Chapter 9

Groundwater in Spain: Legal framework and management issues

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INTRODUCTION

Spain is a country with a large hydrogeologic potential. As in other southern European countries the water resources, besides urban supply, are used mainly for irrigation and much of the groundwater abstraction is concentrated in a number of intensively exploited aquifers. Groundwater was declared a public domain resource in Spain in 1985, but the real implementation of such a declaration has encountered many difficulties in practice. Because groundwater was a private property before the 1985 Water Act, it was not considered a task for water management agencies and water authorities in Spain. As with all the European Union Member States, Spain is nowadays fully involved in the process of implementing the principles of the European Water Framework Directive (WFD) (European Commission, 2000). Such a process constitutes a unique opportunity to improve groundwater protection and knowledge, and achieve effective management of this resource. However, to adapt the WFD principles to the hydro-climatic and socio-economic context of a south European Mediterranean country is not an easy task. The current paper provides an overview of the hydrogeologic context and groundwater management practices in Spain. The main groundwater "facts and figures" of Spain are introduced first, mainly concerning the hydrogeologic knowledge and groundwater use in the country, with a section on specific technical measures. A summary of the groundwater management context is described afterwards, introducing the institutional and legal framework as well as some basic concepts related to groundwater management, and also a section on groundwater cost issues. Next, a section of discussion about the ongoing process of the WFD implementation in Spain is offered. This paper finishes with a general summary and some conclusions.

GROUNDWATER FACTS AND FIGURES IN SPAIN

Traditionally, only highly-yielding geological formations were officially considered aquifers in Spain. These covered an area of about 180,000 km^2, roughly one third of the country's surface area. However, the WFD characterization goals create pressure nowadays to recognize the occurrence of many groundwater bodies in other geological formations such as igneous and metamorphic rocks of moderate yield but with strategic importance, mainly for small towns and rural populations. Considering these, average aquifer recharge in Spain has been estimated to be about 30,000 Mm^3/year, or about 30% of total water resources available in the country (Ministerio de Medio Ambiente (MMA), 2000). The total amount of water stored in aquifers is probably two orders of magnitude higher that these yearly renewable resources (Sahuquillo *et al.*, 2007). This fact is extremely important for countries suffering frequent severe droughts, as does Spain, because groundwater constitutes a strategic resource that allows maintaining supply and irrigation during dry periods, although this has to be modulated by environmental conservation requirements.

It is estimated that groundwater use in Spain increased from 2000 Mm^3/year in 1960 up to 6500 Mm^3/year nowadays (MMA, 2000). Groundwater use can be very different throughout Spain depending on the differences of climate, geology, population density and relative importance of agriculture. Groundwater becomes the main water source available in the archipelagos (Balearic and Canary islands), in the south-eastern Mediterranean part (Jucar and Segura basins) and in some inner areas such as La Mancha. For example, groundwater pumping in an individual south-Mediterranean basin (the Júcar basin) amounts for 25% of the total amount of groundwater exploited in the whole country.

Approximately 75% of groundwater abstracted is used for irrigation, which is by far the main use of groundwater, as is also 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, although locally the driver has also been the tourism sector and industry. Groundwater irrigates around one million hectares, which is about 30% of the total irrigated area in Spain. Increasing groundwater pumping allows farmers to guarantee their crops in drought years when surface water resources are limited or not available. Even though groundwater provides only 20% of all water applied for irrigation in Spain, it serves 30% of all irrigated areas.This means that in Spain, groundwater-based irrigation is more efficient than surface water-based irrigation, as happens in many other semi-arid countries (Llamas *et al.*, 2001). This can be explained by the fact that groundwater resources are used by private operators, with their full direct cost paid by the users, in contrast to irrigation from surface water, which depends on infrastructure that is often heavily subsidized with public funds (Hernandez-Mora *et al.*, 2007).

Groundwater is also the source of domestic water supply for 35% of the Spanish population (i.e. 14 of the 43 million inhabitants). In some large cities, such as Barcelona, groundwater constitutes a key strategic and carefully managed resource to ensure adequate water supply to the population during dry periods (Niñerola *et al.*, 2009; Custodio, 2009). Spain has the second lowest groundwater use for urban supply of large cities in Europe (Hernandez-Mora *et al.*, 2007), equal to about 19% according to the Ministry of the Environment (MMA, 2007). However, the amount of groundwater use is much higher in small towns. Towns with less than 20,000 inhabitants obtain about 70% of the water supply from groundwater (MMA, 2000). Apart from the average figures, groundwater as a source of domestic water supply is crucial in some particularly semi-arid areas, with a proportion of 51% in the Andalusian Mediterranean Basins, 49% in the Canary Islands (where the rest is mostly desalinated sea

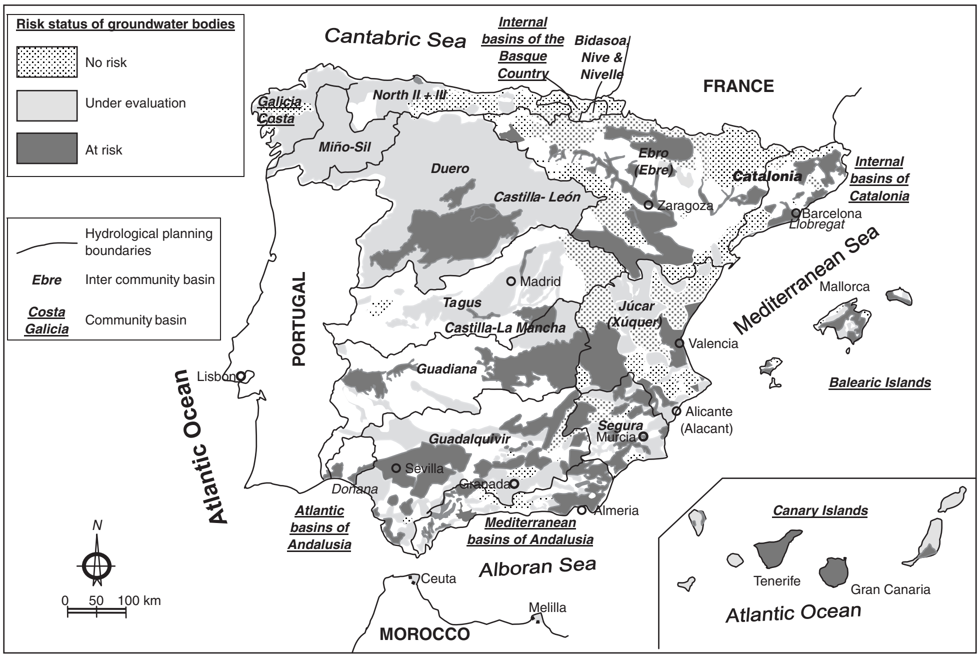

Figure 1 Areas with groundwater bodies in Spain. White areas are devoid of significant aquifers. Shaded areas are the groundwater bodies classifies as "no risk", "under evaluation" and "at risk", relative to the WFD good status to be attained in 2015. The figure is a simplification of maps from the Ministry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

water) or 43% in the Júcar River Basin, and even more in the Balearic Islands. In addition, rural water supply in the humid basins of northwestern Spain relies mainly on groundwater, but this is not considered as groundwater exploitation within the official databases, because they correspond to a myriad of individual small wells and springs, beyond any water exploitation inventory. However, such rural population can be as large as 30% of the total population in some wet regions, such as Galicia or some areas of Asturias, in northwestern Spain.

Following the implementation schedule of the WFD, a report with the main results of the "Initial Characterization Stage" was submitted to the European Union (EU) by the Spanish Water Authorities (MMA, 2006; Lopez-Geta, 2007). According to this report, 699 groundwater bodies have been officially identified in Spain. Considering together quantity and quality aspects, a total of 259 (37%) of these groundwater bodies are classified "at risk" of not attaining the environmental objectives of the WFD by the year 2015, another 184 (26%) are classified "without risk" (they will attain good environmental conditions), and 256 (37%) are awaiting further evaluation to determine their environmental conditions. Figure 1 shows a map with location of the groundwater bodies and their classification. Of the 259 groundwater bodies at risk, 89 have been included for water quantity reasons and the rest due to water quality.

Diffuse pollution, mainly due to high nitrate content, is the most relevant environmental problem identified, affecting 167 groundwater bodies, while saline water intrusion affects 72 groundwater bodies (Lopez-Geta, 2007). Much fewer numbers of groundwater bodies have been classified as being at risk due to point (non-diffuse) pollution. Most probably these figures will increase in the near future when the results of the additional assessment of the 256 pending groundwater bodies are published.

GROUNDWATER MANAGEMENT IN SPAIN

Water management in Spain is based on River Basin Agencies, which were implemented late in the 1920s. This was a great advancement for water management, solving problems created by other territorial divisions. They were established when only one State Government existed. But the current 1978 constitution divides the whole country into Autonomous Communities (called here Regions), with their own Government and exclusive competences in many territorial affairs. This modified the character of the River Basin Agencies or Water Authorities. In order to maintain the river basin administration, when a given hydrological basin is within two or more Regions the water management districts depend on the Ministry of the Environment of the General Government of Spain. When the hydrological basin is entirely located inside a given Region the water management is the full responsibility of the Regional Government, as is the case in Catalonia, Andalusia, the Basque Country, Galicia, and the Balearic and Canary islands. However, a recent transfer of responsibilities of the cross-regional Guadalquivir river basin to Andalusia, under high political pressures, risks breaking down the river basin unit for water management.

The 1985 Spanish Water Act declared groundwater as a public domain resource, as surface water has been since 1866. Previously groundwater was a privately appropriable resource. The total number of groundwater wells, springs and mines (pseudo-horizontal galleries to collect groundwater) is officially reckoned at about half a million, but it is probable that the actual figure may be as high as two million, or even more. The new law left two possibilities to existing groundwater owners: (a) to remain in a transient private regime until 2038 and after that become a public concession, registered in the Public Water Registry, or (b) to remain permanently in a private regime, registering in the Catalogue of Private Waters (Fornés *et al.*, 2005). According to the Water Act, new groundwater exploitations requested after 1986, and changes in the old ones, must be approved by the corresponding River Basin Agency and also inscribed in the Registry of Public Waters. However, after more than 20 years both the Catalogue and the Register are far from being completed. Hundreds of thousands of new wells and boreholes have been constructed since the Water Act of 1985, most of them without submitting any application for approval from the River Basin Authority, so actually they are out of official control. The result is that the actual number of groundwater exploitations in Spain is not known. The public administration did not allocate the needed resources, both human and financial, to implement the provisions of the Water Act. Also the authors of the Water Act did not foresee the complex legal procedures which followed, and the conflicts with the rights already recognized by the Private Property Registry. Actually many of the pre-1985 well owners did not abide by the Water Act and remain illegal or outside the legal framework.

A relevant novelty was that the Water Act foresees the possibility to officially declare an aquifer to be overexploited, even if this concept is unclear and has negative connotations (Custodio, 2002). Overexploitation can be determined based on both quantity and quality indicators. Up to date 16 aquifers have been officially declared overexploited. The Water Act gives River Basin Agencies broad powers for the management of aquifers declared overexploited, requiring that they draw up a management plan and determine annual pumping regimes. Restrictions must apply to users in both the public and private property regimes and no new pumping permits can be granted. All users in the aquifer are required to organize themselves into Groundwater User Associations, which represent the interests of the users and should 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 5 of the 16 aquifers declared overexploited, and management plans have only been drawn up in 3 of them. The actual technical reasons for this failure are unclear, but are probably linked to the reluctance of groundwater users and stakeholders to form associations and share responsibilities, and also to some resistance and fears of losing their power to the staff of the Water Authorities. On the contrary, there are other aquifers not declared overexploited which have serious problems, both of quantity and quality (MMA-ITGE, 1997). It seems that the decision to declare an aquifer overexploited is partly dependent on political and socio-economic factors that have nothing to do with technical and hydrogeologic data.

The assessment of the environmental impact of intensive groundwater exploitation is not as straightforward as it is often stated to be. As an example, the development of heavy pumping in La Mancha area (central Spain) has produced serious environmental impacts on wetlands and on the Júcar River flow. On the other hand, there are several aquifers in semi-arid south-western Spain where intensive exploitation has induced significant groundwater drawdown, but with relatively low environmental impact, limited to some small wetlands and spring flows. However groundwater use in these areas has produced huge economic and social benefits (Sahuquillo *et al.*, 2009). As stated by Llamas and Custodio (2003), in the cases of groundwater-intensive use general rules should be applied with caution, since appropriate solutions are heavily site-dependent, both in terms of physical and socio-economic considerations. Proactive measures are needed in order to effectively solve the problems associated with the intensive use of groundwater. Sound cost and benefits assessments, stakeholder education and participation, and the implementation of effective institutions for collective groundwater management are proposed as the more relevant actions to be promoted. After more than 20 years since enactment of the Water Act, it is apparent that the legal tool of official declaration of aquifer overexploitation does not provide by itself any warranty for effective improvement of groundwater management. Proper groundwater management is linked to the political and social willingness, in combination with adequate technical advice and monitoring, i.e. it is more than just a pure matter of laws and regulations.

User participation in water management has been traditionally understood in Spain as the right of irrigators to organize self-governing institutions for the management of surface water irrigation systems. However, the 1985 Water Act and its subsequent reforms expanded the concept of users to include groundwater users and representatives of other interests besides irrigators. It established user participation quotas in the different participatory boards of River Basin Agencies: the Governing Board, User Assembly, Public Works Board, Aquifer Management Boards, and Dam Management Boards. Stakeholders are also represented in the basins' planning body, known as the Water Council. There exist some examples of successful groundwater user associations and effective cooperation between users and water authorities, but they are still few (Hernandez-Mora *et al*., 2003). A remarkable example of success in participatory management in Spain is the Water Users Association of the Llobregat's Lower Valley and Delta. This Water Users Association was created in 1975, long before the 1985 Water Act, and involves irrigators, industries, water supply companies, water management agencies and other users, although most groundwater abstraction is by drinking water companies and factories, endowed with well trained staffs. They have their own technical department, which promotes effective monitoring and control in the aquifer, and active technical measures for aquifer protection and management such as artificial recharge, and good working relationships with the Water Authority of Catalonia (Niñerola *et al*., 2009; Custodio, 2009). This successful example, and that of other Associations upstream (the Cubeta de Sant Andreu), contrasts with several unsuccessful attempts that have failed after official declarations of aquifer overexploitation according to the Water Act. Once again, it becomes apparent that having a good or bad law is not the most important factor to succeed in proper groundwater management practices. Bottom-up initiatives have proved to be more successful in many instances than legislative approaches.

Changes introduced by the 1985 Water Act and the successive reforms were positive and necessary to deal with the challenges resulting from the more intensive use of groundwater resources, although making groundwater public is neither a necessary condition, nor a guarantee for better management. The Water Act implementation has encountered several difficulties. Two of them are worth highlighting. 1) Basin Agencies lacked any experience in groundwater management and consistently have had insufficient 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, maintenance and management responsibilities to their new broader water management goals. Also, the staff of the River Basin Agencies has been historically dominated by civil engineers, who lacked expertise in other areas (economics, ecology, hydrogeology, geography, education, sociology, etc.) necessary for addressing their new responsibilities. 2) 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, and have not been updated. Hence, reliable records of existing groundwater uses and total extraction volumes are not available, which makes effective water management difficult. Some River Water Agencies, such as the Water Agency of Catalonia and the Ebre and Júcar River Basin Authorities, are trying to catch up despite their limited resources.

TECHNICAL GROUNDWATER ACTIVITIES TO REDRESS WATER SCARCITY AND THE EFFECT OF DROUGHTS

In order to redress water scarcity and the effect of droughts in different areas of Spain, some technical activities have been carried out and recommendations are being

Table 1 Artificial recharge in the area of Barcelona (Custodio *et al*., 1979, 2009; Niñerola *et al*., 2009).

Type of recharge	*Applied water*	*Method*	*Initiation*	*Site*	*Operation and purpose*
Enhanced infiltration	River	River bed scraping	1949	Llobregat Low Valley	When water and river flow are adequate. To restore levels
Basin infiltration	River	Basins in the river bed	1975	Cubeta de Sant Andreu	To restore levels
Basin infiltration	River and treated waste water (with reduced salinity)	Lateral basins to the river bed	2009	Llobregat Low Valley	Just starting. Restore recharge
Well injection	Canal water	Wells with special clean up system	1954	Besós	Now ceased. Treatment of canal water in the ground
Well injection	Treated water	Line of simple purpose and dual purpose wells	1969	Low Llobregat Valley	When there is excess potable water. To increase aquifer storage
Well injection	Treatment waste water with salinity reduction	Line of wells (up to 14)	2007	Llobregat Delta	Under extension. To reduce saline water intrusion

implemented. They include waste water reuse after adequate treatment, salinity reduction by applying membrane technology according to the intended use (agricultural irrigation, irrigation of golf courses, sports facilities and gardens, municipal uses allowing low quality water, industrial supply, artificial recharge of aquifers), and desalinization of seawater and brackish and saline groundwater. Also, dual water supply systems in towns are viewed favorably, even if not still fully implemented. In what follows, different groundwater related technical activities are described.

Artificial recharge has been applied since late in the 1940s in the area of Barcelona (Table 1), and is now being extended, with projects in other areas of Catalonia. Occasional aquifer recharge activities have been carried out in other areas such as Palma de Mallorca plain (treated waste water), Fataga lower valley (Gran Canaria, episodical runoff) and Dehesas de Guadix (Granada, treated waste water), and are being considered to restore aquifer storage in Madrid by means of deep well injection (potable water).

Alternate conjunctive use of surface water and groundwater is a common practice in areas prone to droughts, as is the Mediterranean region of Spain, both for urban water supply and for irrigation. In most cases, the conjunctive use schemes and operation rules have been proposed and handled by the users since the 1960s. In other cases, canals have been built by the Water Authority to substitute groundwater by surface water in areas partly irrigated by groundwater.

When diverted surface water is insufficient to irrigate the entire area concerned and varies from dry to wet years, alternating conjunctive use is instigated. Recently this practice has been legally approved in the Valencia Region, where in more than one third of the irrigated area alternate conjunctive use is applied, and additional conjunctive use schemes have been proposed. In alternating conjunctive use, groundwater is used more in dry periods whereas its use decreases in wet years. Conversely, surface water use increases at times when there is more water available in rivers or stored in surface reservoirs. This strategy enables water supply to be increased without the need to either augment surface storage or resort to artificial recharge, thanks to the use of natural aquifer storage. Storage is provided between extremes in the aquifer water levels, which are high at the end of wet periods and low at the end of dry ones. Losing rivers and leaking surface storage sites can be helpful for the conjunctive use management strategy (Sahuquillo, 2002; Sahuquillo and Lluria, 2003).

Examples are the management of water in the area of Barcelona, which includes the Llobregat, Besós and Ter river basins and the Llobregat, Barcelona Plain and Besós aquifers. The Catalan water authorities have plans to enlarge this scheme in the future. Another interesting example is the Mijares river basin, north of Valencia, involving two losing reservoirs that recharge the aquifers of the Mijares plain and delta (Sahuquillo, 2002).

It is worth mentioning that a common practice in some parts of Spain is to locate wells within karstic springs. In such cases, the effect of pumping on spring flow is felt within a short period of time. As pumping is carried out to increase water availability provided by the spring when natural flow falls below water demand, the spring dries out and soon all the water required must be pumped. Under this type of operation, supply can be augmented above the natural flow of the spring during the irrigation season. In most cases, wells near springs have provided a very high yield, up to several hundreds of liters per second. Thus, the usually large variations in flow in many of these karstic springs can be accommodated to water demand. Alternate use of springs and wells solved the acute supply problem suffered by a very important tourist area near Alicante on the Mediterranean coast of Spain.

The Department of Hydraulic and Environmental Engineering of the Polytechnic University of Valencia has developed a Support Decision System named AQUATOOL to optimize and simulate complex systems, which include conjunctive use (Andreu *et al.*, 1989). This has been applied in many Spanish basins, handling several dozen dams, aquifers, and demand areas, taking into account rivers, canals, aqueducts, and aquifer-river interaction. Simulation of distributed aquifers and their interaction with rivers is explicitly carried out using the "eigenvalue method" in a direct and easy way (Sahuquillo, 1983; Andreu and Sahuquillo, 1987). AQUATOOL can also be used to consider environmental restrictions (Murillo and Navarro, 2008).

GROUNDWATER ECONOMICS AND COST ISSUES

In Spain, in general terms, groundwater is used intensively because the direct benefits users obtain greatly outweigh the direct costs of producing that water. However, the associated indirect (external) costs 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. The price of the water resource taken from Nature is considered negligible in cost reckoning. As a result, the overall costs of intensive groundwater use do not motivate changes toward more economically and socially efficient abstraction. This is why the WFD requires the calculation of both the direct water service costs, as well as environmental and resource costs. Environmental costs will have to be calculated as the cost of applying the corrective measures to achieve the environmental goals of the WFD. This is also needed to accurately assess the economic viability and social desirability of different pumping regimes. In Spain, the work done so far to estimate the cost of groundwater use has focused only on the estimation of the direct service costs. Information about indirect costs is still very scarce.

The average groundwater abstraction costs (year 2003) at the wellhead were estimated by the Ministry of the Environment as 0.08 €/m^3 for urban water supply and 0.12 €/m^3 for irrigation, with a range for urban water supply of 0.03–0.37 €/m^3, and 0.04–0.74 €/m^3 for irrigation. It is worth noting that other direct costs have to be added to obtain the total cost of water use, such as those linked to irrigation infrastructure and distribution.

Issues related to irrigation

Historically, public subsidies have been granted for the conversion of rainfed agriculture to irrigation. Regional governments as well as the State Ministry of Agriculture continue to give economic assistance for the modernization of the irrigation infrastructure, mostly using surface water. However, most often, Spanish farmers pay for all direct costs associated with groundwater irrigation, and even taxes that surface water users do not pay.

Since groundwater users never pay for environmental or resource costs, there is no relationship between water scarcity and cost of the resource, except when that scarcity requires deepening existing wells or drilling new ones. Quality of irrigation water is rarely considered except in cases where this has a clear influence on crop yield and sustainable use of soil.

Existing data indicate that in Spain, even where piezometric levels are very deep, the costs of energy consumption only represent a small portion of an average farmer's income and therefore are not a deterrent to deeper abstraction levels or to changing current pumping patterns. This is due to the growing of cash crops such as fruits and vegetables under plastic or in greenhouses. This may not be the case for other basic crops. As an example, in La Mancha Region, in south–central Spain, Llamas *et al.* (2001) estimated that the energy cost of pumping water from a depth of 100 m is about 84 €/ha/year, or about 5% of a local average farmer's gross income. However, the Spanish situation cannot be extrapolated to developing countries since the cost of groundwater abstraction may represent a higher fraction of the crop value (Llamas *et al.*, 2007).

It is apparent that if the full cost recovery required by the WFD is applied to intensively used aquifers, many existing groundwater uses would not be economically viable. Likewise, the individualistic nature of groundwater abstractions, together with the inadequate enforcement of existing rules and regulations, has resulted in not taking into account the scarcity value, and has 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 in Spain.

Evaluation of existing data (Hernández-Mora *et al.*, 2007), even if patchy and incomplete, shows that:

1 Average gross economic productivity of irrigated agriculture is 4.4 times that of rainfed agriculture, although there are significant regional differences from 1.1

times with profitable rainfed crops to as much as 50 times (or 12 €/m^3) for intensive horticultural production under plastic and in greenhouses in southeastern Spain.

2 In areas that rely on groundwater sources to produce highly profitable horticultural crops, the European Common Agricultural Policy (CAP) subsidies represent as little as 1% of farmers' incomes, when for surface water use they can be as much as 50%.

3 Average water services costs to the farmer vary greatly between surface water users (106 €/ha/year) and groundwater users (500 €/ha/year).

In Andalusia (Corominas, 2001; Vives, 2003), irrigated agriculture using groundwater is economically over five times more productive than agriculture using surface water, and generates two to three times the employment per unit volume of water used. This is attributed to the greater control and supply guarantee provided by groundwater (more efficient irrigation techniques), the greater dynamism of the farmer that has sought out his own sources of water and bears the full costs of drilling, pumping and water distribution, and the fact that the higher financial costs borne by the farmers motivate them to seek more profitable crops that allow them to maximize the return on their investments.

The availability of groundwater allows agriculture to survive severe drought sequences when surface water supply dwindles out. This explains the widespread use of alternative conjunctive use of surface and groundwater for irrigation, using cheaper surface water when available, and applying groundwater in other periods.

Issues related to domestic water supply

Urban water users pay for treatment and distribution costs, but do not pay for the resource itself or for external or opportunity costs. Home consumers in Spain paid, in 2004, in the range of 0.80–1.72 €/m^3, with an average tariff of 1.17 €/m^3, which often includes sanitation. The available statistics often do not differentiate between surface and groundwater sources. Usually, these tariffs do not cover the cost of the necessary infrastructure associated with the service, which is normally paid for by the state or local government general revenue. On average, they cover 80% (57–95%) of the total cost of providing the service. The comparatively low tariffs that urban consumers pay in Spain do not encourage savings or good management, resulting in inefficient distribution networks. However, improvements are being introduced. The situation is good when public supplies are large or are managed by technically competent utilities, as in Barcelona and Madrid, where actual water distribution losses are as low as around 10%.

Total household expenditure on water supply services is so low (0.09 €/day for the average 167 liters per day per person of water consumed by domestic users) that water fees are hardly an incentive for lower consumption. Water conservation campaigns are often much more effective than raising prices in reducing household water consumption. Water conservation campaigns have been effective in Madrid and Barcelona in reducing water use per person while maintaining a good service.

In the case of domestic water supply, groundwater excess hardness, and even excess salinity or nitrate content, have to be addressed through treatment prior to distribution, at a high cost. Often poor quality of groundwater has resulted in an increased use of bottled water, at least for drinking and cooking. Reliable data on the resulting increased costs to society are not available.

The special case of the Canary Islands

The Canary Islands are faced with the need to be self-sufficient in terms of water resources leading to the situation that groundwater becomes a resource of great strategic importance. Groundwater provides almost 80% of all water resources in the islands. Surface water is only a small contribution and only in some of the islands. The general scarcity of water resources relative to agricultural, urban and tourist demand has resulted in a unique water supply and use system characterized by the prominent role of the private sector in the exploration, 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 wastewater 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, although the public sector has recently invested in regulation ponds and transportation canals, sometimes in conflict with the private sector. Agriculture is responsible for the consumption of more than 60% of all water used.

Water pricing

Municipal water supply prices have to be approved by the corresponding municipality (the ultimate responsible entity) or a consortium of municipalities, under the control of the Regional Government, or through the Water Authority (especially when public investment is important), after a proposal and negotiation with the supply company, being it public or private (a concession).

Agriculture plans are the responsibility of Regional Governments, adapting to the general plans set by the Ministry of Agriculture (Garrido *et al.*, 2006), which has recently been joined to the Ministry of the Environment. Pricing is set by the River Water Authorities when they manage the water works, and have to be approved by their regulatory councils. In the case of private undertakings, which most groundwater exploitations are, the price is set in an imperfect free market, without public involvement, although the public sector may compete by providing water, transportation, distribution, and storage means, releasing water in critical moments, or guaranteeing the quality.

IMPLICATIONS OF THE EUROPEAN WATER FRAMEWORK DIRECTIVE

The WFD (European Commission, 2000) provides a framework for the protection, improvement and sustainable use of all water bodies in the environment across Europe, from source to sea. These water bodies include surface, underground and coastal waters. The main aim of the Directive is to protect and improve the water environment. This includes preventing the deterioration of aquatic ecosystems and, where possible, restoring ground and surface waters to achieve a "good status" by 2015. Subsequently, the European Parliament approved the daughter Groundwater Directive on the protection of groundwater against pollution and deterioration, GWD (European Commission, 2006) which, while respecting the requirements and terms of the WFD (European Commission, 2000), explicitly reinforces key aspects dealing with groundwater.

According to Sahuquillo *et al.* (2007), two different sets of actions are required in order to achieve a proper implementation of WFD: (1) technological actions, and (2) management and legal actions. In this way, the process is proceeding in parallel, from the transposition of the WFD into Spanish law, which has been recently done, to the technical work and public participatory activities being carried out by the different River Basin Agencies and other water research and management institutions, under the supervision and coordination of the Ministry of the Environment. From a legal standpoint, the first legal reform of the 1985 Water Act 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. Two partial reforms followed, now integrated into a combined legal text. However a new, better adapted and updated Water Act is demanded by many water administrators and users.

As pointed out in Hernandez-Mora *et al.* (2007) 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 to it, and is the responsibility of each country. 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 European Mediterranean countries, where excessive groundwater abstraction with its potential impact on water quality, stream flows, and wetlands has been the primary concern. If WFD provisions are 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, not only by the 2015 deadline, but also by 2021 and 2027 if extensions are agreed for some groundwater bodies based on detailed studies. As pointed out by Llamas and Garrido (2007), this situation may be caused by the insufficient representation of European Mediterranean experts in the preparation of the WFD, which was mostly influenced by central and western European water issues. In Spain, as in other semiarid Mediterranean countries of southern Europe, about 80% of the water is used for irrigation and intensive use of groundwater is a common practice. While water quality problems are indeed important in the Mediterranean countries, it must also be taken into account that effective actions to achieve a good chemical and ecological status of the groundwater are much more difficult to implement in the Mediterranean countries than in other central and north European humid and temperate countries. Even under natural groundwater conditions some southern European areas may not be able to comply with the proposed objectives. The WFD also states clearly (article 4) that Member States shall implement the measures needed to prevent or limit the input of pollutants into groundwater and to prevent the deterioration of all groundwater bodies. However, restoration of contaminated aquifers in semiarid regions can be an extremely costly, long-term and technically difficult task in practice. The challenge for the scientific-technical, political and social stakeholders in the southern European countries is to find paths to achieve an effective implementation of WFD principles in their specific hydro-climatic and socio-economic context.

SUMMARY AND CONCLUSIONS

Spain is among the most arid countries in the European Union, but has a large hydrogeologic potential. Annual aquifer recharge in Spain has been estimated to be about 30,000 Mm^3, which amounts to 30% of the total water resources available. Current groundwater use in Spain amounts to 6500 Mm^3/year, mainly used for irrigation of about 1 million hectares, which corresponds to 30% of the total irrigated surface of the country. Groundwater-based irrigation shows higher economic and employment efficiency than irrigation based on surface water, which is heavily subsidized.

A total of 699 groundwater bodies have been identified in Spain during the "Initial Characterization Stage" of the implementation works of the WFD. Of these groundwater bodies, 259 (38.65%) are classified "at risk" of not achieving the environmental objectives of the WFD by the year 2015. Diffuse pollution, mainly due to high nitrate content, is the main identified environmental problem, affecting 167 groundwater bodies, and saline intrusion, which affects 72 groundwater bodies. It is expected that these figures will increase in the near future when the results of the additional assessment of the 256 bodies pending evaluation of groundwater are published.

Groundwater in Spain has been a public domain resource since 1985. The changes introduced by the 1985 Water Act and different successive reforms were needed to deal with the challenges resulting from the intensive use of groundwater resources. However, the implementation of the Water Act has encountered many difficulties, which in some ways continue to this day. River Basin Agencies lacked experience in groundwater management and have consistently been short of sufficient human and financial resources to deal with their newly acquired responsibilities. They have also had difficulty shifting their focus from traditional water infrastructure development and management responsibilities to their new broader and multiscoped water management goals.

The WFD provides a framework for the protection, improvement and sustainable use of all water bodies in the environment across Europe, from source to sea. This has been incorporated into the Spanish Water Act, following the subsidiarity principle. The main aims of the Directive are to protect and improve the water environment, and to achieve the "good status" of all waters by 2015. The WFD states that groundwater abstraction should not cause a significant environmental impact on the connected surface water bodies. If this provision is strictly enforced, many groundwater-intensive developments in Spain may have to cease. The challenge for the technical, political and social stakeholders in the southern European countries is to find appropriate paths for the effective implementation of the WFD principles in their specific hydro-climatic and socio-economic contexts.

REFERENCES

Andreu J. and Sahuquillo A. (1987) 'Efficient aquifer simulation in complex systems', *Journal of the Water Resources Planning and Management Division,* ASCE 113(1): 110–129.

Andreu, J., Capilla, J. and Sanchís, E. (1996) 'AQUATOOL, a generalized decision support system for water-resources planning and management', *Journal of Hydrology*, 177: 269–291.

Corominas, J. (2001) 'El papel económico de las aguas subterráneas en Andalucía' [Economic role of groundwater in Andalusia]; in: Hernández-Mora, N. and Llamas, M.R. (eds.) *La Economía del Agua Subterránea y su Gestión Colectiva*, 111–139, Madrid: Mundi–Prensa/Fundación Marcelino Botín, (in Spanish).

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

Custodio, E. (2009) *Utilització de les aigües subterrànies a Catalunya i recuperació d'aqüífers: aspectes bàsics, implicacions econòmiques i integració* [Groundwater use in Catalonia and aquifer reclamation: basic aspects, economic implications and integration], Nota d'Economia 141–163, Barcelona: Generalitat de Catalunya (in Catalan).

Custodio, E., Isamat, F.J. and Miralles, J.M. (1979) 'Twenty five years of groundwater recharge in Barcelona (Spain)', *Intern. Symp. on Artificial Groundwater Recharge*, Dortmund. DVWK Bull 11, 171-192, Hamburg-Berlin: Verlag Paul Parey.

European Commission (2000) *Directive 2000/60/EC* of 23 October 2000 of the European Parliament and of the Council, known as Water Framework Directive.

European Commission (2006) *Directive 2006/118/EC* of 12 December 2006 of the European Parliament, Daughter Directive to the WFD (2000) on the Protection of Groundwater Against Pollution and Deterioration, known as the Groundwater Directive.

Fornés, J.M., de la Hera, A. and Llamas, M.R. (2005) 'La propiedad de las aguas subterráneas en España: la situación del Registro y del Catálogo' [Groundwater property in Spain: the present situation of the Register and the Catalogue], *Ingeniería del Agua*, 12(2): 125–136 (in Spanish).

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

Hernandez-Mora, N., Martínez-Cortina, L. and Fornés, J. (2003) 'Intensive groundwater use in Spain', in: Llamas, M.R. and Custodio, E. (eds.), *Intensive Use of Groundwater: Challenges and Opportunities*, Chapter 19, 387–414, Netherlands: Balkema.

Hernández–Mora, N., Martínez Cortina, L., Llamas, M.R. and Custodio, E. (2007) *Groundwater issues in southwestern EU member states: Spain country report*, European Academies of Sciences Advisory Council (EASAC), Madrid: Fundación Areces.

Llamas, M.R., Fornés, J.M., Hernández-Mora, N. and Martínez Cortina. L. (2001) *Aguas subterráneas: retos y oportunidades* [Groundwater: challenges and opportunities], Madrid: MundiPrensa /Fundación Marcelino Botín, (in Spanish).

Llamas, M.R. and Custodio, E. (2003) 'Intensive use of groundwater: a new situation that demands proactive action', in: Llamas, M.R. and Custodio, E. (eds.), *Intensive Use of Groundwater: Challenges and Opportunities* Chapter 1, 13–31, Netherlands: Balkema.

Llamas, M.R. and Garrido, A. (2007) 'Lessons from intensive use in Spain: economic and social benefits and conflicts', in: Giordano, M. and Villholth, K.G. (eds.), *The Agricultural Groundwater Revolution: Opportunities and Threats to Development* (2007), 266–295, Wallingford: CAB International.

Lopez Geta, J.A. (2007) 'Estado actual de la implementación de las Directivas en España [Current status of WFD implementation in Spain]' in: *Las Aguas Subterráneas en España ante las Directivas Europeas: Retos y Perspectivas*, Asociación Internacional de Hidrogeólogos-Grupo Español, (in Spanish).

MMA (2000) *Libro blanco del agua en España* [White book of water in Spain], 1–637, Madrid: Secretaría de Estado de Aguas y Costas, Ministerio de Medio Ambiente (in Spanish).

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* [Summary of the information submitted by Spain to comply with articles 5 and 6 of the WFD concerning groundwaters], Memoria, 1–85, Madrid: Dirección General del Agua, Ministerio de Medio Ambiente, (in Spanish).

MMA (2007) *El agua en la economía española: situación y perspectivas* [Water in the Spanish economy: situation and perspectives], Working Document (internal), Madrid: Ministerio de Medio Ambiente, (in Spanish).

MMA-ITGE (1997) *Catalogo de acuíferos con problemas de sobreexplotación o salinización* [Catalogue of aquifers with overexploitation or salinization problems], 1–43 & Appendix, Madrid: Ministerio de Medio Ambiente/Instituto Tecnológico Geominero de España, (in Spanish).

Murillo, J.M. and Navarro, J.A. (2008) *Las aguas subterráneas en la investigación y la gestión hídrica medioambiental: uso conjunto y caudal ambiental: aplicación al sistema de aprovechamiento del Quebrajano-Víboras* [Groundwater in environmental water reconnaissance and management: conjoint use and environmental flow: application to the Quebrajano-Víboras water system], 1–235, Instituto Geológico y Minero de España, (in Spanish).

Niñerola, J.M., Queralt, E. and Custodio, E. (2009) 'Llobregat delta aquifer', in: Quevauviller, Ph., Fouillac, A.-M., Grath, J. and Ward, R. (eds.), *Quality Assessment and Monitoring*, Wiley (in press).

Sahuquillo, A. (1983) 'An eigenvalue numerical technique for solving unsteady groundwater models continuously in time', *Water Resources Research*, 12: 87–93.

Sahuquillo, A. (2002) 'Conjunctive use of surface water and groundwater', Chapter E2-09-08-06, in: Silveira, Luis (ed.), 'Theme 2.9 Groundwater', in: *UNESCO Encyclopedia of Life Support Systems* (EOLSS), Oxford: Eolss Publishers.

Sahuquillo, A. and Lluria, M. (2003) 'Conjunctive use as potential solution for stressed aquifers: social constraints', in: Llamas, M.R. and Custodio, E. (eds.), *Intensive Use of Groundwater: Challenges and Opportunities*, 1–478, Netherlands: Balkema.

Sahuquillo, A., Custodio, E. and Llamas, M.R. (2009) 'La gestión de las aguas subterráneas' [Groundwater management], *Tecnología del Agua*, March and April 2009, 305: 60–67 and 306: 54–67, (in Spanish).

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