THE OBSTACLES TO INCLUDE GROUNDWATER IN THE INTEGRATED WATER RESOURCES MANAGEMENT: THE SPANISH CASE

[1]LLAMAS M.R.[*], [2]CUSTODIO E., [3]DE LA HERA A. and [3]FORNÉS J.M.

[1] Complutense University, Faculty of Geological Sciences, Jose Antonio Novais 2, 28040 Madrid, mramonllamas@gmail.es,
[2] Technical University of Catalonia (UPC). Department of Geo-Engineering, Jordi Girona 1-3, Building D-2, 08034 Barcelona, emilio.custodio@upc.edu
[3]Geological Institute of Spain (IGME), Ríos Rosas 23, 28003 Madrid, a.delahera@igme.es, jm.fornes@igme.es

Keywords: Water planning, Water governance, Water policy, Integrated water resources management, Obstacles, Spain.

Abstract

For many decades there has been a general consensus on the need for considering surface and groundwater jointly in order to achieve the more general paradigm of an integrated water resources management. Nevertheless, in practice, in many countries, this goal is far from being achieved; the Spanish case will be presented. Spain is probably the most arid country in the European Union (EU). Therefore, the use of groundwater for urban water supply and irrigation should be relevant. However, aside from some continental and island areas, Spain uses the least average percentage of groundwater for urban water supply in the EU, except for Norway. The use of groundwater for irrigation has increased significantly in the last decades but fifty years ago was almost negligible in many areas, where it is now dominant. This situation is related to the “hydroschizophrenia” of many Spanish water planners. This word was suggested in 1972 by an American expert to describe the mind-set of those planners who undependably consider surface and groundwater, generally paying little attention to groundwater. The hydroschizophrenia was rooted in Spain due to a series of historical circumstances, framed at the end of the 19th century in government’ water policy. This mind-set of the governmental water planners had an influence in the 1985 water code, and also in the transposition to Spain of the EU 2000 Water Framework Directive. Although some improvements have been made, general groundwater management is still chaotic in some aspects. In this paper some significant aspects of groundwater policy are considered, such as its mitigation role of climate variability and change, water mining of aquifers, associations of groundwater users, and groundwater ecosystems.

1. Introduction

The preparation of this paper was due to an invitation by the IAH Greek chapter to the first author to do a presentation in the *IAH 10th International Hydrogeological Conference* to be held in October 2014 in Thessaloniki. The origin of this invitation was a talk in Athens with Professor Stourmaras during a Workshop organized by Cornell University, an American university, on water problems in the Mediterranean Region. Prof. Stourmaras remembered the article of Llamas (1975) on the Spanish case and wanted to know its evolution and current situation. So the initial thought was to deal with the specific topic, “The Spanish hydroschizophrenia: origin, evolution and current status”. Nevertheless, in agreement with the other co-authors of this presentation, it was decided to consider a broader perspective and a more general title, “The obstacles to including groundwater in integrated water resources management: The Spanish case.”

The term and concept of “h*ydroschizophrenia”* was first mentioned by R. Nace (1972). Llamas soon published the application of this concept to the Spanish situation, first in Spanish and then in English in 1975. He later applied the concept to the global groundwater intensive use (Llamas and Martínez Santos 2005a) and also to the ethical issues related to the use of groundwater (Llamas 2004; Llamas 2005b). In the last few years a good number of books, monographs and articles dealing more or less directly with this topic have been published within the *Water Observatory* of the Botin Foundation (www.fundacionbotin.org/agua.htm). For the sake of brevity, only a few of them will be quoted.

Obviously Spain is not a unique case history to analyse the role of groundwater in global water policy. There are excellent general publications on the global issues. Those of the IGRAC (International Groundwater Resources Assessment Centre, www.un-igrac.org) deserve a special mention--for example, 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 in India, the country that uses almost 50% of the global groundwater withdrawal. See, for instance, Shah (2012) or Llamas *et al.* (2006).

The EU Water Framework Directive, enacted in the year 2000, has had a beneficial effect in the attention paid to groundwater in Spain, but for the sake of brevity will not be considered in detail in this presentation. The European Academies of Sciences Advisory Council (EASAC, 2010) analysed the situation of groundwater in the southern EU member states.

2. Scope and aim

This presentation analyses almost exclusively the water policy situation in Spain, a member state of the EU, taking in consideration the global situation, which present differences across the country. There are several circumstances that make the Spanish case relevant. Among them:

a) The size and population: 500,000 Km^2, and almost 50 million inhabitants

b) The dramatic changes in the political and economic situation during the last half century: from authoritarian to democratic government; from US$ 300 to 30,000 GNP/person/year

c) The knowledge of water uses and their socio-economic implications

The aim of this study is to provide a clear view of the past and present strengths and weaknesses of the Spanish situation in groundwater policy. This allows to design of a road map for future, more efficient water governance in Spain, and perhaps in other countries.

3. The beginning of the intensive use of groundwater about six decades ago

Up until the mid-20th 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 it or discovered it'. There was little understanding of the subterranean part of the water cycle. The technology required for drilling water wells and for the extraction of groundwater was underdeveloped. López-Geta and Fornés (2013) have coordinated the publication in Spanish of a comprehensive book, *One Hundred Years of Hydrogeology in Spain*. What follows in this section uses the book's contents extensively.

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. In the 1960s, the *Instituto Nacional de Colonización* (INC, National Institute for Colonisation), dependent on the Ministry of Agriculture, in coordination with the Geological Institute of Spain (IGME), and supported by the United Nation's Foog and Agriculture Organization (FAO), initiated a series of hydrogeological studies and successful experimental operations with groundwater in different regions of Spain, including Doñana, La Mancha, Almería, and Murcia, among others, mostly oriented to agriculture development. These projects were originally government-run but local farmers soon realised 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 being carried out with private investments.

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 was the specific aim of the *Plan Nacional de Abastecimiento a Núcleos Urbanos* (PANU, of Urban Supply National Plan) drawn up by the same institution. In spite of these schemes and the traditional important role of groundwater in some large Mediterranean and island towns, Spain is among the countries that uses the least percentage of groundwater for urban water supply worldwide (Llamas *et al.* 2001). This is closely related to Spain's acute 'hydroschizophrenia' that is described in the following section. Other important studies preceded the ones mentioned above, or were developed at the same time, and will be discussed later on.

The roots of the problem at the government level, not always at the local level, can be outlined as follows. At the end of the 19th century, in France, the neighbouring country of reference for Spain, the trend was to use groundwater from the *sables verts* (green sands), *of the* Cenomanian aquifer, to solve the acute water supply problems of the city of Paris. The prestigious *Cuerpo de Ingenieros de Minas* (Corps of Mining Engineers) proposed the same solution for Madrid's water supply, while the *Cuerpo de Ingenieros de Caminos, Canales y Puertos* (Corps of Civil Engineers) maintained that the solution was to build 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 and drilling techniques at the time did not enable a sufficient understanding of the problem. The result was the creation of the *Canal de Isabel II*, designed to supply Madrid with surface water. Also, there was the increasing loss of prestige of groundwater within the Civil Engineers lobby, the professional body which until very recently acted as general factotum with regard to water policy in Spain. At that time, Spain had a much centralised government system that often paid poor attention to what happened away from the capital.

In the 1960s a new phenomenon emerged in the Ministry of Public Works, the domain of the Civil Engineers. The Eastern Pyrenees Basin Authority–now renamed *Cuencas Internas de Cataluña* (Inner Basins of Catalonia)–, set out a series of topics in relation to groundwater, which led a select group of professionals from the ministry to embark on an in-depth study of the subject, including training in France, Germany and Israel. The result was that for the first time in Spain, a joint study of surface and groundwater was carried out and published in 1965, initially only of the Besós and the Baix Llobregat Rivers, around Barcelona. Shortly afterwards, in 1970, this analysis was extended to include the whole Eastern Pyrenees basin, and was in fact an advance on what would later be required in the EU Water Framework Directive 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 Llobregat Delta. It has served as a model for some twenty other similar associations all over the country (Thuy *et al.* 2013), today integrated into the *Asociación de Usuarios de Aguas Subterráneas* (Groundwater Users Association). Also a comprehensive study on the water resources of the Canary Islands (SPA-15), mostly groundwater, was carried out between 1970 and 1975 by the Ministry of Public Works with the support of UNESCO.

Some authors (Martínez Gil 1991) consider 1965 as the starting point for scientific hydrogeology in Spain. Evidence of this is that a couple of years later, the first 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 in 2016 will have been running continuously for fifty years; in fact, it is the longest running Spanish university postgraduate course. The course materials were published in the major work, *Hidrología Subterránea* (Custodio y Llamas 1976), which with more than 1000 mentions in Google scholar, is still a best seller in its field and has been translated into Italian.

Around the same time, in the 1970s, the first associations of hydrogeologists were formed in Spain, 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: Llamas (1980/1984) and Custodio (2004/2007).

López-Geta (2000) considers that the period 1970-1985 stands out as the one that made a major contribution to generating the infrastructure of hydrogeological science in the history of Spain, thanks to the work of the *Servicio Geológico de Obras Públicas* (SGOP, Geological Survey of Public Works*)*, of the IGME, and of all the hydrogeologists working in Spanish companies and universities.

In the second half of the 20th century, agriculture in arid and semiarid countries experienced a true "silent revolution" of intensive groundwater use (Fornés *et al.* 2007). In general terms, groundwater irrigation is more productive in economic (€/m^3) and social terms (jobs/m^3) than surface water irrigation. In that period, Spanish water authorities played a secondary role due to groundwater being under private ownership. Therefore, groundwater abstraction has escaped Government's control and therefore appropriate management, as in many arid and semiarid countries worldwide.

In the year 2000, the Directive 2000/60/CE of the European Parliament was approved, establishing 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 costs 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 (see López-Geta and Fornés 2013). The influence of this Directive is commented upon at the end.

4. The pervasive "hydroschizophrenia" among the water policy and decision makers and its consequences

In section 3, the debate in the 19th century on the potential role of groundwater to supply drinking water to Madrid, the capital of Spain, has been mentioned. The groundwater solution failed because there was a lack of geological knowledge that the big fault between the Central Range and the "Tertiary graben" placed the expected "green sands" at a depth of more 3000 metres. On the other hand, the water wells drilling technology was at its infancy and the boreholes drilled were sterile. The water wells drilled in the 1970s, with modern technology, can yield up to 100 L/s.

Spain had a much centralised (French type) Administration. As previously said, water policy was conducted by the Corps of Civil Engineers. For this "lobby," groundwater was not a good means to provide the necessary water for urban water supply and for irrigation. As a matter of fact the 1879 Water Act assigned the property of the "found groundwater" to whoever obtained it, in the same way other mineral resources were considered. So groundwater was not "public domain" like surface water. The surface water-groundwater relationships were not recognized in practice.

In the 20th century, mainly in the second half, the Spanish Government promoted a strong plan of building hydraulic infrastructures (mainly dams and canals) for urban water supply and irrigation. A good number of dams were also built for only hydropower, but these were mainly done by private electric utilities.

The result of this policy is that at the beginning of the 21st century, Spain has some 1200 high dams and is the fourth country in the world for the number of high dams. At the same time, Spain has the second lowest use of groundwater for urban water supply out of the countries in Europe (Llamas *et al.* 2001).

The several regional studies to promote irrigation with groundwater initiated in the 1950s the INC, jointly with the IGME, and in the 1960s with the aid of FAO were an efficient catalyst to promote the development of groundwater in Spain.

5. Water legislation in Spain

The 1879 Spanish Water Act, valid until 1985, allowed for a dual ownership regime: public for surface waters, and private for groundwater, although there were some exceptions to this rule.

Apparently, small springs, rivers, and lakes occurring naturally within private land could also be considered under private ownership in certain cases. According to this law, ordinary (domestic use) wells were the property of the landowner, while water from artesian wells or galleries was owned by whoever found them. Legal constraints on private ownership of groundwater were generally few and arose as a means to avoid damages to third parties. These included a minimal 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.

In the early 1980s the Socialist Party won the elections and in its political program included a new Water Act in substitution of the former Water Act of 1879. The main changes announced were that all waters, including groundwater, would become public domain and all water uses had to be in agreement with the water plan of each river basin. These plans would be coordinated in a national water plan where the potential water transfers between river basins would be included.

Several authors warned that the government had not realised the complexity of the water issues, mainly because of poor knowledge of the relevance of groundwater issues (see Llamas 1983 and Ariño *et al.* 1985) and also that the new water law tried to create a kind of "water big brother" able to decide about the fate of every drop of water. No attention was paid to these warnings. This solution has not worked because most groundwater owners totally ignored the proposal and have not even registered their private ownership. The situation now is that no one knows how many private water wells and rights exist today.

The 1985 reform of Spain's Water Act put groundwater under public ownership. Its main innovation is that the state, not individuals, is responsible for groundwater management. In order to avoid the government had to expropriate and pay for groundwater rights, according to Spain's constitution, it was ruled that the owners of private groundwater could maintain their property forever, but if they graciously donated their rights to the government they would obtain administrative protection (a poorly defined concept), could keep the current use for fifty years, and have a priority for future concessions. While the declaration of groundwater as a public domain, posed an evident change in groundwater rights, the practical implications of the law have not been significant. In fact, the 1985 Water Act introduced significant changes for wells drilled from 1986 onwards and created a Public Water Registry and a Catalogue of Private Waters above mentioned as instruments for groundwater management, permitting a three-year period for the adaption of existing wells to a new legal framework. Under the law, all well owners had to join one of these two types of groundwater ownership, and basin authorities could apply coercive fines in order to enforce this rule.

A three-year deadline (31 December 1988) was set for the private groundwater owners to graciously deliver their ownership to the government and to join the Registry of public waters. Alternatively, well owners wishing to maintain private ownership might choose to apply for inclusion in the Catalogue. However, they would not be granted administrative protection under the 1985 Water Act. As a consequence, the inclusion of wells in either the Registry or the Catalogue constituted a legal imposition on all owners. However, those failing to join are still in full possession of their rights, because inclusion in the Catalogue was not a prerequisite for ownership (Del Saz 2002).

The experience showed that this approach was insufficient. Several legal complications have arisen as a result. For one, 80-90% of wells are still undeclared, and therefore in an uncertain legal position. On the other hand, thousands of well owners who actually applied to the Registry or the Catalogue have submitted administrative appeals against the decision of the corresponding Basin Authority. At times, these administrators have found themselves unable to process so many cases and the corresponding appeals. Thus, even if the 1985 Water Act states that groundwater belongs to the public domain, the reality is quite different. In fact, most of it is still under private ownership by law.

In order to solve the legal situation of groundwater, the Groundwater Registry and Catalogue Update Program (ARYCA) was initiated in 1995 by the Ministry of Public Works, Transport and the Environment, as an ambitious attempt to solve the legal situation of Spain's wells. The results of the ARYCA project were very poor and in the year 2001, the Ministry of the Environment launched a new Update Program for the Registry and Catalogue Books Program, denominated ALBERCA. More than ten years later, the situation of the Catalogue and the Registry is quite deficient. Nonetheless, the ALBERCA program does not seem to address the situation of those wells whose owners never applied to the Registry 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 the data on the registered wells are not available through internet, which was a requirement of all the public water rights. Besides this, the number of existing wells not considered in the ALBERCA program might total over one million.

The current situation of keeping in one aquifer coexisting public and private groundwater has been a source of problems. Other important causes of the current groundwater management chaos are the lack of funds and of training of personnel in most water authorities.

6. Groundwater and ecosystems

Spain is part of the southern Europe, where crop irrigation represents 85 % of the use of groundwater, often from intensely exploited aquifers. The extraction of the groundwater for irrigation is done in concurrence with the urban and industrial supply and in competition with the so-called environmental use. The current situation is such that in many cases the groundwater flow systems have been dramatically modified. For the most part, this concerns groundwater levels, the base flows of the rivers, the flows of the springs, and the chemical quality of groundwater (EASAC 2010).

The ecosystems have been commonly studied from an exclusively ecological perspective; nevertheless, in the last years, they have begun to be perceived from a different perspective: connected to the hydrological cycle. This supposes a new approach of ecohydrological character, more wealth producing, which endures the joint work of ecologists and hydrogeologists. Ecosystems need a water contribution to survive, but a part of them specifically needs groundwater to survive, particularly in the countries of an arid or semiarid climate, where rainfall not only is scanty, but much dispersed over time.

The groundwater constitutes the support of great part of the natural capital, particularly of the terrestrial, aquatic and coastal ecosystems. They support the ecological integrity of certain ecosystems. These ecosystems consist of biotic and abiotic elements that form the ecological integrity of each one, and they have to be analysed individually.

The relationship ecosystems-groundwater takes place in areas located in the landscape. Habitually, they are in the environment of aquatic ecosystems, or zones where the groundwater level is near the surface of the soil (Sophocleous 2002).

This ecosystems-groundwater interaction has been recognised by the European legislation and today there are four the Directives related to this subject: Directive 2000/60/CE known as Water Framework Directive, the Daughter Directive 2006/118/CE on pollution and the deterioration of groundwater, the Directive Habitats 92/43/CEE, and the Directive Birds 2009/147/EC. In a particular way, the WFD establishes that the chemical composition of the water body or a group of water bodies in good chemical condition must be such that it does not prevent that the surficial associate waters from reaching the environmental aims, and does not cause significant damage to terrestrial associate ecosystems. This means that the ecosystems constitute key elements to determine the condition of the groundwater bodies associated with them. The principal problem is determining which ecosystems must be kept in mind in the evaluation of the chemical condition of the groundwater bodies.

The attention that the before mentioned European Directives give to the quantitative and qualitative aspects of the groundwater dependent ecosystems is a key aspect in groundwater management plans in the country members-- among them Spain-- and constitutes a hanging task. This recognition of the groundwater role in ecosystems has coined the term "groundwater dependent (related) ecosystems," (GDE). GDE are those ecosystems that need groundwater for all or some of their water requirements so that they could support the communities of plants and animals, the ecological processes that they support, and the services that they provide to the ecosystems.

The first problem that appears, derived from the implementation of the European Directives, is that a methodology established at European scale to characterise the GDEs does not exist. Thus, each country proceeds according to its own criteria. Most of the European countries have considered the natural protected areas that form a part of the Network Nature 2000 (Directive Habitat) to analyse the relations of dependence with groundwater.

Secondly, it is also necessary to consider also the consequences that stem from the official recognition of an area of the territory as GDE, at the administrative level, management of the territory, and economically, due to the necessary follow-up needed according to the requirements of the mentioned European Directives.

Thirdly, it is necessary to define and to establish the range of application of what is described in the WFD as "significant damage" to the ecosystems. The guide of the Common Implementation Strategy no. 2 provides a guideline for it, considering two factors: the characteristics of a specific year and the ecological or socioeconomic importance of the (terrestrial) ecosystem.

Recently, Australia published its Atlas of Ecosystems Dependent on Groundwater. This work constitutes a modal in the identification of the ecosystems dependent on groundwater at continental scale. The GDE Australian Atlas departs from abundant works and documents spread over two decades of previous work, by using remote sensing and the Geographical Information Systems (GIS) as principal tools of a work on the continental scale. The GDEs are classified in three groups, in agreement with Eamus *et al.* (2006a, b): (1) Ecosystems dependent on the presence of groundwater in the subsurface (essentially all the terrestrial ecosystems); (2) Ecosystems dependent on the surface expression of groundwater (rivers with base flow, springs, lakes, wetlands, coastal waters, and estuaries) where groundwater appears visibly on the surface of the soil; that is to say, they constitute what, in the Water Spanish Plans, is the " associate superficial water bodies"; and (3) groundwater ecosystems (aquifers and caves). The methodology applied for the study of each one from these groups is different.

Spain has begun to identify the ecosystems that depend on the groundwater in the area of the intercommunitary basins. The work realised by the IGME in the frame of a commission of management IGME-DGA has identified the springs, sections of river, wetlands, and protected areas that form a part of the Network Nature 2000, which depend somehow on groundwater. This work has been fundamentally realized by compiling the results of previous studies. Therefore, it does not constitute an updated picture of the situation in the territory; nevertheless, it provides the first approximation to consider areas of possible protection of the territory and to evaluate the costs of implementation of the management plans.

7. Groundwater role in the mitigation of climate variability and change

In arid and semiarid areas, and also in temperature areas, droughts are natural recurring phenomena. Their effects are greater the more arid the area is and the more intensive the use of water resources is. Significant droughts last several years, with variable intensity. There are many indices in order to measure the impact of a drought.

Spain is historically prone to serious droughts, with records going back to the Middle Age. Serious social and economic consequences were often a result, and triggered important human migrations. Currently, economic losses may be important and stress society up to the point of becoming a political concern during the drought, with the adoption of sometimes bizarre, costly and poorly effective solutions. Two Spanish examples are the last serious drought in the south in Cádiz in the 1990s and in the Barcelona area in the 2000s. In both cases water was imported water by boat, respectively from Huelva (Spain) and from Marseilles (France) to avoid urban water restrictions, but as a high cost and, irrelevant in quantity. It was a political decision directed to please the poorly informed public. Usually the impact of dry spells in agriculture is less relevant today and can be mitigated with surface water reservoirs and crop insurance--and in some cases by recurring to groundwater. The groundwater irrigation farmers make more money during the dry spells because they can continue to irrigate. The so-called drought wells have been provided in some cases by the water authorities to be operated only during a drought to complement water supply. Another new and relevant method to mitigate drought is the import of food and fibre (virtual water) from other countries (see Garrido *et al.* 2010). It is well known that the Spanish cities that use aquifers for their urban water supply have had minor problems compared to those based only on surface water (see Martínez Cortina 2002). However, during normal and wet years the possibility of a new drought is not on the political agenda, although the Water Authorities are always more conscious of it and keep some actions alive, included in their respective Water Plans.

The generally very small ratio of annual recharge to groundwater volume stored in the aquifer systems (or long renovation time) is an important asset for drought mitigation. This is a fact that has been known for only a short time, since important groundwater development is relatively young-- less than 60 years in most cases, and often a few decades (see section 3). 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 is replenished between droughts. Nevertheless, this may not be the real situation and then a ground water mining or overdraft occurs (see section 8). Groundwater management is needed, as part of the integrated water resources management (IWRM) and needs a wide scale temporal and spatial vision. The topic of IWRM has been a preferred topic of the Water Observatory of the Botin Foundation (Aldaya, Martínez Santos and Llamas 2013). How to use groundwater to tame the effects of climate variations is variable from country to country and depends on existing regulations, capability to carry out plans, the seriousness of the effects, and people understanding the problems. In some areas of Spain, mostly in the eastern Mediterranean agricultural areas, but not exclusively, drought wells 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 to be not an easy task, although solutions are adopted or devised.

The resilience of aquifers to drought varies according to local circumstances. In some cases it implies quite large groundwater head lowering –with increasing operation 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 produced. This recovery can be natural or forced by means of artificial actions, if appropriate and costly–effective, such as enhanced surface water infiltration and artificial actions, if appropriate and cost-effective, such as enhanced surface water infiltration and artificial recharge. Conjunctive and alternative use of groundwater is often a good, feasible solution, proposed and analysed since long time ago, with some good experiences, but this needs IWRM in depth-, something still not generally adopted, but increasingly favoured. With a few exceptions, in Spain all this is still in its early stages due to still poor knowledge of conditions for efficient application, lack of financing, and some unresolved legal aspects on the rights to groundwater. A good approach to IWRM is practiced today in the Metropolitan Area of Barcelona, being the aquifers the water storage for drought conditions, and combining surface water, local and imported, reclaimed water, seawater desalination and artificial recharge to replenish aquifer storage and help control seawater intrusion. Nevertheless, it is significant mentioning that in order to achieve the good current situation, the action began long time ago (see Llamas 1969).

The expression "climate variability" usually refers to a temporal scale of decades. Instead of that, "climate change" is usually used to consider slow climate changes, across centuries and millennia. This is a common situation along geological history, and their results are clearly shown in the sediments' records. Being the human life so short relative to these long term events, only those produced in the past few centuries are well known, such as the small glacial age in the northern hemisphere in the 16th to early 19th century. This produced moderate effects in Spain. Since then humanity has lived in a climate bonanza, but with a natural trend that is poorly known.

The massive burning of fossil fuels and the increasing human gas and dust emissions have significantly affected atmospheric conditions. Most scientists admit today, that human-originated climate change is being produced, mostly starting from the 1970s, and accelerating since the 1990s. This is not a continuous trend but a fluctuating one, and over imposed on the poorly known natural climate change, in very complex, worldwide interactions. Temperature is warming but the behaviour of rainfall is quite more uncertain, although it seems that extreme events will increase, among them drought length and severity. Predictions for Spain are no unanimous but point out increased extreme events in the central and Mediterranean areas and the two archipelagos, which are currently the more arid areas.

This climate change is compounded with what is today called *global change*, which refers to the effect of the increasing impact of humans on the land and the oceans. This impact is mainly a result of massive deforestation, agriculture expansion, other changes in soil use, fast growing and expanding urban areas, and improving living standards that demand more natural resources for an increasing population that also wants to improve their standard of life in food and other commodities.

"Global change", including climate, means increased pressure on water resources, in concurrence with ecological needs for ecosystems conservation and their services to humans. The available quantity of freshwater is not the main issue, since there is plenty for the growing population. But this implies efficient use, protection against pollution, compensating poorly endowed areas by means of reconsidering economic activities and making adequate use of virtual water trading. It also implies wise use of the large groundwater storage–and protecting it–to soften fluctuations, the current ones and possibly the more fluctuating future conditions. Climate change and variability have been and are considered in water planning in Spain, but often more as a formal requirement than for adopting adaptation measures.

In the areas currently with an excess of the use of water resources and aquifer intensive exploitation, the local water planners look mostly for solutions based on physical (blue) water transfer from other areas or seawater desalination. Generally the proposed solutions lack the necessary economic analysis and try to obtain the necessary funds by means of wicked subsidies; in other words, in Spain, water has become a political weapon in order to buy votes in the elections. Some relevant persons have spoken on the need of a state water pact among the main political parties in order not to use water as a political weapon. Nevertheless, prospects are not very encouraging about the implementation of such a pact.

How climate and global change will affect natural aquifer recharge is very uncertain, although a lot of effort is being done to increase the understanding of the highly non-linear relationships of rainfall and recharge, especially depending more on the temporal and spatial rainfall patterns than on annual rainfall change. Higher rainfall does not necessary mean increased aquifer recharge, and vice-versa.

8. Evaluation of intensive groundwater development and aquifer mining

In many arid and semiarid areas around the world, the intensive development of groundwater is a common fact, with diverse backgrounds depending on local, hydrogeological, economic and social circumstances. Good examples can be found in many areas varying from central United States, northern Mexico, north-western India, north-eastern China, western Pakistan, and the north of Africa and the Arab countries. This is a common situation in south-eastern and central Spain, the Balearic Islands and the Canary Islands.

This topic is frequently considered in the water resources literature in a simplistic way that may lead to wrong decisions. The most frequent suggestion is that this activity is not sustainable and should be avoided. Several authors have questioned such a simplistic approach (see Custodio

2002; Delli Priscoli *et al.* 2004; Llamas 2004). In this section the main characteristics of the issue are summarized.

In low recharge areas, when groundwater development is very intensive, total water abstraction may exceed actual recharge, including rainfall recharge, river infiltration, irrigation return flows, and transfers from other aquifers and associated aquitards.

A common fact is groundwater head deepening, which is accompanied by increasing water abstraction costs, the need to substitute or deepen wells, early replacement of pumping, and energy supply facilities, and not rarely, water salinity increase and quality impairing. A sustained groundwater head lowering is the necessary hydraulic behaviour to redirect previous aquifer system discharge to the abstraction wells. This will last until abstraction rate plus natural discharge rate is close to the recharge rate. This is commonly a slow process that depends on aquifer hydrogeological properties and aquifer size, lasting from years to many centuries, even millennia for very large aquifer systems. In the meantime, part of the abstracted groundwater comes from depletion of aquifer storage. Initially, most abstracted groundwater is from aquifer storage. Aquifer development may fail when part of the aquifer system gets dry during this long transient stage, the groundwater level is too deep, or groundwater quality becomes unacceptable.

When abstraction exceeds recharge, the groundwater head lowering continues since a steady state cannot be attained. Then, aquifer development at current rate is unsustainable in the long term, with a limit when the aquifer systems becomes empty, or well in advance, due to excessive abstraction cost or water quality impairment. Commonly, there is a progressive reduction in abstraction, and only the water uses that can afford high prices will remain, including water quality treatment if needed.

Intensive aquifer development and groundwater mining have many common aspects, especially during the early stages. They are often called “overexploitation”, although this term is misleading and centres on the negative aspects, so 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 externalities, including environmental impacts as one of the relevant ones (see Custodio, 2002).

Intensive water storage depletion due to groundwater development and the possible aquifer mining situation all have positive and negative aspects to be considered and evaluated (see Delli Priscoli *et al.* 2004 and Llamas 2004). In addition to quantifiable individual and collective direct benefits and costs, indirect (externalities) costs and benefits are more difficult to evaluate, most of them of social and environmental nature.

There are also intangible costs that cannot be quantified but that may play an important social and even political role (see Martínez Santos *et al.* 2013). The most important benefits are wealth creation and social development and improvement. This is an important asset. Many areas in the world have moved from poverty to reasonable life conditions and food security, even being able to export excess production. Increasing exploitation costs would reduce benefits if technological improvements were not implemented using previous benefits.

Environmental losses, and in some cases, land subsidence effects have to be evaluated. Decreasing net benefits may evolve into net losses, with serious social problems and unrest. However, experience shows that this has not happened up to now, except for very small aquifers. Evolution is so slow that there is time to adapt. Economic resources from the previous benefits, 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 forces and civil society are often capable of dealing with deteriorating situations to maintain benefits, even when groundwater is mined, provided that the public sector acts responsively instead of trying to consolidate previous unsustainable situations by means of inappropriate regulations, subsidies, and offering artificially cheap water.

Current aquifer storage depletion in Spain is about 15 Km^3 in the Iberian Peninsula, mainly in the south-eastern area, and about 2 Km^3 in Gran Canaria and Tenerife islands (Canary Islands) (Custodio 2014 in preparation). 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 remain, although they become expensive to be abstracted or have poor quality due to salinity derived from the geological formations (mainly Triassic rocks in south-eastern Spain) or excess of sodium bicarbonate and or high fluoride content in deep layers of the Canary Islands volcanic rocks. In Gran Canaria and Tenerife 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 depletion is the result of a long lasting transient stage.

In the arid and semi-arid areas of Spain there is still significant recharge, which means that groundwater storage will recover after ceasing the abstraction, except when the storage capacity has been artificially reduced, as in the case of Tenerife, where the storage volume drained by the water tunnels (water galleries) used to get groundwater at high and intermediate altitudes cannot be recovered. The recovery time can be decades and even more than a century in some of the aquifers. In practice this means a permanent depletion for the present and the coming generation. However, in spite of very intensive development, these aquifers continue yielding water after 50 years-a costly water, but due to their placement far from the coast, at a cost lower than that of other sources of water. Nevertheless, the prices of water-not the cost- is highly influenced by the wicked subsidies system.

This is understood by technical water managers but is difficult for policy makers and politicians. Consequently it is difficult for this to be considered in IWRM and translated into appropriate regulations, with long-term vision and flexibility to adapt to a changing world at the actual scale of the evolution, which is something that is not in the conception of classical Spanish water regulations.

The European WFD does not help and forbids this water mining even if socially convenient and environmentally tolerable, although some elements in the Directive can be used to address these special problems if properly analysed and managed. Generally, politicians and water managers in Spain prefer the easiest and less compromising way to accept, without discussion, rules that are almost impossible to comply with by simply saying they will solve the problems in the future. Thus they try to avoid present responsibilities of action, knowledge, and monitoring.

9. Ethics

Many media have echoed the declaration of an interesting workshop with the title "Humanity Sustainability, Nature Sustainability: Our common responsibility" held in the Vatican Academy of Sciences in May 2014. Perhaps the significant outcome of that workshop is the sentence "Humanity has become a technological giant but is now an ethical child" (see Pontifical Academy 2014).

This is a general situation but it clearly applies to the problems in water management and has a great impact in the water governance. This has been a clear focus in the tasks performed by the authors of this paper and for the Water Observatory of the Botin Foundation (see, for instance, Llamas 2012).

But the importance of ethical issues is still more important when dealing with groundwater. Llamas (1975) wrote that the scarce attention paid to groundwater by the water policy makers is due a mix of four factors: ignorance, arrogance, neglect, and corruption. The proportion of each of these factors varies from region to region and depends mainly on the socio-political conditions.

Ignorance is mainly due to the fact that only a few decades ago hydrogeology has become a recognized science. Still, in many countries, water watchers or dowsers are more numerous and influential than groundwater hydrologists, and the corresponding tasks are carried out by improperly trained personnel.

Arrogance is related to the professional cliques or groups that have controlled the water policy, and with few exceptions were mainly or only trained to design hydraulic infrastructures, and those who often that call themselves as groundwater specialists, without the corresponding training.

Neglect is a usual vice or shortcoming of human nature. Learning the relatively new concepts of the groundwater hydrology needs an effort that not many people are willing to do and forget the old proverb, "What Johnny did not learn, never is learnt by John".

Last but not least is the issue of corruption. Surface water infrastructures are more prone to bribery or other type of corruption than groundwater development projects. Surface water projects usually require a longer time, from ten to thirty years, from the beginning to the full operation. Groundwater projects usually are implemented by steps of no more than three to five years. The investment is usually significantly smaller than with conventional surface infrastructures. Additionally, it is worth to quote the impact in the media: beauty of the inauguration of a water well field cannot be compared to the inauguration of a big dam, and most politicians are slaves of the media. A further kind of corruption if related to excluding other professionals who are not in the same corps or group.

10. The way forward

Intensive groundwater exploitation in Spain, partly by mining aquifers, mostly in the Southeast and in the two main islands of the Canary Islands Archipelago, Gran Canaria and Tenerife, has bolstered an impressive economic and social development based in specialised intensive agriculture and tourism, mostly since the 1960s. Low income areas have been converted into relatively rich ones, now complementing groundwater in the areas where it was the main water resource, with desalinated seawater, wastewater reclaimed and "de–brackishing" brackish groundwater. Nevertheless, all these stupendous benefits have occurred with a chaotic groundwater management that is a consequence of the defects in the Water Law of 1985 (that created public and private groundwater in the same aquifer) and mainly the lack of human and economic means inside most of the Water Authorities. And this situation has significantly deteriorated the Spanish natural capital in some regions.

Moreover, the socio-economic success of a time may not be the good solution for the future. A change in groundwater Spanish policy is currently needed. In the new situation, the economic and social development incentives are not currently the leading factors. Water cost and its relative scarcity is not a usual key factor since tourism can pay for more costly water, and the price of water is not a main deterrent to achieving high-tech irrigation; preserving and expanding markets for their products, fertilizer and energy prices, and labour costs are the key factors for the feasibility of the new situation. However, the cost of water, even if small, is always a battle pursued by the farmers lobbies because it affects the net benefit of their business, while the other assets are not under their direct control. The trend to subsidise agriculture by the government only delays the necessary change of paradigm and increases the future stress.

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 first step might be progressively cutting direct and indirect subsidies to water in order that user pay for the full cost, including environmental costs and other indirect and opportunity costs. This will help reduce excessive groundwater development and/or aquifer mining, and to improve in some areas the environmental values, although some of the previous natural values are practically non recoverable.

This needs bold policies and ethical behaviour (not using water as a political weapon), effective regulations applied by a capable water public administration, co-ordinately with the other public administrations. Also, the participation of the civil society is crucial, with better implementation of the requirements of participation and transparency that the FWD requires. The groundwater users' associations have to play a leading role in implementing these changes.

In Spain, the rather well developed institutions for surface water irrigation, some of them with a long tradition like the millenarian *Tribunal de las Aguas de Valencia* (Water Court of Valencia), are a good base to promote and empower the Groundwater Users Associations, which are typically bottom-up institutions. Fortunately, the initial association created in 1975 for the Llobregat delta has been imitated, and now almost twenty similar associations exist. These institutions differ from the common Irrigators Communities, widely entrenched and with numerous institutions, since they administer the land and the water given to them, but not the resource, as the former ones do. Nevertheless, together with these bottom-up institutions, top-down institutions are always needed for regulation, policy and governance, i.e., the River Basin Water Authorities, which play an important role in order to look for the common good or natural capital of the country.The impact of the EU Water Framework Directive on the Spanish groundwater policy is an important issue that has been treated in detail in several recent papers: Molinero *et al.* (2010); De Stefano *et al.* (2014); De Stefano *et al.* (2012). WFD has had a beneficial impact mainly because of two reasons: a) in the hydrological plans the groundwater bodies have to be identified, their ecological health assessed, and a program of measures to correct the situation, if necessary, has to be proposed; and b) all this information has to be duly submitted to the stakeholders in a detail. For the preparation of the second series of Hydrological Plans (2015-2021) to be submitted in the year 2015, the Spanish Groundwater Associations, with the help of the IGME, organized a two days conference (Madrid, 7 and 8 May 2014) to present and debate the Schemes of Important Topics for the preparation of each Plan. This well organized conference had very good participation by the Water Authorities representatives and also by the stakeholders in general. Later, on June 23, the Ministry for the Environment (MAGRAMA) also organized a similar conference in Madrid, but was not only related to groundwater issues. The outcome was that part of the obstacles mentioned in this paper are in the way of a solution in some areas, but there still remain unsolved aspects and areas that are quite 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 and the current delays in planning and in adopting measures. But this is only part of the reason, as excess of political interference, unwillingness to move from obsolete old paradigms, wicked subventions, and poor ethical behavior also play an important role. Spanish society is demanding a political pact on water, which the current government included in its electoral program, but it 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 close on time the 2009-2015 water plans asked by the WFD, due in 2008 and unfinished in mid-2014, when the second planning period 2015-2021 has to be set by the end of 2014. The reason resides in the fact 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 administration intervention but lacking general and long-term vision. Steps are slow and seriously affected by legal constraints and litigation, and Water Districts try to solve their own management problems via securing the politically friendly increase of water offer to an increasing water demand by demanding the central government to provide water imports from nearby river basins or desalination with subvention from public economic sources. This is a physically insoluble and too costly economically problem. The inadequate knowledge and consideration of groundwater and the water quality issues –some related to excess salinity—add to the complexity of the problem and not allow an effective water management. This actual experience shows that a change in the legal framework, social behavior and water use is urgently needed, even if it is a politically unpalatable duty. The way goes through a well-organized, informed, involved and ethically behaving civil society.

11. References

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