drainage water is used for urban uses, as in the Barcelona Plain. There is also an increasing use of treated waste water for irrigation in new areas or to substitute for surface and groundwater resources, or to develop sport facilities such as golf courses. In this last case treated waste water application in new areas may be compulsory.

Artificial recharge of aquifers is rarely done. An exception is provided by the surroundings of Barcelona, where excess irrigation water recharge has been an important term in aquifer water balance. Enhanced river water infiltration by carefully scrapping the Llobregat river bed has been practiced since the 1940's under favourable hydrological conditions. Artificial recharge through deep wells started in the 1950s in the low Besós river area using excess water from a canal, and since the late 1960s in the low Llobregat river area by injecting excess potabilized river water (Custodio, 2009). In 2007 a pilot facility is being operated to control seawater intrusion in the Llobregat's delta deep aquifer by injecting advanced treated waste water, with reverse osmosis salinity reduction, and has now expanded to form a 14 well barrier (Niñerola *et al*., 2009). Recharge basins, first receiving river water and afterwards with inverse osmosis salinity reduction of treated waste water, are being installed to compensate for recharge reduction due to increasing land occupation by motorways and railways. Other artificial recharge activities with occasional runoff exist in southern Gran Canaria Island, with potable municipal water in Madrid, and with treated waste water in Mallorca Island and in Dehesas de Guadix (Granada).

Groundwater levels and quality monitoring is an important task, which is compulsory under the WFD and the GWD. Groundwater quantity (piezometric levels) networks, mostly operating wells and some dedicated boreholes are being installed, with irregular densities and patterns. The oldest network, dating back to the mid-1960s is that around Barcelona, later extended to all Catalonia, with recent significant improvements being made (Custodio, 2009; ACA, 2008). A dedicated, especially designed piezometric network was constructed in the 1970s and 1980s in the Doñana area (southwestern Spain), in which up to four point piezometers per site are available (Custodio & Palancar, 1995; Manzano *et al*., 2009). The Spanish Geological Survey (IGME) operated a Spain-wide quantity and quality groundwater monitoring network between the 1960's and the late 1990's, when the responsibility was assigned to the River Basin Authorities.

4 GROUNDWATER ECONOMICS IN SPAIN

4.1 *General issues*

The few economic studies that did exist before the passing of the WFD were constrained to particular regions or sectors, and for the most part did not differentiate between surface and groundwater sources. An exception of this situation was the research project funded by the Marcelino Botín Foundation (Hernández-Mora & Llamas, 2001; Llamas, 2003).

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. Consequently the MMARM created the Economics Analysis Group, an internal working group that has been coordinating and guiding the work of the different Basin and Water Management Agencies in the economic aspects of water use. The group has issued internal reports that summarize the content of the work undertaken to comply with WFD Article 5 and Annex II and III reporting obligations (MMA, 2007). Even though the reports have been elaborated with limited and inconsistent economic data, it is possible for the first time to have a more clear understanding of water use economics in Spain. However, the information in the reports mostly fails to distinguish between surface or groundwater sources, so that information specific to the economics of groundwater use is still limited and in some aspects less deta iled than in the White Book of Water in Spain (MMA, 2000).

4.2 *Costs of groundwater use*

In Spain and most other semi-arid countries, 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 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, even by future generations. As a result, the overall costs of intensive groundwater use do not motivate changes toward more economically and socially efficient abstraction regimes.

In order to deal with this discrepancy 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 issued in 2003 an internal study evaluating the extraction costs associated with groundwater use for irrigation and urban water supply in Spain. 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 on environmental or resource costs, which can be significant. What follows is a review of some of the data that can be gathered from these sources.

Service or direct costs. Pumping costs are a function of well yield, terrain characteristics, pumping technology used, depth of water table and energy costs. The 2003 internal study of the Ministry of the Environment 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, in the Guadiana basin, to as high as 0.74 €/m^3 in the Segura river basin. As Llamas & Garrido (2007) point out, this assessment was done without specific field surveys and therefore it should be considered only as a preliminary approach, and refer to 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.

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, mostly using surface water, in order to increase water use efficiency. However, most often, Spanish farmers pay for all direct costs associated with groundwater irrigation, as there is no public support or subsidy for energy use by irrigators.

Existing data indicate that, even where water table levels are very deep, the costs of energy consumption only represent a small portion of farmer's income and therefore are not a deterrent for deeper abstraction levels. In the case of La Mancha Region, in south-central Spain, Llamas *et al.* (2001) estimate that the energy cost of irrigating one hectare by pumping water from a depth of 100 m is about 84 €/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. 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 to 25,000 €/ha, pumping costs still represent less than 10% of total crop value, as indicated by Garrido *et al.* (2006, p. 346), who point out that as land without water is valueless, farmers will not be deterred by such productivity erosion.

A final set of costs associated with groundwater use for irrigation are the distribution costs. These occur when various users share a well so that pumped water is distributed among them using networks that can be very complex and often inefficient from an economic and a resource use perspective. Shared wells used by irrigators associations are very common in coastal eastern and southeastern Spain, and in the Canary Islands. 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 costly (see Chapter 13 to learn how water charges are implemented in these complex organizations). Table 2 shows some results for groundwater costs in the region of Valencia. For comparative purposes, they include 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; (2) groundwater users pay a higher price for water than surface water users since they pay for all direct costs and also are charged with the added value tax, which is not the case when using surface water; (3) users never pay for environmental or resource costs of groundwater use, except when scarcity requires deepening existing wells or drilling new ones.

Data do not include water quality parameters, mainly water salinity. Salinity may affect crop yield and/or irrigation depth and frequency. Also an inadequate use of relatively saline water may enhance soil salinisation and alkalinisation. This is a serious problem in many irrigated areas in Spain, though no nationwide official report on this issue exists. Except for some analyses conducted in the Ebro delta rice paddies, irrigated with variable quality river water, very little is known about the impact on worsening groundwater quality.

In some cases, farmers have begun to pay attention to these facts and they price water of various salinity and chemical composition differently. In the Canary Islands, farmers have at times selected the best-quality water from their sources for irrigation and sold the worse-quality water for urban and tourist uses. Currently some farmers, aware of the salinity problems, pre-treat irrigation water

Table 2. Average cost of irrigation water in the Valencia region (modified from Carles *et al*., 2001a).

Groundwater management areas	Source of water	Crop	Average cost[1] (€/m^3)
Mijares-Plana de Castelló	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
	Groundwater[2]	Various	0.26

[1] Average values of all irrigator associations in each region weighted by surface area.
[2] Groundwater costs in the region in 1999 were 0.51 €/m^3, after Rico and Olcina (2001).

by low pressure reverse osmosis, which adds to the direct water cost. The cost of disposing the produced brines is often not considered, and may involve serious environmental costs, or require costly public investments, as in Fuerteventura Island or in the Campo de Cartagena region in the Segura river basin, which are often not accounted for.

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 and to accurately assess the economic viability and social desirability of different pumping regimes. Intensive and uncontrolled groundwater use can have negative consequences such as aquifer salinisation 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 no estimates of the environmental and resource costs associated with groundwater use in Spain. Environmental costs will have to be calculated as the cost of applying the corrective measures to achieve the WFD environmental goals. In any case, it is apparent that if the full cost recovery principle is applied to intensively used aquifers, many existing groundwater uses would not be economically viable. The individualist nature of groundwater abstractions together with the inadequate enforcement of existing rules and regulations, as will be discussed later on, has resulted in the elimination of the scarcity value and made it difficult to guarantee existing rights. It is thus difficult to achieve the goals of the WFD in many intensively used aquifers.

4.3 *Economic issues of groundwater use in Spain*

In spite of data scarcity, Llamas *et al.* (2001) and Hernández-Mora *et al.* (2001) developed a rough estimate of the economic value of groundwater use in Spain, which shows the magnitude of the economic contribution of groundwater. The discussion will be limited to groundwater use for irrigation and public water supply.

Public water supply. In most cases water supply data consider together surface and groundwater. Users pay for the treatment and 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, with a wide range, from the 0.80 €/m^3 paid by home consumers in Castilla y León or Castilla-La Mancha (Duero and Guadiana River Basins respectively), to the 1.72 €/m^3 paid in the southeastern Mediterranean region of Murcia, in the Segura River Basin (MMA, 2007 and other internal reports of 2007). Often these tariffs do not cover the investment costs of the necessary infrastructures associated with the service (dams, canals, facilities, etc.), which are usually paid for by general revenue of the State, Region or local government (see Chapter 8 for a more detailed analysis or urban water issues). Current information (MMA, 2007) 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 average 167 liters per day and person of water consumed by domestic users) that water fees are hardly an incentive for lower consumption. However, public education campaigns and careful maintenance of distribution networks have being effective in Madrid and Barcelona in reducing per person water use, keeping a fully satisfactory service quality. In the densely populated areas of Barcelona in-house consumption is currently less than 125 l/day/person.

Irrigation. The primary economic contribution of groundwater in Spain is for irrigation. The recent reports on the economic analysis of water use (MMA, 2007 and internal reports) present updated information on irrigated agriculture economics, 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 groundwater economics in agriculture:

1. Average gross economical productivity of irrigated agriculture is 4.4 times that of rainfed agriculture, although there are significant regional differences. In areas with profitable rainfed crops (olives, grapes, or cherries) the ratio can be as little as 1.1. In the southeastern regions 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, or 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. In areas which rely on groundwater sources to produce highly profitable horticultural crops, these subsidies represent as little as 1%.
3. Average water services costs to the farmer vary greatly between surface water users (106 €/ha/year), and groundwater users (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. This 9% concentrates primarily in river basins and islands that rely heavily on groundwater.

The most comprehensive analysis of the economic contribution of irrigation using groundwater is the Irrigation Inventory for Andalusia (CAPJA, 2003), originally carried out in 1996 and 1997, and updated in 2002. Using data from the original 1997 study, Hernández-Mora *et al*. (2001) show that irrigated agriculture using groundwater is economically over five times more productive and generates almost three times the employment than agriculture using surface water. This can be attributed to several causes: the greater control and supply guarantee provided by groundwater, which allows farmers to introduce more efficient irrigation techniques; the greater dynamism that has characterized farmer that sought out their own water sources and bear the full costs of their water supply; 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.

Using data from the 2002 update, Vives (2003) shows that in Andalusia groundwater supplies 27.3% of all irrigated agricultural land and represents 22.7% of all water used for irrigation. It generates almost 50% of all agricultural output and 50% of employment (Table 3). Irrigation using groundwater is three times more productive than that using surface water, it is at least 20% more efficient in the water use 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. In order to compare surface and groundwater productivities, Vives (2003) uses information on the water volume applied in the field, not the volume of water actually pumped or diverted from reservoirs. If the latter data were used (Llamas *et al*., 2001), the difference between surface and groundwater productivities is even greater since a significant amount of surface water is lost in transportation canals or evaporated in dams and storage basins.

Table 3. Economic indicators in Andalusia for irrigation with ground and surface water, after Vives (2003) and CAPJA (2003).

	Groundwater	Surface water	Total
Irrigated area (km^2)	2440	6480	8920
Percentage of irrigated area (%)	27	73	100
Average water consumption (m^3/ha)	3900	5000	4700
Total production (10^6 €)	2222	2268	4490
Specific production (€/ha)	9100	3500	5100
Employment generated (jobs/ha)	0.232	0.126	0.154
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

The same set of data serves to highlight the economic importance of groundwater, not only for its extractive value, but also for its stabilization value. 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 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 Almería (see Figure 1), where 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 greenhouses for the production of highly profitable fruits and vegetables, has allowed the dramatic economic growth of the area since the 1950s, when irrigation begun. Today, irrigation of over 20,000 ha of greenhouses directly or indirectly generates an estimated 1200 M€/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 8000 inhabitants in the 1950s to more than 120,000 in 1999 (Pulido *et al*., 2000). But the lack of planning or control of these developments by either the water authorities or the users themselves has resulted in social tensions from inadequate integration of the necessary immigrant labor, as well as problems of saline water contamination of soil in some areas, and the need to deepen or relocate some wells.

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 8000 ha irrigated in the Alfamén-Cariñena region, an area of intensive groundwater use in Central Ebro river basin, under less favourable climatic conditions. Net water productivity ranges between 0.15 and 0.50 €/m^3, depending on the type of fruit crop, while estimated productivities of some large surface water irrigation networks in this semi-arid region, such as Bárdenas or Monegros, are around 0.03 €/m^3. Arrojo (2001) 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. The advantage can be attributed to the water supply guarantee provided by groundwater, 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. 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, which provides almost 80% of all water resources in the islands. The general scarcity of water resources has resulted in a unique water resources system that is characterized by three factors: the prominent role played by the private sector in the search,

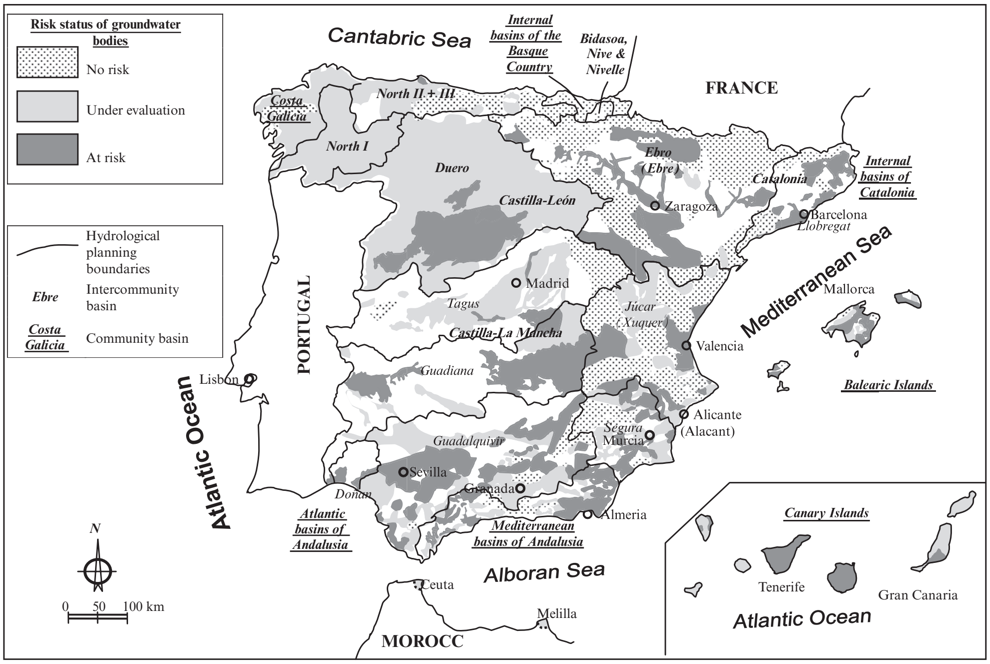

Figure 1. Areas with groundwater bodies in Spain. White areas inside Spain are devoid of significant aquifers. Shaded areas are the groundwater bodies classifies as no risk, under evaluation and at risk, relative to the WFD good status to be attained in 2015. The figure is a simplification of maps from the Ministry of the Environment, of year 2006.

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 and brackish groundwater, and treated waste water with salinity reduction. Water resources have historically been distributed in the islands through largely unregulated and imperfect water markets where both the resource and the transportation canals are privately owned (Aguilera, 2001), although recently the public sector has invested in regulation ponds and transportation canals, thus concurring with the private sector. The economic and social importance of agriculture in the Canary Islands decreased significantly in the second half of the twentieth century, rapidly losing ground to industrial production and tourism in Gran Canaria. In 1998, agriculture was responsible for only 3.8% of the islands' total economic output and provided 7.5% of all employment, similarly as what has been observed elsewhere in Spain. 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 about 280 Mm^3/year, or 60% of all water used. For the island of Tenerife, which relies in a larger proportion on agriculture tomatoes under greenhouses is the most profitable crop, about 4.75 €/m^3, and the traditional banana crop is losing profitability.

5 PRESSURES, IMPACTS AND MEASURES TO ACHIEVE THE GOALS OF THE WATER FRAMEWORK DIRECTIVE ON GROUNDWATER ISSUES IN SPAIN

5.1 *General considerations*

The Water Framework Directive (WFD, 2000) aims to achieve water good ecological status of all water bodies by 2015, with possible negotiated extensions to 2021 and 2027, if it is demonstrated that the delay is technically, economically, and socially warranted due to the implementation difficulties or involved costs. The WFD asks for halting ecological deterioration, reversing negative trends, and carrying out action to achieve a good water quality status.

The application of the WFD to groundwater presented some uncertainties and difficulties and consequently a *daughter* Groundwater Directive (GWD, 2006) has been passed to clarify and develop the WFD concepts. By application of the subsidiarity principle, a guideline of all European Union policies, the WFD and the GWD have to be duly incorporated into European Union Member States water-related acts.

The WFD included, and thus canceled, previous EU Directives on continental and littoral water, except the Nitrates Directives (ND, 1991), which will be in force until the goals of the WFD will be attained. It is aimed at correcting the surface and groundwater increase of nitrates. For groundwater it asks the definition of nitrate sensitive areas due to agricultural practices, in which control measures have to be undertaken.

The main goal of the WFD is that by 2015 all water bodies (surface and groundwater bodies) achieve a good ecological status (see Chapter 16 for a description of the WFD). 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 Mediterranean EU Member States. The WFD is dominantly influenced by Central Europe problems, and consequently may be in conflict with actual situations in other areas, especially in the Mediterranean area, and especifically in Spain, where even natural conditions may not comply with the WFD terms. Exceptions, many of them referring to groundwater bodies, must be fully documented and demonstrated. Excessive groundwater abstraction with its potential impact on water quality degradation and on stream flows and wetlands is a primary concern since, after the WFD, groundwater abstraction should not cause a significant impact on related surface water bodies. If this provision is strictly enforced, many groundwater intensive developments in Spain may have to cease. The social and economic sustainability of such a decision, and its political viability, is problematic (Sahuquillo *et al*., 2009; Molinero *et al*., 2008), and if viable, they may need a significant delay to be implemented. Current concerns are also linked to: a) the absence of a long-standing tradition of public participation in policy decision-making; b) the fact that groundwater management results are significantly delayed with respect surface water, and may only be seen after decades; c) the fact that in the Mediterranean countries the consumptive use of water for irrigation usually represents about 80% of total consumptive use; d) the need to deal with thousands of individual farmers and small communities, which is more complex than dealing with less numerous and usually more organized water supply companies, electric utilities and industries; e) the fact that the natural situation may not comply with the WFD requirements. Further experience and rethinking are needed.

In spite of the above mentioned difficulties, the authors of this chapter consider that the enforcement of the provisions of the WFD in the Mediterranean countries, and especially in Spain, is being, and will be, positive and beneficial from the hydrogeological, economical and social points of view. Even if Spain applies for delays in implementing the goals of the WFD, clear and thorough information on the hydrological, economic and social dimensions of water resource use, accompanied by active public participation will need to be provided. Cost/efficiency analyses of the different measures will need to be undertaken and publicized. Such an exercise of transparent information and public participation will provide a positive outlook on the role of groundwater in water policy and enhance management processes.

5.2 *Pressures on groundwater bodies*

The situation of many intensively used aquifers in Spain can help illustrate some of the difficulties to implement the WFD. As described in Chapter 11, 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 (MMA-ITGE, 1997) in addition to 15 units in the Canary Islands and the Internal Basins of Catalonia, which have their own water administration.

But the legal declaration of overexploitation was often embedded in intense political and social debate, so that many aquifers subject to intensive use have not been declared overexploited (see Chapter 15). While these declarations should be accompanied by strict regulatory measures, they have most often not been successfully implemented. This explains that exploitation, management and water quality issues are still chaotic.

Water management efforts in Spain have focused primarily on quantity, while quality concerns have been secondary. In 1997 there were 60 hydrogeological units where estimated total pumping volumes exceeded estimated natural recharge rates. Although estimates have to be taken cautiously, given the significant data uncertainty and the fact that terms such as natural recharge, overexploitation or water deficit are sometimes misused, they indicate that there is an overall groundwater storage deficit in those aquifers of approximately 665 Mm^3/year (MAPA, 2001). Most of them are located in southeastern Spain and in the Balearic and Canary islands. Perhaps the most emblematic case of intensive groundwater use where overdraft is most acute is the Western La Mancha hydrogeological unit, in the Upper Guadiana River basin, where water-table drawdowns have dramatically impacted the wetlands in the "Mancha Húmeda" Biosphere Reserve (Martínez Cortina, 2001, de la Hera, 1998). Other interesting case is that of the Doñana area wetlands, in southern Spain, an emblematic Ramsar site and important European Natural Park, in which groundwater irrigated agriculture established in the late 1970s and early the 1980s has affected groundwater discharges and depth to the water-table (Custodio *et al*., 2008; Manzano *et al*., 2009).

It what refers 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 excess high salinity irrigation water. Table 4 shows the degree of salinization (chloride and sulphate) observed in stations of the national groundwater monitoring network. Quality limits are naturally attained in some aquifers and springs in arid and semi-arid areas of Spain.

Another water quality concern is nitrate pollution, mostly due to diffuse pollution from agricultural and cattle rising activities. Table 4 shows that 20% of the control points yield values in excess of the WFD and water potability norms threshold of 50 mg/LNO_3. The Guadiana and Júcar (Xúquer) river basins being the most affected. High nitrate values are found in many aquifers in Catalonia, Murcia, Balearic Islands or the Canary Islands. According to the WFD, values in excess of 25 mg/L oblige to systematic monitoring every four or eight years. Thus, contamination by nitrates is one of the main challenges faced in Spain with regard to groundwater quality, especially because in areas with deep water-tables a large inventory of nitrates is in the unsaturated zone and thus will continue to leach into the aquifers even if new surface sources disappear. Nitrate sensitive areas are extensive, but the affected surface area should be still larger for adequate action and protection, although this results in unwanted political problems.

Table 4. Percentage of groundwater quality monitoring stations classified after chloride, sulphate and nitrate contents, in mg/L, in some of the water districts. Data from MMA of 2003 (http://www.mma.es).

River basin district	Annual average chloride		Annual average sulphate		Maximum 6-month nitrate value		
	0–100	>100	0–150	>150	0–25	25–50	>50
North	100	0	100	0	100	0	0
Duero	87	13	93	7	84	12	4
Guadiana	72	28	65	35	24	41	35
Guadalquivir	72	28	69	31	66	16	18
Mediterranean Basin of Andalusia	60	40	74	26	79	5	16
Segura	40	60	33	67	72	15	13
Júcar	62	38	N.A.	N.A.	27	27	46
Ebro	77	23	61	39	62	18	20

5.3 *Characterization and risk assessment of groundwater bodies*

In order to comply with the WFD requirements, the reports submitted to the European Commission by the Spanish government classify groundwater bodies according to three categories (see Figure 1):

1. *at risk*, which will presumably not attain good status by 2015 and require further characterization.
2. *at risk under evaluation*, in which available information does not allow a clear diagnosis on the possibility of achieving good status, and require additional studies.
3. *no risk*, which according to available data will attain good status by 2015.

The initial characterization identifies two types of pressures: chemical risk as a result of point and non-point (diffuse) pollution, and seawater intrusion; 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: a) diffuse pollution, primarily nitrate pollution; b) point source pollution (often with limited and insufficient data); c) seawater intrusion; and d) groundwater abstractions (difficult to evaluate because of insufficient information in the terms established by the WFD).

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

Table 5 presents the summary results of applying this methodology for risk assessment of groundwater bodies (GWB) in all river basin management districts in Spain. Of the 699 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 the remaining 256 (37% of the total) as being *at risk under evaluation*. The most frequent causes of *risk* are diffuse or non-point source pollution (167 GWB or 24% of those characterized) and quantitative (164 or 23%). In terms of saltwater intrusion, the *risk* results from a deterioration of water quality resulting from inadequate pumping patterns: 71 GWB in all coastal areas except in the North, are at risk for salinization.

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 Spanish Geological Survey (IGME) have developed a methodological guide to support and homogenize the additional characterization work that must be carried out by River Basin Authorities. Only preliminary work on the additional characterization has been done so far, with some results available in the River Basin Authorities' websites.

6 INSTITUTIONS FOR MANAGING INTENSIVELY EXPLOITED GROUNDWATER BODIES IN SPAIN

Spain has experimented with different solutions for groundwater resources management: 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 intensive groundwater use and transforming 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 (see Chapters 10 and 11). As a result River Basin Authorities

Table 5. Risk assessment classification of groundwater bodies (MIMAM, 2006).

River basin district	Number of GWB	GWB at risk: Chemical P	D	I	Quantitative E	Total characterized: At risk	Under evaluation	No risk
Shared River Basins								
North I	6	0	0	0	0	0	6	0
North II and III	34	0	0	0	0	0	12	22
Bidasoa, Nive and Nivelle	2	0	0	0	0	0	1	1
Douro	31	0	3	0	1	3	28	0
Tagus	24	NE	1	0	NE	1	18	5
Guadiana	20	0	9	1	6	11	9	0
Tinto, Odiel and 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 Coast	18	0	0	0	0	0	15	3
Internal Basins of Basque Country	14	2	0	0	0	2	0	12
Internal Basins of Catalonia	39	23	23	10	10	25	0	14
Mediterranean Basin of Andalusia	67	1	20	11	23	29	23	15
Balearic Islands	90	42	36	30	41	42	35	13
Canary Islands	32	NE	8	8	15	19	13	0
TOTAL*	699	80	167	72	164	259	256	184

P: point source; D: diffuse; I: saline 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) Now within the Atlantic Internal Basin of Andalusia planning district.

acquired, at least on paper, a relevant role in the management of public groundwater resources, and were responsible for granting permits for any uses starting after 1985. The Water Act created a registry system for public water use permits or concessions for both surface and groundwater rights, the Registry of Public Waters. Groundwater 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. In practice this has been the preferred option by most irrigators.

Second, the Water Act gave Basin Authorities broad powers for the management of aquifers declared overexploited in accordance with the law. When an aquifer is declared legally overexploited, River Basin Authorities 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 Users Associations, and a General Users Association has to be formed that encompasses all associations existing in a given aquifer system (see Chapters 12 and 16).

Third, the concept of user participation in water management was legally extended and reinforced. 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 River Basin Authorities in the 1920s, representatives of these irrigators associations were part of their governing and management bodies. However, the 1985 Act expanded the concept to groundwater users and representatives of other interests and uses beyond irrigators (See Chapter 12).

The changes introduced by the 1985 Water Act were necessary to deal with the challenges resulting from the intensive use of groundwater resources, although declaring groundwater a public domain is neither unavoidable nor the only possible solution. The implementation of the changes has encountered difficulties which in some ways continue up to present. Two are worth highlighting:

First, River Basin Agencies, without experience in groundwater management, have consistently lacked sufficient human and financial resources to deal with their acquired responsibilities. They have also had difficulties shifting their focus from their traditional water infrastructure development and technical management responsibilities to their new broader water and ecosystem management goals.

Second, the absence of updated groundwater rights records is a significant difficulty, since the Registry of Public Waters and the Catalogue of Private Waters are still quite incomplete. There is no up-to-date record of existing groundwater uses and of total extraction volumes in spite of costly efforts launched by the Ministry of the Environment to try to cover this gap. 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. The situation is still not resolved. Moreover, Fornés *et al*. (2005) and Llamas *et al*. (2001) have estimated that the total number of water wells and captured springs in Spain is in the order of two million. If these estimates are accurate, about 90% of all groundwater abstractions in Spain are not registered, and are either illegal or allegal.

6.1 *The reform of the Water Law and the National Hydrologic Plans*

A significant landmark in Spanish water law was the approval in 2001 of the National Hydrologic Plan 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 Spain. It meant to coordinate river 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 1050 Mm^3/year from the lower Ebre river basin to northern and southern areas along the Mediterranean coast, in part to replace excessive pumping in overexploited aquifers along the coast (see Chapter 19). 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 of inter-basin transferred water (Sánchez, 2003). It required users in the receiving aquifers to be organized in users associations, and established that the user communities would hold the title to the transferred water, making them responsible for reducing pumping rights proportionally to the volume of water received, until total groundwater abstractions were reduced to sustainable levels. In essence the Hydrologic Plans put users for the first time in charge of allocating and limiting their water rights, thus making them responsible for aquifer management decisions together with Basin Authorities.

However, the Ebro river transfer proposal was very controversial and received intense criticism from academics, environmental organizations, other public interest groups nationwide 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, and also in favor in receiving regions, such as Valencia. In March 2004 the Ebro river transfer plan was cancelled, and the government presented the alternative AGUA Programme (Actions for Water Management and Use), a multifaceted plan aimed to increase available resources in coastal Mediterranean river basins through water efficiency and saving measures, increased use of recycled waters and the construction of new desalination plants along the coastline, in order to address water shortages. The plan was enacted in 2005, modifying the 2001 National Hydrologic Plan. In reality the AGUA programme maintains many of the other controversial dams and public infrastructures that were proposed in the 2001 National Hydrologic Plan with the exception of the Ebro basin transfer. One of them is surface water irrigation scheme for the Garrigues-Segarra area, south of Lleida, in the Ebro basin, a recently completed part of the National Hydrological Plan, with at least a similar impact on the Ebro Delta as the canceled Ebro river transfer.

Furthermore, the AGUA programme proposes the construction of some twenty seawater desalination plants to produce about 600 Mm^3/year for urban water supply and irrigation in coastal Mediterranean basins. However, some authors argue that the acceptance by the farmers of this water is dubious if they have to pay the full cost of that water. It seems that the government is ready to heavily subsidize the cost of desalinated seawater for irrigation (Llamas & López-Gunn, 2007), which is at odds with the full recovery principle that guides the WFD.

6.2 *Organizations for water management: River Basin Authorities and water users associations*

As Chapter 12 shows, Spain has a long-standing tradition of irrigator participation 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 being transferred successfully, by duly considering aquifer characteristics.

Groundwater user associations in Spain are extremely diverse. According to their goals and objectives they can be grouped into two categories (after Carles *et al*., 2001b): 1) *associations for the collective management of irrigation networks* whose objective is the common exploitation of a well or group of wells and where members generally pay for all drilling, installation, operation and maintenance costs; and 2) *associations for the collective management of aquifers*, which comprise all or a majority of users within one aquifer; and that, in addition to pursuing their own interests also contribute to the aquifer's management and conservation, a social goal.

In terms of the tenets of the law, associations included in this second group are the ones that can play a significant role in the management of groundwater resources. Of the thousands of existing groundwater users associations, currently only six can be truly included in this last group, and only two (Western Mancha and Campo de Montiel aquifers user associations) were created in response to a legal declaration of overexploitation.

A particularly interesting example of successful groundwater user communities are the Water Users Associations of the Low Llobregat and of the Cubeta de Sant Andreu, both located in Barcelona, Catalonia. These are two linked civil organizations created before the 1985 Water Act, when groundwater was private property. Their members are primarily industrial users and public water supply entities, but also include farmer associations. Affiliation is compulsory for all aquifer users, including those which drain water from structures and buildings. Further to the administrative and legal personnel, they have technical staff that has increased over time. Currently they share a detailed flow and salinity aquifer transport model with the Water Authority of Catalonia in order to facilitate decision-making on aquifer and river water joint use, groundwater recharge operations, and seawater intrusion control. With the exception of the Western Mancha Aquifer User Association, the Spanish Water Administration has so far not succeeded in creating similarly effective organizations in the other aquifers that are *legally* overexploited.

7 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 groundwater is usually much more productive in economic and employment terms 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 for water used than irrigators using surface water, and motivating them to look for more profitable crops and using water more efficiently. The Spanish situation should not be extrapolated to any other areas, especially to developing countries, where the crop value is smaller and the cost of abstracting groundwater may be higher (Llamas & Custodio, 2003).

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, or 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 and to future generations. 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 existing institutional arrangements (both formal and informal) 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 Water Act gave River Basin Authorities the power to limit access to the resource and to regulate use. Following a well established Spanish tradition of user participation in water management, the Water Act created the figure of groundwater users 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 to 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-although not subject to-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 a general solution through regulatory means.

The regulatory measures contained in the 1985 Water Act and its reforms have so far proven to be insufficient to solve the problems resulting from intensive groundwater use. It can be expected that the requirements of transparency and participation that derive from the WFD will contribute significantly to improve the situation of groundwater management in Spain. However, considering the still scarce Spanish tradition in transparency and participation, the success needs strong enforcement of the provisions of the WFD from the EU Commission, or groundwater governance has the risk of continuing to be poor. This means that Universities, research institutions, civil organizations and NGOs have to make an important effort in a short time to participate in the discussions, and assume their responsibility instead of blaming the Government for wrongdoing and poor understanding of problems and solutions.

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