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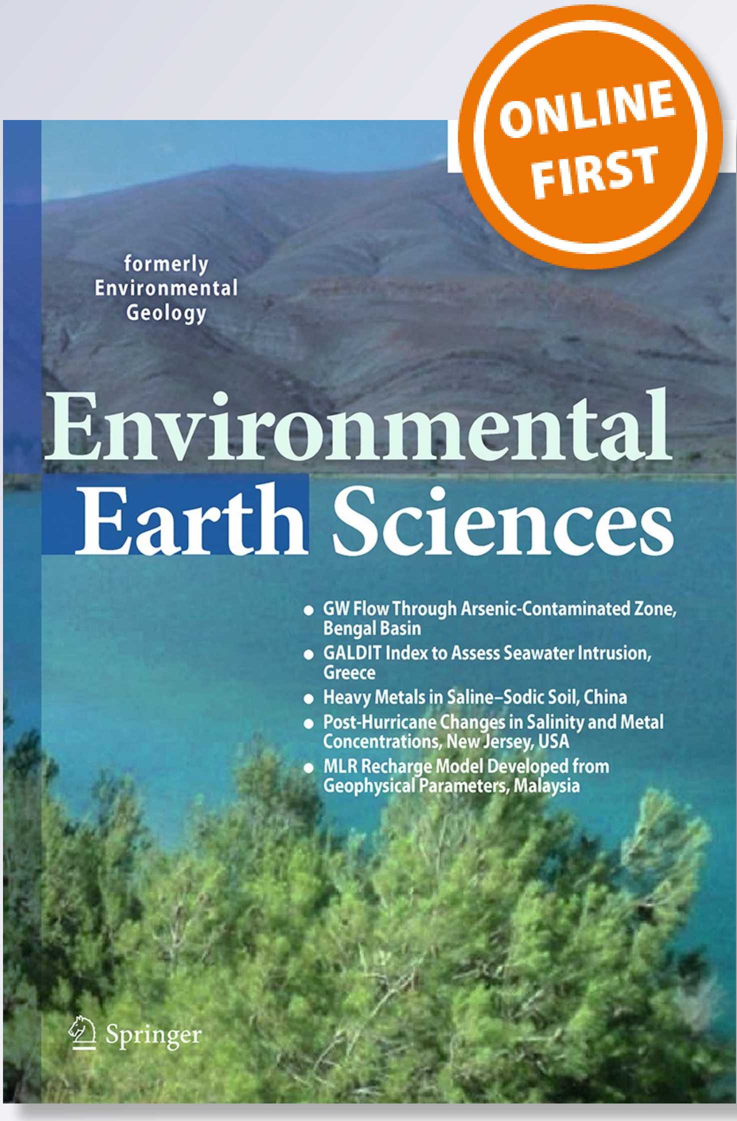

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THEMATIC ISSUE

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Abstract For many years there has been a general consensus on the need to consider surface and groundwater together to achieve the more general paradigm of integrated water resource management. Nevertheless, in many countries this goal is far from being achieved in practice as in Spain, presented here. Much of continental and insular Spain conditions are semi-arid, making it the most arid country in the European Union (EU). The use of groundwater for urban water supply and irrigation is therefore relevant, especially along the Mediterranean coast, the south and the center, and in the islands. There is however divergence between the reality of groundwater use and the attitude of many policy makers who do not consider it and favor other water resources, traditionally surface water and recently seawater desalination, in many parts of Spain. This mindset of the governmental water planners influenced the 1985 water code and also affected the implementation in Spain of the EU Water Framework Directive 2000. Although some improvements have been made, overall groundwater management is still chaotic in some aspects. A significant handicap is that although in theory groundwater is in the public domain, most of it remains in private hands. Water planning also relies on concessions and this creates stressful situations and problems which are difficult to solve. In this paper some significant aspects of groundwater policy are outlined, such as its role in mitigating the effects of climate variability and change, the water mining of aquifers, the associations of groundwater users, and the groundwater ecosystems.

Keywords Groundwater · Water management · Water planning · Water law · Water policy · Integrated water resource management · Spain

Introduction and background

Spain, with an area of over half a million km^2, extends over a large part of the Iberian Peninsula and includes two main archipelagos, the Balearic Islands in the Mediterranean Sea and the Canary Islands in the Atlantic Ocean, plus two enclaves in North Africa. As one of the European Union (EU) Member States it has to adapt its own legislation to the general rules of the EU. Spain is a complex, varied territory in SW Europe, comprising humid and semi-arid areas with some near-arid areas, covering more than two-thirds of its land area, mostly in the center, along the eastern and southern coastal areas and in the archipelagos, with a high percentage of the population and the corresponding industry and services, an important tourism industry and especially rich well-developed intensive agriculture based on irrigation. Spain is the most arid of the EU members, with a high water demand leading to unique situations that need special consideration. The current

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groundwater abstraction volume in Spain is around 7 km^3/year and the recharge volume is around 30 km^3/year.

Water supply for urban and irrigation uses has been problematic in Spain since pre-Roman times, with different solutions adopted depending on the moment in time, technological capacity, social response and political situation. These ways of addressing the problems and their solutions consist of physical infrastructures and installations but also rest on social and legal instruments, with an important Roman and Arab heritage. As is the case in most countries, surface water was considered a priority but some groundwater developments were also implemented, although until the late nineteenth and early twentieth centuries these were only of local significance due to poor understanding and technological difficulties.

This paper considers almost exclusively the groundwater policy in Spain taking into consideration the global situation, with noticeable differences throughout the country. There are several factors that make the Spanish case relevant, including (1) the size and population: 500,000 km^2 and almost 50 million inhabitants, (2) the dramatic political and economic changes over the last 50 years, with income per capita increasing from US$ 300 to 30,000 GNP/person/year, and (3) the understanding of water use and its socioeconomic implications.

The aim here is to provide an overview of the past and present strengths and weaknesses of Spanish groundwater policy, to enable a road map to be designed for future, more efficient water governance. It is important to take into account that considerations and figures at country level and even at a regional level are poor and biased representations of reality as circumstances vary dramatically from area to area.

Obviously, Spain is not a unique case study for the analysis of the role of groundwater in global water policy. There are excellent general publications on the global issues. Those of the International Groundwater Resources Assessment Centre (IGRAC, www.un-igrac.org) deserve a special mention, e.g. the report by Vrba and van der Gun (2004) and the book by Margat and van der Gun (2013). Perhaps the most interesting groundwater problems and advantages of its use are found in India, the country that uses almost 50 % of global groundwater withdrawal (Llamas et al. 2006; Shah 2009). The global situation and how it affects sea level has been dealt with by Konikow (2013). The European Academies of Sciences Advisory Council (EASAC 2010) analyzed the groundwater situation in the southern EU member states, including Spain (Hernández-Mora et al. 2007).

The EU Water Framework Directive of year 2000 (WFD 2000) has had a beneficial effect on the attention paid to groundwater in Spain, but cannot be considered in detail within the scope of this paper.

The beginning of groundwater development and the intensive use of groundwater in Spain

Until the mid-twentieth century, when Spain entered a new era of economic development, governmental water policy was based mainly on the artificial regulation of river flows and to a much lesser extent on groundwater extraction. Surface water was generally regulated on a statewide basis, except for hydroelectricity production. In contrast, groundwater was normally considered as a mineral resource to be used by whoever 'tapped or discovered it'. There was little understanding of the subterranean part of the water cycle and the technology required for drilling water wells and for the extraction of groundwater was underdeveloped, as is recognized in the book edited by López-Geta and Fornés (2013).

The history of hydrogeology and groundwater development in Spain has been the subject of several studies, such as Martínez Gil (1991) and Custodio (2013a, b) and the many relevant documented references cited in them. Although early technological developments date from the late nineteenth century, intensive development started in the mid-twentieth century, first on the Canary Islands and the Guadalentín valley for irrigation and for industrial supply and urban supply around Barcelona and later in the 1950s for new intensive irrigation developments, most of them in southeastern Spain.

The considerable scientific and technological changes from the 1950s and 1960s onwards had a significant impact, although the construction of large dams to regulate water was still a predominant feature of government policy. In the late 1940s, the *Instituto Nacional de Colonización* (INC, National Institute for Settlement, later transformed into the IRYDA, Institute for Agrarian Reform and Development) started to sink a large number of drilled wells using modern machinery to boost agricultural development in new areas promoted by the government.

In the early 1960s, a detailed study in the Barcelona area (lower valley and delta of the Llobregat and delta of the Besós) was carried out by the *Servicio Geológico de Obras Públicas* (SGOP, Geological Service of Public Works) and the *Comisaría de Aguas del Pirineo Oriental* (CAPO, Eastern Pyrenees Water Authority), both parts of the Ministry for Public Works, and was afterwards extended to the Eastern Pyrenees river basins (REPO), leading to new scientific approaches and technology.

In the 1960s, the Ministry of Agriculture, in coordination with the *Instituto Geológico y Minero de España* (IGME, Geological Institute of Spain), and supported by the United Nations Food and Agriculture Organization (FAO), initiated a series of hydrogeological studies and successful experimental operations with groundwater in different regions of southeastern and southern Spain, mostly intended for agricultural development. These projects were originally government-run but local farmers soon realized the importance of the results and started their own new irrigation projects using groundwater. These private developments were generally subsidized by the Ministry of Agriculture, but in other areas were financed by private investment.

At the same time, the IGME embarked on systematic studies of aquifers in Spain, through the *Plan de Investigación de Aguas Subterráneas* (PIAS, Groundwater Investigation Plan), which encouraged the setting up of new irrigation schemes and urban water supply systems using groundwater. The latter were the specific aim of the *Plan Nacional de Abastecimiento a Núcleos Urbanos* (PANU, Urban Supply National Plan) drawn up by the same institution.

Studies of the hydrogeology and groundwater resources of the volcanic Canary Islands were also undertaken by the SGOP and UNESCO (Project SPA-15), which provided new advanced knowledge on these particular hydrogeological conditions (Cabrera et al. 2011).

In the period 1950–1970, 10 years later than in southwestern United States and at the same time as in Mexico and France (including the French-administered territories in North Africa), a dramatic development took place in Spain, with groundwater becoming an important fresh water source for irrigation and for the water supply of many large towns in the Mediterranean area and in the archipelagos. Even so, Spain is one of the countries in Europe that uses the lowest percentage of groundwater for urban water supply (Llamas et al. 2001).

At the level of the highly centralized government of the time, the root of the problem can be outlined as follows. In the second half of the nineteenth century in France, the neighboring country of reference for Spain, groundwater from the *sables verts* of the Cenomanian aquifer was the solution for the acute water supply problems of Paris. The Corps of Mining Engineers proposed the same solution for Madrid's water supply, while the Corps of Civil Engineers maintained that the solution was to build surface water reservoirs in the nearby Central Range and pipe the water to Madrid. Various deep wells were sunk around Madrid, but the outcome was not satisfactory as the existing geological knowledge at the time did not enable a sufficient understanding of the problem and drilling techniques were still underdeveloped. In fact, the water wells drilled in the 1970s, with modern technology, can yield up to 100 L/s. The result was the creation of the *Canal de Isabel II*, designed to supply Madrid with surface water. Groundwater, as an important water supply source, lost prestige within the Civil Engineers lobby, the professional body which until very recently acted as general factotum with regard to water policy in Spain, mostly paying little attention to what happened outside the capital, thus ignoring noticeable realizations.

As a result of the above and also because groundwater was at that time in the private domain, surface water–groundwater relationships were not recognized in practice. In the twentieth century, mainly in the 1940–1960 period, the Spanish Government promoted an intensive plan to build hydraulic infrastructures (mainly dams and canals) for urban water supply and irrigation. Many dams were also constructed only for hydropower, mostly by private electric utilities. This is related to what has been described as the pervasive 'hydroschizophrenia' of Spain's public water administration (Llamas 1975). The result of this policy is that at the beginning of the twenty-first century, Spain has some 1,200 high dams, which puts it fourth country in the world ranking. At the same time, Spain has the lowest use of groundwater for urban water supply in Europe (Llamas et al. 2001).

The situation outlined above did not start to change until the 1960s, as a result of the study mentioned above in the Besós–Llobregat, led by Civil Engineers, other engineers and geologists linked to the Ministry of Public Works institutions in Barcelona, far away from Madrid. The training required was undertaken in France, Israel and Germany, but was also generated locally in close cooperation with the Academia in Barcelona. The result was that for the first time in Spain a joint study of surface and groundwater was carried out and published in 1965, and in 1970 was extended to include the whole Eastern Pyrenees basin. This was in fact an advance on what would later be required in the EU WFD River Basin Management Plans.

Meanwhile, in 1975 the first Community of Groundwater Users to deal with groundwater issues, independently of the type of use, was set up in Spain in the Lower Llobregat valley and delta. It has served as a model for some 20 other similar associations all over the country (Custodio 2010; Thuy et al. 2013), today integrated into the *Asociación de Usuarios de Aguas Subterráneas* (Groundwater Users Association).

The year 1965 can be considered as the starting point for scientific hydrogeology in Spain. Evidence of this is that in 1967 the first international postgraduate courses specializing in hydrogeology were offered in Barcelona and Madrid. The *Curso Internacional de Hidrología Subterránea* (International Groundwater Hydrology Course) is still offered, and by 2016 will have been running continuously for 50 years; in fact it is the longest running Spanish university postgraduate course. The course materials were compiled and published in the major work: *Hidrología Subterránea* (Custodio and Llamas 1976), which with more than 1,000 mentions in Google scholar, is still a reference book in its field, especially in Spanish and Portuguese speaking countries and in Italy as it has been translated into Italian.

At around the same time, the first associations of hydrogeologists were formed in Spain in the 1970s, and they soon started to organize congresses and regular scientific and technical symposia. Two Spanish experts in the field were elected President of the International Association of Hydrogeologists: MR Llamas (1980/1984) and E Custodio (2004/2007).

López-Geta (2000) considers that the period 1970–1985 made an outstanding major contribution to generating the infrastructure of hydrogeological science in the history of Spain, thanks to the work of the SGOP, the IGME, various University Departments in different cities and the many hydrogeologists working in Spanish companies and universities.

In the second half of the twentieth century, agriculture in arid and semi-arid countries saw a 'silent revolution' of intensive groundwater use, especially in Spain (Llamas and Martínez-Santos 2005, 2006; Fornés et al. 2007), challenging regulations and the resistance quite a large number of government officials. In general terms, groundwater irrigation is more productive in economic (€/m^3) and social terms (jobs/m^3) than surface water irrigation. During that period, Spanish water authorities played a secondary role due to groundwater being under private ownership, as explained below. Therefore, groundwater abstraction escaped from governmental control and so also did its appropriate management, as is the case in many developing and developed arid and semi-arid countries worldwide. The evolution of water and groundwater use and economics in agriculture is shown in a simplified form in Fig. 1, in which some of the countries and the corresponding period in each stage are indicated.

Two important documents have been released recently, the white paper on Groundwater in Spain (MOPTMA-MINER 1994) and the white paper on Water in Spain (MIMAM 2000), as well as a preliminary evaluation of the costs and prices of groundwater in Spain (MIMAM 2003).

The Directive 2000/60/CE of the European Parliament (WFD 2000) establishes a framework for community action in the field of water policy from an environmental viewpoint; the main aim is water protection through sustainable use, with ongoing reduction of contamination and pricing water use on a full-cost recovery basis. This opened up a new panorama for water studies, widening the range of research possibilities and integrating groups of scientists from different areas, which undoubtedly has enriched water science overall and a clear improvement in aquifer knowledge (López-Geta and Fornés 2013).

Water legislation in Spain and groundwater

As Spain is partly a semi-arid country, competing demand for urban water supply and for irrigation, particularly in many areas with good soils and climatic conditions, is a recurrent topic for public discussion. Regulations for water acquisition and use have thus existed for centuries but at a local level and with varied rules adapted to the different circumstances, historical heritage and local population. This has proved a major handicap for countrywide development. These regulations rarely referred specifically to groundwater, a minor and poorly known resource at the time. In general terms, the water below the land surface was considered the property of the land owner. In 1866 the first national Water Act was drawn up, in which both surface and groundwater were designated public domains. This was too advanced at that time, when groundwater was hardly susceptible to regulation. It was replaced by the 1879 Water Act, in force until 1985. The 1879 Spanish Water Act allowed for a dual water ownership regime: public for surface waters and private for groundwater, with some exceptions to this rule. According to this law, ordinary wells for domestic use were the property of the landowner, while the water from artesian wells (normally drilled, deep wells) or galleries (water tunnels) was owned by whoever found and abstracted it. There were few legal constraints on private ownership of groundwater and these existed as a means to avoid damages to third parties, including the public water domain. These included a minimum distance between wells as well as other limitations designed to avoid interference with public surface waters and to guarantee the safety of buildings, canals, railways and roads. A significant exception affecting the right to obtain groundwater in a given land property, requested by groundwater users, was introduced in the Canary Islands in 1924 and later reformed in 1958 to cope with the important interference between wells and galleries and with springs.

The water laws played and still play a relevant role in Spain and strongly condition water policy and even how to comply with the EU water planning requirements.

In the early 1980s, the Socialist Party came into power with a political manifesto which included a replacement for the 1879 Water Act. The main changes announced were that all water, including groundwater, would be included in the public domain and that all water uses would have to comply with the water plan of each river basin. These plans would be coordinated in a national water plan which would include potential water transfers between river basins.

Several authors warned without success that the government had not realized the full complexity of the water issues, mainly because the relevance of groundwater issues was not fully understood (Llamas 1983; Ariño et al. 1985) and also that the new water law was attempting to create a "big brother" scenario to decide the fate of every last drop of water.

The 1985 reform of the Water Act placed groundwater in Spain under public ownership. Its main innovation is that

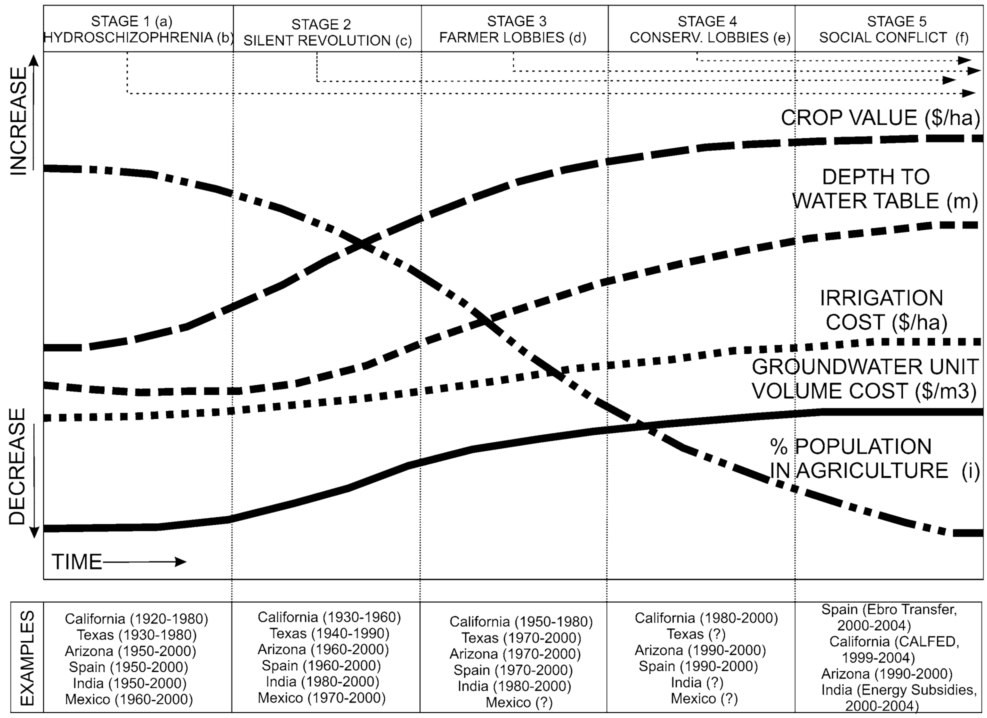

Fig. 1 Idealized water and groundwater policy trends in arid and semi-arid countries (modified from Llamas and Martínez-Santos 2005)

the State, not the individual, is responsible for groundwater management. To avoid the Government having to expropriate and pay for groundwater rights, according to Spain's Constitution, the ruling was that the owners of private groundwater could retain their property for ever, but if they voluntarily ceded their rights to the government they would obtain official protection (a poorly defined concept), could continue the current use for 50 years, and have priority for future concessions. Nevertheless, the declaration of groundwater as a public domain was an evident change in groundwater rights. In fact, the 1985 Water Act introduced significant changes for wells drilled from 1986 onwards. A Register of Public Water and a Catalogue of Private Water were created as instruments for groundwater management. As a result, the inclusion of wells in either the Register or the Catalogue constituted a legal imposition on all owners. A 3-year period (with deadline 31 December 1988) for the adaptation of existing wells to a new legal framework was established, all well owners had to choose one of these two types of groundwater ownership, and water authorities could impose coercive fines to enforce this rule. Well owners wishing to retain private ownership could apply for inclusion in the Catalogue, but they would not be granted administrative protection under the 1985 Water Act, a poorly defined concept that discouraged well owners from requesting inclusion. Nevertheless, those who are not included are still in full possession of their rights, because inclusion in the Catalogue was not a prerequisite for ownership (Del Saz 2002), which was protected by the private property Register under civil law, which has a higher legal ranking than the Water Act.

Experience proved that this 3-year period was insufficient and several legal complications ensued. In fact, 80–90 % of wells are still undeclared and therefore in an uncertain legal situation, while thousands of well owners who actually applied to the Register or the Catalogue have submitted administrative appeals against the decision of the corresponding Basin Authority, most of them with still pending resolution many years later. At times, the water authorities have found themselves unable to process so many cases and the corresponding appeals, and many applications and legal claims are largely unresolved. Thus, even if the 1985 Water Act states that groundwater belongs to the public domain, the reality is quite different. In fact, most groundwater is still legally in private ownership.

To clarify the legal situation of groundwater, the Groundwater Register and Catalogue Update Program (ARYCA project) was initiated in 1995 by the Ministry concerned as an ambitious attempt to solve the problematic legal situation of Spain's wells. The results were very poor and in 2001 the Ministry of the Environment launched a new Update Program for the Register and Catalogue Books Program, denominated ALBERCA. More than 10 years later, the situation of the Catalogue and the Register is still unsatisfactory and the ALBERCA program does not seem to address the situation of those wells whose owners never applied for inclusion in the Register or the Catalogue. In addition, it also seems to ignore the thousands of illegal wells drilled after 1986. On the other hand, after almost 30 years, in most river basins data on registered wells are not available online. This is a legal requirement for all public water rights. The number of existing wells not considered in the ALBERCA program may total over one million. Thus, legal groundwater rights are only partially known, except for some exceptional cases as in the Vinalopó River Basin, in the Júcar (Xùquer) Basin and on the islands of Gran Canaria and Tenerife.

The current situation of the coexistence of public and private groundwater in a single aquifer has been a constant source of problems. Other important causes of the current groundwater management chaos are the lack of funds and trained personnel in most water authorities. This situation is further aggravated by a newer constraint: illegal wells. "Hydrological insubordination" has become widespread in many of Spain's aquifers. In this context, a more proactive approach on the part of legislators and Basin Authorities is needed, especially as approximately half of Spain's irrigated production depends on groundwater (Llamas 2004; De Stefano and López-Gunn 2012). The existing legal and technical instruments seem unsuited to bringing such anarchy under control.

The 1985 Water Act has been modified to transpose the EU Directives that affect continental and littoral waters, especially the WFD 2000 and the later Groundwater Daughter Directive (GWD 2006), and the previous Directive on Nitrates of Agricultural Origin. Several reforms have been the outcome of the 2001 consolidated and revised text (TRLA 2001).

Groundwater role in droughts in Spain

Droughts are naturally recurring phenomena in arid and semi-arid areas, and also in temperate areas. Their effects are greater the more arid the area is and the more intensive the use of water resources. Significant droughts last several years, with variable intensity. Spain is historically prone to serious droughts, with records going back to the Middle Ages. Their serious social and economic consequences often triggered important famines and human migrations. Currently, droughts can cause significant economic and social stress and may even become a serious political concern. At times bizarre, costly and largely ineffective solutions have been adopted by politicians intended to placate the uninformed public and the biased and politically oriented media, often contrary to what is recommended by the experts and by common sense. Two examples in Spain are the most recent serious droughts, affecting Cádiz in the south in the 1990s, and the Barcelona area in the 2000s. In both cases very costly but ineffective water supplies were imported by tanker ships, to try to avoid urban water restrictions.

The impact of dry spells on agriculture is usually less relevant today and can be mitigated with surface water reservoirs and crop insurance and especially by recurring to groundwater storage where this solution has been adopted and is administratively feasible. In fact, farmers using groundwater for irrigation benefit more during dry spells because they can continue to irrigate and send their products to poorly supplied markets. In some cases "drought wells" have been provided by the water authorities, operating only during a drought to complement water supply. This is well established in SE Spain (Senent and García-Aróstegui 2013). The Spanish cities that use aquifers for their urban water supply have had minor problems compared to those relying only on surface water. Another relevant new method to mitigate supply problems during a drought is to import food and fiber (virtual water) from other countries (Garrido and Iglesias 2006) but this may mean financial loss for local farmers.

However, during normal and wet years, possible future drought is generally not a priority issue in the political agenda, although currently water authorities in Spain are gradually becoming more conscious of droughts and maintain some actions and emergency solutions active, included in their area water plans. These actions consist mostly of temporary groundwater aquifer over-pumping combined with optimized use of other natural water sources, such as surface water; options to import purchased waters from other areas; industrial water sources such as seawater desalination; brackish groundwater salinity reduction; and reuse of tertiary treated used water. All these are commonly used in the most water-stressed areas of Spain, such as the Barcelona Metropolitan Area, the south east, Mallorca in the Balearic Islands, and Gran Canaria and Tenerife in the Canary Islands.

The generally very small ratio of annual recharge to groundwater volume stored in the aquifer systems (long renovation time) is an important asset for drought mitigation. This has only been recognized recently as significant groundwater development is relatively new. The groundwater abstracted from the aquifer systems during a drought depletes part of the storage, and it is usually expected that under the right conditions this storage will be replenished between droughts. Nevertheless, this may not be the real situation and then groundwater mining (continuous depletion) of groundwater reserves occurs. Groundwater management is needed, and this is an important aspect of the integrated water resource management (IWRM) concept, which needs a wide-scale temporal and spatial view. IWRM has been a preferred topic of the Water Observatory of the Botin Foundation.

How to use groundwater to mitigate the effects of climate variations varies from country to country and depends on existing regulations, capacity to implement plans, the severity of the economic and social effects, and the extent to which people understand the problems. In some areas of Spain, mostly but not only in the eastern Mediterranean agricultural areas, the drought wells already mentioned have been promoted and constructed by the water authorities or agreed with well proprietors to be used only under officially declared drought conditions. This requires appropriate maintenance of the wells and the associated facilities, which in some cases has proved difficult, although solutions have been or are still being implemented in the Spanish Mediterranean area.

The resilience of aquifers to drought varies according to local circumstances. In some cases, the over pumping implies quite considerable groundwater head drawdown—with increasing operational costs—and in others, depletion of freshwater storage, which is replaced by saline water, as may happen in coastal aquifers. In any case, later recovery has to be ensured. This recovery can be natural or forced by means of appropriate and cost-effective artificial actions, such as enhanced surface water infiltration and artificial recharge. Joint and alternative use of groundwater is often a satisfactory and feasible solution, proposed and analyzed long ago and with some interesting experiences reported, but this requires in-depth implementation of IWRM, which is increasingly favored but still not generally adopted. This is still in its early stages in Spain due to an ongoing lack of knowledge of the conditions for efficient application, lack of funding, and some unresolved legal aspects relative to groundwater rights, although some good examples of this solution do exist. A good approach to IWRM can be seen currently in the Barcelona Metropolitan Area. Local aquifer storage provides the water complement needed for drought conditions after the other sources are pushed to their limit. A combination is envisaged of local and imported surface water, reclaimed water, seawater desalination and artificial recharge to replenish aquifer storage and control seawater intrusion through a coastal injection barrier. This integrated water management vision began in the 1950s (Llamas 1969).

Evaluation of intensive groundwater development and aquifer mining in Spain

In many arid and semi-arid areas around the world, the intensive use of groundwater is well established, with diverse backgrounds depending on local, hydrogeological, economic and social circumstances. Good examples can be found in many areas including central United States, northern Mexico, north-western India, north-eastern China, western Pakistan, and the north of Africa and the Arab countries (Llamas and Custodio 2003; Custodio 2010; Margat and van der Gun 2013). It is also common in southeastern and central Spain, the Balearic Islands and the Canary Islands (Hernández-Mora et al. 2003; Custodio et al. 2009), and is the subject of a detailed study underway at present (Project Groundwater Mining in Spain MASE, referred to in the acknowledgements).

A common reality is groundwater head drawdown, which is accompanied by increasing water abstraction costs, the need to replace or deepen wells, early replacement of pumping and energy supply facilities, and often increased water salinity and impaired quality. Sustained groundwater head drawdown is the hydraulic behavior needed to redirect the previous aquifer system discharge to the abstraction wells. This will last until abstraction rate plus natural discharge rate is close to recharge rate. This is usually a slow process that depends on the hydrogeological properties and size of the aquifer and may last years, centuries, or even millennia for very large aquifer systems. In the meantime, part of the abstracted groundwater comes from depletion of the aquifer storage. Initially, most abstracted groundwater is from aquifer storage. Aquifer use may fail when part of the aquifer system dries up during this long transient stage, the groundwater level is too deep, or groundwater quality becomes unacceptable. Groundwater is stored in both the aquifers and in the associated aquitards, although the release timing is different. All these are well-known groundwater hydraulics but are often not taken into account by water planners and managers, and here Spain is no exception.

When abstraction exceeds recharge, the groundwater head drawdown continues, as a steady state cannot be attained. The aquifer development at the current rate is then unsustainable in the long term, with a limit when the aquifer system becomes empty, or even before that point, due to excessive abstraction cost or water quality impairment. Usually, there is a gradual reduction in abstraction, and only the water uses which can afford high water prices will continue, including water quality treatment if needed.

Intensive aquifer development is frequently considered in the water resource literature in a simplistic way that may lead to wrong decisions. The most frequent suggestion is that intensive aquifer development with groundwater mining is not sustainable and should be avoided. Several authors have questioned such a simplistic approach (Collin and Margat 1993; Margat 1993; Hernández-Mora et al. 2001; Custodio 2002, 2003; Delli Priscoli et al. 2004; Llamas 2004; Foster and Loucks 2011).

Intensive aquifer development and groundwater mining have many aspects in common, especially during the early stages. They are often called "overexploitation", although this term is misleading as it puts the emphasis on the negative aspects so that its use, even if widespread, is not recommended. Distinguishing between simple intensive groundwater developments and mining often cannot be done until development is advanced, there is good-enough monitoring, and detailed studies are carried out. It is essential to know the temporal evolution, sustainability, and relevant externalities, including environmental impacts (Custodio 2002).

Both intensive water storage depletion due to groundwater development and the possible aquifer mining situation have positive and negative aspects to be considered and evaluated (Delli Priscoli et al. 2004; Llamas 2004). In addition to quantifiable individual and collective direct benefits and costs, indirect costs and benefits (externalities), most of them social and environmental, are more difficult to evaluate. There are also intangible costs that are not quantifiable but may play an important social and even political role (Martínez Santos et al. 2013). The most important benefits are wealth creation and social development and improvement. This is an important asset and many areas throughout the world have progressed from poverty to reasonable living conditions and food security, and are even able to export excess production. Increasing running costs would reduce benefits if technological improvements were not implemented using previous profits. The dramatic development and living standards' improvement in many areas of Spain are due to or were started by intensive aquifer development, in agriculture (most of the Mediterranean areas: the south, the central highlands and the Canary Islands), industry (Barcelona and Tarragona areas and some valleys in Catalonia and Valencia), and tourism (Mallorca, some of the Canary Islands, the south).

Environmental losses and, in some cases, land subsidence effects have to be evaluated. Decreasing net profit may evolve into net losses, leading to serious social problems and unrest. However, experience shows that this has not happened to date except in very small aquifers. Evolution is so slow that there is enough time to adapt. Financial resources from previous profit, if carefully used, can be used to develop new water resources and especially to change the way in which water is used, changing the paradigm. Social stakeholders and the wider public are often capable of dealing with deteriorating situations to maintain benefits, even when groundwater is mined, provided that the public sector acts responsibly instead of trying to consolidate previously unsustainable situations by means of inappropriate regulations, subsidies, and demanding cheap water. However, the current trend in many of the recent Basin Water Plans in Spain is offering more artificially cheap water instead of managing water demand.

Current aquifer storage depletion in Spain is about 15 km^3 in the Iberian Peninsula, mainly in the southeastern area, and about 2–4 km^3 in the Gran Canaria and Tenerife Islands. Storage depletion is partly associated with dynamic effects, and partly to abstraction exceeding recharge. Depletion rates up to 15 m/year can be found in some aquifers. But important reserves still remain, although their abstraction is increasingly expensive, or they are of poor quality due to salinity derived from the geological formations (mainly Triassic rocks in SE Spain), or their sodium bicarbonate and fluoride content is excessively high in deep layers of the Canary Islands volcanic rocks. On the islands of Gran Canaria and Tenerife, groundwater abstraction is less than recharge, but a large fraction of recharge is inevitably discharged into the sea as diffuse outflow along the coast, so groundwater storage depletion is the result of a long-lasting transient stage.

In the arid and semi-arid areas of Spain there is a small but significant recharge, which means that groundwater storage will recover after abstraction ceases, except when the storage capacity has been artificially reduced, as in the case of Tenerife, where the storage volume is permanently drained by the galleries (water tunnels) used to obtain groundwater at high and intermediate altitudes. The recovery time can be decades and even more than a century in some of the aquifers in SE Spain. In practice, this means permanent depletion for present and future generations. However, in spite of intensive development over the last 50 years, these aquifers continue to yield high-cost water, but due to their emplacement far from the coast and close to where it is used, it still costs less than water from other local sources. Nevertheless, the public water tariffs are lowered by direct and indirect subsidies. An important issue, much valued by water users in some areas, is the security of availability and against natural and administrative–legal fluctuations of other water sources.

The above considerations and circumstances are understood by water managers but policy makers and politicians find them difficult to understand and accept. This means that it is difficult to ensure that this situation will be considered in IWRM and translated into appropriate regulations, with long-term vision and flexibility to adapt to a changing world at the present scale of evolution, which is something that is not envisaged in the Spanish water regulations conception and underlying philosophy.

The European WFD does not help in addressing current problems and forbids water mining, even when it is socially convenient and environmentally tolerable, although some elements in the Directive can be used to address these special problems if properly analyzed and managed. Generally speaking, politicians and water managers in Spain prefer the easiest and least compromising way to avoid confrontation and discussion (i.e. not to rock the boat), and accept without discussion a set of rules, constraints and results that are almost impossible to comply. They simply declare that the problems are known and will be solved in the coming planning periods, thus trying to avoid present responsibilities of action, knowledge and monitoring. The reaction of the EU Commission is still not known, but it will surely insist on a definition of the action to be adopted. Asking about and agreeing on possible exceptions according to the law, due to particular situations and disproportionate damage, happen only rarely as this demands in-depth knowledge and convincing explanations, in addition to well-prepared negotiators, and this is not politically rewarding.

In most semi-arid countries water is considered a scarce resource, although this is not necessarily true of domestic water. Small savings in agricultural irrigation can ensure the water supply for many people. The crucial problem is generally food and fiber production, and can be solved to a large extent through importation from other areas better endowed with water resources, provided fair trading conditions exist. This virtual water trade also helps to improve aquifer management and conservation to cope with droughts and mitigate the possible negative effects of climate and global change. As is the dominant situation reflected in this paper, water quantity is the main subject, but water quality aspects are just as or even more important for many water uses and will continue to be so in the future. So water quality is an important aspect of water governance and this is also true for groundwater (Custodio 2013b). However, little attention is paid to all the preceding aspects in Spain. Further degradation of the groundwater may be needed before the required reaction takes place and is duly reflected in laws, official attitudes, user behavior and people's expectations.

The way forward to sustainable use in Spain

Intensive groundwater exploitation in Spain, partly by mining aquifers, mainly in the southeast and in Gran Canaria and Tenerife, the two main islands of the Canary Archipelago, has bolstered impressive economic and social development based on specialized intensive agriculture and tourism, mostly since the 1960s (Llamas and Garrido 2007). Low income areas have become relatively rich, now complementing groundwater in the areas where it was the main water resource with imported water, desalinated seawater, reclaimed wastewater, and desalinated brackish water. Nevertheless, all these important benefits have been achieved with chaotic groundwater management as a result of the defects in the 1985 Water Act (permitting public and private groundwater in the same aquifer) and mainly the lack of human and economic resources in most of the water authorities. This situation has led to the significant deterioration of the Spanish natural capital in some regions, to the point where this has been considered as an example of 'tragedy of the commons' (Sevilla et al. 2010). To some extent this degradation is unavoidable and is needed to trigger the reaction of water authorities and users to halt it, attempt to restore it in part and revert to a sustainable situation. The sooner this reaction occurs, the more effective it will be, but an in-depth understanding of the problem is needed as well as the participation of users and the general public. This is something new that needs experience, economic and social evaluation, and has important ethical implications, especially with reference to groundwater quality.

What is a socioeconomic success at one point in time may not be the best solution for the future. A change in current Spanish groundwater policy is essential. In the new situation, economic and social development incentives are not currently the dominant factors. Water cost and its relative scarcity are not usually key factors as tourism can afford higher water costs, and the price of water is not a main deterrent to high-tech irrigation. Preserving and expanding markets for products, fertilizer and energy prices, and labor costs are key factors for the feasibility of the new situation. However, the cost of water, even if small, is always a battleground for farming lobbies because it affects the net profits of the sector while the other assets are not under their direct control. The trend to official government subsidies for agriculture only delays the necessary paradigm shift and increases future stress. The EU agricultural subsidies (EU Common Agricultural Policy) have led to unscrupulous reactions and income expectations, but this is starting to change. This has an influence on Spanish water policy but has little effect on the more intensively exploited aquifers as their economy is almost unaffected.

The way forward is currently unclear and largely does not depend on the water and groundwater availability and the institutions in charge of water management. This is particularly clear when considering the import–export of virtual water.

A possible first step might be gradually to cut direct and indirect water subsidies so that water users pay the full cost, including environmental and other indirect and opportunity costs. This would help to reduce excessive groundwater development and/or aquifer mining, and to enhance environmental values in some areas, although some of the previous natural values are practically non-recoverable.

This needs bold policies and ethical behavior (not using water as a political weapon) and effective regulations applied by capable public water governance, in coordination with the other public sector administration. The participation of the general public is also crucial, with better implementation of the WFD requirements of participation and transparency, but this needs improved information.

The solution to this problem is partly pending (Hernández-Mora 2008), although it is improving in Spain but not in all water authorities. The current economic recession and the stressed and deteriorating political situation are delaying and in some cases holding back previous advances. The groundwater users' associations must play a leading role in implementing the needed changes.

The impact of the WFD on Spanish groundwater policy is an important issue that has been treated in detail in several recent papers: Molinero et al. (2011), De Stefano and López-Gunn (2012) and De Stefano et al. (2014). The WFD has had a beneficial impact, mainly for two reasons: (a) in the hydrological plans the groundwater bodies have to be identified, their ecological health assessed, and a program of measures has to be proposed where necessary to correct the situation; and (b) all this information has to be duly submitted to the stakeholders in detail. For the preparation of the second series of Water Plans (2015–2021) to be submitted in the year 2015, the Spanish Groundwater Associations, with the help of the IGME, organized a 2-day conference in 2014 to present and debate the outline schemes of important topics for the preparation of each Plan. The outcome was that the solution to remove some of the obstacles mentioned in this paper is underway in some areas, but there still remain unresolved aspects and areas lagging behind in knowledge, management and interest, in spite of the EU and social pressure. The current economic crisis in Spain and in Europe in general is used as an excuse for the problems encountered and for the current delays in planning and adopting measures. But this is only part of the reason, as excessive political interference, unwillingness to move on from obsolete paradigms, unscrupulous use of subsidies, and poor ethical behavior also play an important role. The general public in Spain demands a political pact on water, which was included in the current Government's electoral manifesto but has since been ignored.

Spain is a country with a long tradition of water management and planning at river basin level. However, it has failed to present on time the 2009–2015 water plans required by the WFD by the 2008 deadline. They are still unfinished in mid-2014, when the second planning period 2015–2021 has to be outlined by the end of 2014. The reason for this is that, according to the Spanish Water Act and its Regulations, all water has to be allocated and allocation affects existing rights and creates new rights. This is legal excess but common in a water-scarce country with too much public intervention but lacking an overall long-term view. Steps are taken slowly and are seriously affected by legal constraints and litigation. The Water Districts try to solve their own management problems via securing a politically friendly increased water offer to satisfy the increasing water demand by assuming that the central government will provide water imports from nearby river basins or desalinization subsidized by public funding. This problem is insoluble in physical terms and too costly in economic terms. An inadequate knowledge and consideration of groundwater and the water quality issues—some related to excess salinity—add to the complexity of the problem and do not allow effective water management. Current experience shows that changes in the legal framework, social behavior and water use are urgently needed, even if these are politically unpalatable. The way forward is through a well-organized, informed, involved and ethical civil society in Spain, and also through a bold paradigm shift (Llamas 2006; Villarroya et al. 2010).

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