13 Lessons from Intensive Groundwater Use In Spain: Economic and Social Benefits and Conflicts

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Introduction

Background

Groundwater development has significantly increased during the last 50 years in most semiarid or arid countries of the world (Shah, 2004; Deb Roy and Shah, 2003). This development has been mainly undertaken by a large number of small (private or public) developers, with minor, if any at all, scientific, administrative or technological control. This is why some authors consider this new phenomenon as a *silent revolution* (Llamas and Martínez-Santos, 2005a,b). In contrast, the surface water projects developed during the same period are usually of larger dimension and have been designed, financed and constructed by government agencies, which also take on management and control, whether for irrigation or urban public water supply systems. This historical situation has often produced two effects: (i) most regulators have limited understanding and poor data on the groundwater situation and value; and (ii) in some cases the lack of control on groundwater development has caused serious problems that are later on reviewed in detail.

Spain, as the most arid country in Europe, is no exception to these trends. In Spain, and almost everywhere else, these problems have been frequently magnified or exaggerated by groups with lack of hydrogeological know-how, professional bias or vested interests (Llamas *et al.*, 1992). For instance, the World Water Council (2000, p. 13) states: 'Aquifers are being mined at an unprecedented rate – 10% of world's agricultural production depends on using mineral groundwater'. However, this 10% estimation is not based on any reliable data. In recent decades, the term groundwater overexploitation has become a pervasive and confusing concept, almost a kind of *hydromyth*, that has flooded the water resources literature. A usual axiom derived from this confusing paradigm or *hydromyth* is that groundwater is an

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unreliable and fragile resource that should only be developed if the conventional large surface water projects are not feasible. This groundwater resource fragility concept has been dominant in Spain during the last 20 years (López-Gunn and Llamas, 2000). In the last decade a good number of authors have also voiced this fragility as a common issue (Seckler *et al.*, 1998; Postel, 1999).

Another usual wrong paradigm or *hydromyth* is the idea that mining non-renewable groundwater is by definition a case of overexploitation, which implies that groundwater mining goes against basic ecological and ethical principles. Some authors (Delli Priscoli and Llamas, 2001; Abderraman, 2003) have shown that in some cases the use of non-renewable groundwater may be a reasonable option. This point of view has been approved by the UNESCO World Commission on the Ethics of Science and Technology (COMEST), as can be read in Selborne (2000).

Purpose

This chapter provides an overview of the positive and negative aspects of the intense groundwater development in Spain during the last 3–4 decades. During this period, Spain has become an industrialized country. The analysis of the changing role of groundwater in Spain's water policy may be useful for other countries that are undergoing or will undergo a similar processes. Llamas and Martínez-Santos (2005a,b) suggest that a worldwide debate on this topic is desirable. One step for this aim has been the organization by the Interacademy Panel (IAP) of an International Symposium on Groundwater Sustainability (Alicante, Spain 24–27 January 2006). The Spanish Water Act of 1985 is one of the few in the world that sets provisions for 'overexploited aquifers'. Relying on the Spanish experience, the main aim of this chapter is to present and discuss: (i) the many meanings of the terms groundwater (or aquifer) overexploitation and sustainability; (ii) the main factors to take into consideration in analysing the pros and cons of intensive groundwater development; and (iii) the strategies to prevent or correct the unwanted effects of intensive groundwater development.

What does intensively used or stressed aquifer mean? During the last decade the expression *water stressed-regions* has become pervasive in the water resources literature. Usually this means that there are regions prone to suffer now or in the near future serious social and economic problems resulting from water scarcity. The usual threshold to consider a region under water stress is 1000 m^3/person/year (United Nations, 1997, pp. 10–13), but some authors increase this figure to 1700 m^3/person/year. If this ratio is only 500 m^3/person/year, the country is considered to be in a situation of absolute water stress or water scarcity (Seckler *et al.*, 1998; Postel, 1999; Cosgrove and Rijsbesman, 2000). This is far too simplistic. Considering only the ratio between water resources and population has meagre practical application. Most water problems are related to quality degradation, and accentuated drought cycles, but not to its relative scarcity. As an example, a good number of Spanish regions with a ratio lower than 500 m^3/person/year enjoy high economic growth and high living standards. Yet, development reinforces itself, and water demand increases, providing rationale for more public investment in water projects. In general, resource scarcity results from economic development, which in turn is endogenous to processes well beyond the boundaries of water policies. Often, the cause–effect direction is mistakenly reversed to conclude that making more water will promote economic development. This causality does not resist close scrutiny.

In its 1997 Assessment of Global Water Resources, the United Nations did a more realistic classification of countries according to their water stress. This assessment considered not only the water/population ratio but also the gross national product per capita (United Nations, 1997, p. 138). Other experts, like Sullivan (2001), have also begun to use other more sophisticated indices or concepts in order to diagnose the current or future regions with water problems. While laudable, even these have yet to prove themselves.

Groundwater development during the past decades has significantly contributed to Spanish agricultural and regional development. These improvements have also taken place in developing countries as particularly highlighted in the cases of South Asia and China (Shah, Chapter 2; and Wang *et al.*, Chapter 3, this volume, respectively). However, there is a pressing need to manage groundwater development and mitigate the externalities of groundwater extraction, accounting for the temporary or intrinsic uncertainties related to water. Sustainable groundwater use requires, sine qua non, the participation of educated and informed groundwater users and other stakeholders. This demands urgently the development of institutional arrangements for groundwater management where users can work jointly with the corresponding water agencies. But close cooperation among individuals does not come naturally, especially when societies face zero-sum gains (Livingston and Garrido, 2004).

What Does Sustainability Really Mean?

Since its early appearance in 1987, the concept of sustainability has been proposed by many as a philosophy to solve most water problems or conflicts. The US Geological Survey (1999) defines groundwater sustainability, though from an exclusively hydrological point of view. The European Union's (EU) Water Framework Directive (WFD), enacted in December 2000, establishes that it is necessary to promote sustainable water use. Probably, most people agree with this general principle, but its practical application in natural resources management is daunting. Shamir (2000) considers that the sustainability concept has up to ten dimensions including hydrology, ecology, economics, policy, intergenerational and intragenerational. It is out of the scope of this chapter to elaborate more on this concept. However, it will be used with specific meaning as much as possible.

In our view, sustainability integrates the concept of future generations. But how many of these should be considered? No scientist is able to predict the situation 1000 years from now, and very few dare to present plausible scenarios for the 22nd century. Most current predictions refer to the needs of humans in one or two generations, i.e. not more than 50 years from now. It is clear that environmental problems have a natural science foundation, but also, and perhaps primarily, a social science foundation. Recently, Arrow *et al.* (2004) have argued that the accumulation of human capital at a faster rate than the consumption of natural stocks could be considered a sustainable growth path. While saving and investment can make growth sustainable, irreversible effects may warrant more precautionary extraction patterns.

The way to solve the existing water problems, mainly the lack of potable water, is not to persist on gloom-and-doom unrealistic campaigns, trying to create *environmental scares* and predicting *water wars in the near future* (see The Economist, 1998; Asmal, 2000; World Humanity Action Trust, 2000) but to improve its management. In other words, the crisis is not of physical water scarcity but of lack of proper water governance, capital and financial resources (Rogers *et al.*, 2006).

The Polysemic and Increasingly Useless Concept of Overexploitation: Overview

This section will consider first the concept of overexploitation from a general perspective, and then the failure of its application in Spain. The term overexploitation has been frequently used during the last three decades. Nevertheless, most authors agree in considering that the concept of aquifer overexploitation is one that resists a useful and practical definition (Llamas, 1992; Collin and Margat, 1993). Custodio (2000, 2002) and Sophocleous (2000, 2003) have most recently dealt with this topic in detail.

A number of conceptual approaches can be found in the water resources literature: safe yield, sustained yield, perennial yield, overdraft, groundwater mining, exploitation of fossil groundwater, optimal yield and others (see glossaries in Fetter, 1994, and Acreman, 1999). In general, these terms have in common the idea of avoiding *undesirable effects* as a result of groundwater development. However, this *undesirability* is not free of value judgements. In addition, its perception is more related to the legal, cultural and economic background than to hydrogeological facts.

For example, in a research study on groundwater-fed catchments, called Groundwater and River Resources Action Programme at the European Scale (GRAPES) (Acreman, 1999), three pilot catchments were analysed: the Pang in the UK, the Upper Guadiana in Spain and the Messara in Greece. The main social value in the Pang has been to preserve the amenity of the river, related to the conservation of its natural low flows. In the Messara, the development of irrigation is the main objective and the disappearance of relevant wetlands has not been a social issue. In the Upper Guadiana the degradation of some important wetlands caused by groundwater abstraction for irrigation has stirred an ongoing conflict between farmers and conservationists (Bromley *et al.*, 2001).

The Spanish Water Act of 1985 does not mention specifically the concept of sustainability in water resources development but indicates that use rates should be in balance with nature. It basically considers an aquifer as overexploited when the pumpage is close to, or larger than, the natural recharge.

The Regulation for the Public Water Domain enacted in pursuant to the 1985 Water Act says that 'an aquifer is overexploited or in risk of being overexploited, when the continuation of existing uses is in immediate threat as a consequence of abstraction being greater or very close to the mean annual volume of renewable resources, or when it may produce a serious water quality deterioration'. According to the law, 14 aquifers have been declared either provisionally or definitively overexploited, for which strict regulatory measures have been designed. However, to a large extent, these measures have not been successfully implemented and a situation of legal chaos still persists in many of these aquifers (MIMAM, 2000).

The misconception of considering that *safe yield* is practically equal to natural recharge, already shown by the late well-known American hydrologist Theiss in 1940, has been voiced by many other hydrogeologists (see Custodio, 2000; Sophocleous, 2000; Hernández-Mora *et al.*, 2001).

Several national and international conferences have been organized by Spanish hydrogeologists over the last two decades to discuss and help dispel the misconceptions related to aquifer overexploitation (see Custodio and Dijon, 1991; Simmers *et al.*, 1992). Nevertheless, the success of these activities was rather limited in Spain and abroad.

It was suggested that a possible definition is to consider an aquifer as overexploited when the economic, social and environmental costs that derive from a certain level of groundwater abstraction are greater than its benefits. Given the multifaceted character of water, this comparative analysis should include hydrologic, ecological, socio-economic and institutional variables. While some of these variables may be difficult to measure and compare, they must be explicitly included in the analysis so that they can inform decision-making processes. Following Hernández-Mora *et al.* (2001), the basic categories of extractive services and *in situ* services are taken into account in the description of costs and benefits of groundwater development. The National Research Council (1997) recognizes that the monetary value of groundwater's *in situ* services (avoiding subsidence, conservation of wetlands or maintaining the base flow of rivers, among others) is a rather complex and difficult task for which there is only limited information. Yet the WFD foresees that Member states must evaluate the environmental and resource costs, providing motivation to environmental economics to build on new applicable methods. Recently Llamas and Custodio (2003) have tried to present 'intensive groundwater use' as a more practical concept. According to the editors of that book 'groundwater use is considered intensive when the natural functioning of the corresponding aquifer is substantially modified by groundwater abstraction'. This concept only describes the physical changes but does not qualify its advantages or disadvantages from the many dimensions of the sustainability concept, including ecological, hydrological, economical, social, intragenerational and intergenerational. On the contrary, other terms such as overexploitation, overdraft and stressed aquifers have a derogatory meaning for most people.

Fortunately, the scientific literature on intensive use of groundwater is increasing rapidly. In the book previously mentioned 20 chapters written by more than 30 well-known authors are included. A second book dealing with intensive use has also been recently published (Sahuquillo *et al.*, 2005).

Water Resources of Spain

Climatic and hydrologic setting

Spain has an area of approximately 505,000 km^2. The average precipitation is 700 mm/year. However, this average has considerable spatial deviation, ranging from 100 mm/year in some islands in the Canary Archipelago to more than 2000 mm/year in the humid north. The average annual temperature is 14°C. The average potential evapotranspiration is about 700 mm/year. In most of Spain potential evapotranspiration is higher than precipitation. The average stream flow is about 110 km^3/year (220 mm/year). From this amount, about 80 km^3/year (160 mm/year) is surface runoff and about 30 km^3/year (60 mm/year) is groundwater recharge. At least one-third of Spain is endowed with good aquifers. These aquifers may be detrital, calcareous or volcanic (Fig. 13.1). The Water Administration has formally identified 411 aquifer systems or hydrogeological units (see Table 4.1 in Llamas *et al.*, 2001), which cover an area of approximately 180,000 km^2. The estimated natural recharge of these aquifers averages 30 km^3/year but varies with weather conditions between 20 and 40 km^3/year (Fig. 13.2).

Water uses

Spain's current total water use is about 36 km^3/year or about one-third of the total water resources (110 km^3/year). Use is distributed between irrigation (67%), urban water supply and connected industries (14%) and independent industrial uses and cooling (19%).

Spain has about 43 million inhabitants. This means there is an average usage of almost 3000 m^3/person/year, considering the whole country, but in some areas this indicator is in the range of 200 or 300. Table 13.1 shows the range of groundwater volumes used in Spain in recent years. The higher numbers correspond to dry periods in which groundwater use increases. The dramatic increase in the use of groundwater during the last 40 years is illustrated in Fig. 13.3.

This growth in groundwater use has been the result of groundwater development by individuals, small municipalities and industries. It has not been planned by government agencies. As a matter of fact, Spain is a serious case of *hydroschizophrenia*, i.e. of an almost complete separation of surface and groundwater in the mind of water planners (Llamas, 1985). These water planners have been almost without exception conventional civil engineers working in the Ministry of Public Works (and since 1996, in the Ministry for Environment). The Ministry of Agriculture, independently of the general water resources policy driven by the Ministry of Public Works, promoted the initial use of groundwater for irrigation in Spain in the 1950s. As a result, Spain is among the countries with the highest number of large dams per person: 30 large dams per million inhabitants (Fig. 13.4). The pace of large dam construction in Spain during the last 50 years has been almost 20 large dams per year (Fig. 13.5).

Within the EU, Spain has the lowest percentage (25%) of groundwater use for urban water supply (see Fig. 13.6). The explanation of this anomaly is not the lack of aquifers, but the *hydroschizophrenia* of the government water planners of the water supply systems to large cities and for grand surface water irrigation schemes.

Groundwater ownership and markets

Until the 1985 Water Act came into force, groundwater in Spain was private domain. In contrast, surface water was almost always public domain, ruled by government agencies. Because of the real or imagined problems related to the uncontrolled development of groundwater, the 1985 Water Act declared all

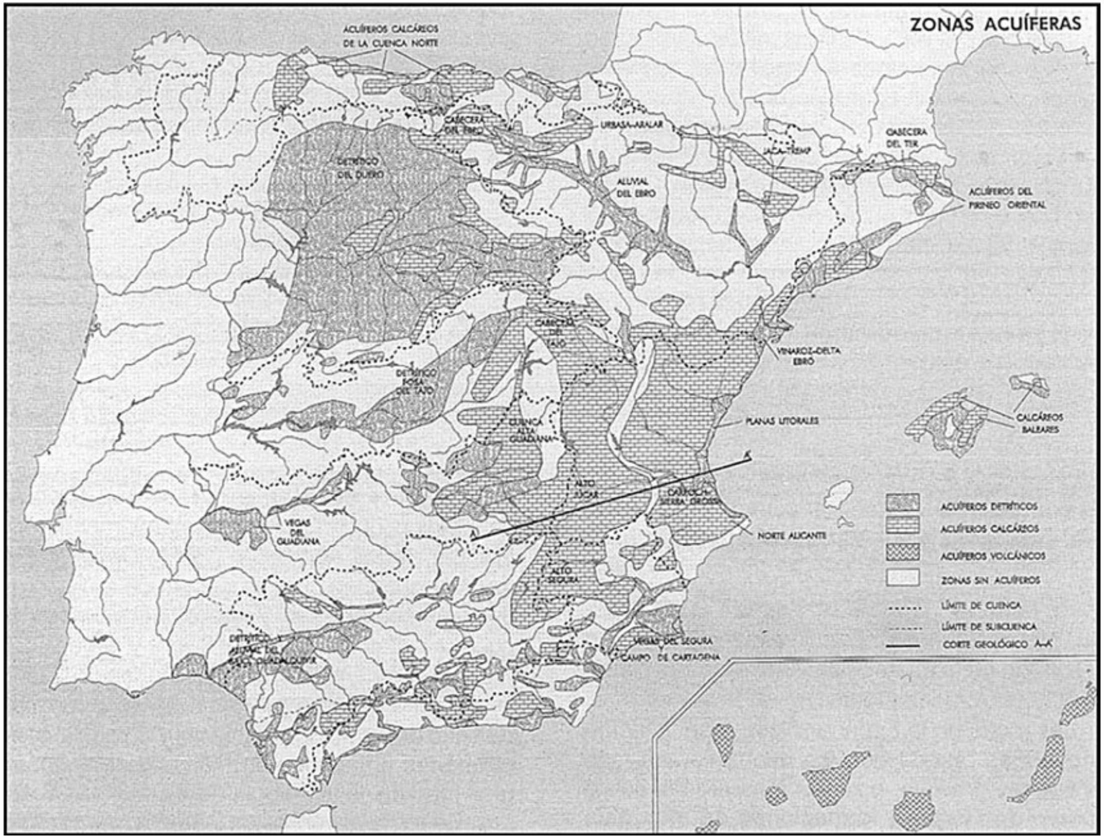

Fig. 13.1. Locations and types of main acquifers in Spain. (From MIMAM, 2000.)

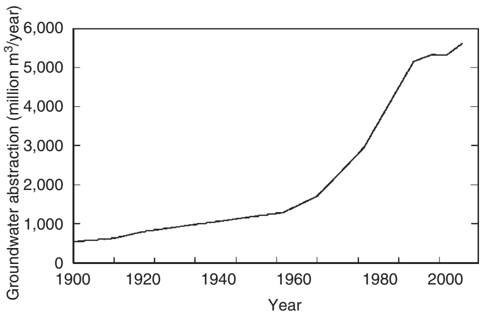

Fig. 13.2. Estimated natural groundwater recharge in Spain, 1940–1995. (From MIMAM, 2000.)

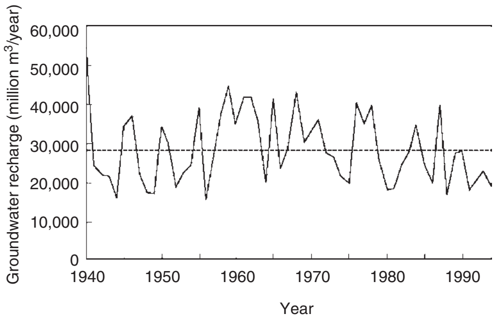

Fig. 13.3. Consumption development of groundwater in Spain, showing a rapid increase from the 1960s to date. (From MIMAM, 2000.)

Table 13.1. Spain's groundwater use summary (estimated from several sources). (From Llamas *et al.*, 2001.)

Activity	Volume applied (million cubic metres per year)	Percentage of total water (surface + groundwater)
Urban	1,000–15,000	~20
Irrigation	4,000–5,000	~25
Industrial and cooling	300–400	~5
Total	5,500–6,500	15–20

groundwater in Spain as public domain. Every new groundwater abstraction requires a permit granted by the corresponding water authority.

The groundwater developments made before 1 January 1986 may continue as private domain, using the same amount of groundwater as before. All these wells, galleries and springs should be inventoried and registered within the basin agencies registries. The main problem is that the legislators and the water authorities underestimated the number of groundwater abstractions and did not provide the economic means to register all the grandfathered groundwater rights. Even

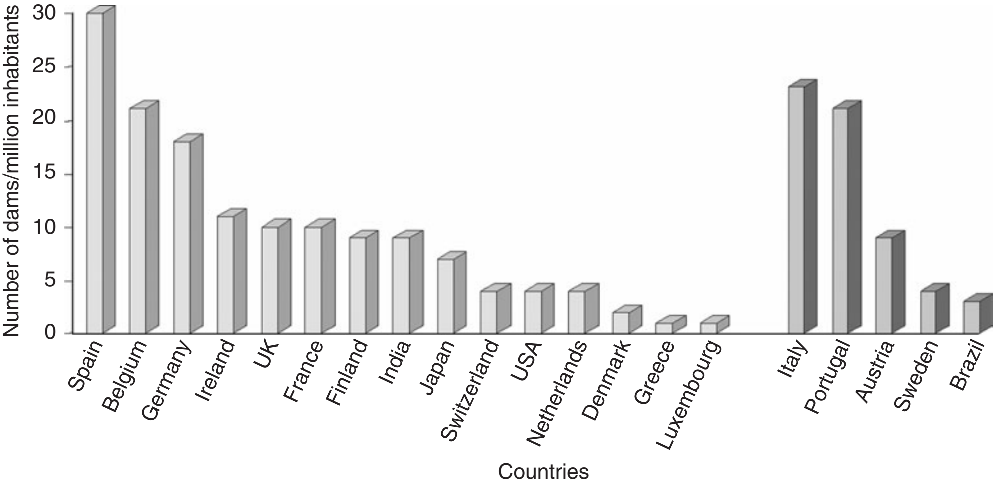

Fig. 13.4. Number of dams per capita in different countries. (From Llamas *et al.*, 2001.)

20 years after the enactment of the 1985 Water Act the number of private groundwater abstraction rights remains uncertain as do, by extension, the pumped volumes. Llamas *et al.* (2001, ch. 8) have estimated that the number of water wells in Spain is between one and two million. This means there are between 2 and 4 wells/km^2; however, this ratio is three times higher if it is applied only to the surface of the 400 aquifer systems. The average groundwater withdrawal from each well is low (between 2500 and 5000 m^3/year), indicating that most are meant for domestic use or small irrigation. The 1985 Water Act states that a permit is not necessary to drill a new well for abstracting less than 7000 m^3/year. Probably 90% of the private groundwater developments have an illegal or alegal status. In order to cope with this complex situation, in 1995 the government began a programme (called ARICA) with a cost of €60 million to have a reliable inventory of the water rights in Spain. The results of the ARICA programme were discouraging and it was practically abandoned. In 2002 the government began another similar programme (this time called ALBERCA) with a budget of €150 million. Detailed information on the progress of the ALBERCA programme is not available yet. However, according to Fornés *et al.* (2005) a larger budget would be necessary to clarify in full the inventory of groundwater rights.

On top of these disappointing results, and prompted to increase the economic efficiency of both surface and groundwaters, the 1985 Water Act was partly amended in 1999, mainly to introduce water markets in some way. This was mainly done to allow greater *flexibility* to sell or buy water rights. In principle, this new flexibility is not relevant to groundwater markets because in Spain most groundwater resources are still in private ownership and they could be sold or bought and leased like any other private asset. The importance of these groundwater markets varies according to the different Spanish regions. In most cases, these are informal (or illegal) markets and the information on them is not reliable (Hernández-Mora and Llamas, 2001). The Canary Islands are an exception to this general situation. This autonomous region of

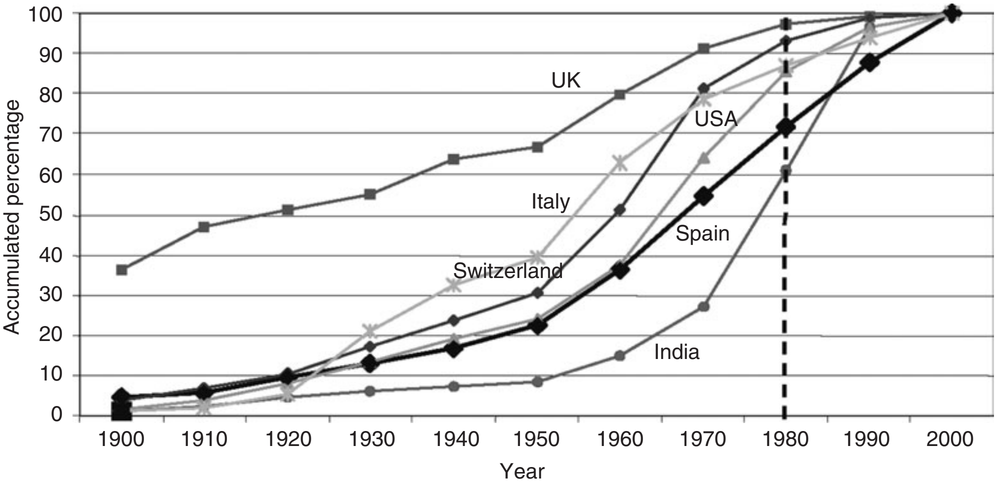

Fig. 13.5. Temporal dam construction rhythm in several representative countries. (From Llamas *et al*., 2001.)

Spain has a different water code. Almost 90% of the total water uses are supplied by groundwater. Practically all groundwater is in private ownership. Aguilera Klink (2002) has studied the pros and cons of the water markets in this archipelago. Other than this, the 1999 amendment has not produced any substantial water reallocation, even under the 2005 pre-drought conditions prevailing in the country.

Benefits of Groundwater Development

Groundwater sustainability must necessarily take into account the numerous dimensions of this concept, among them the socio-economic and even ecological benefits that result from groundwater use. Socio-economic benefits range from drinking water supply to economic development, as a result of agricultural growth in a region. With respect to the potential ecological benefits, the use of groundwater resources can often eliminate the need for new large and expensive hydraulic infrastructures that might seriously damage the natural regime of a river or stream and/or create serious social problems (World Commission on Dams, 2000).

Drinking water supply

Groundwater is a key source of drinking water, particularly in rural areas and on islands. In Spain, for example, medium and small municipalities (of less than 20,000 inhabitants) obtain 70% of their water supply from groundwater sources (MIMAM, 2000). In some coastal areas and islands the dependence on groundwater as a source of drinking water is even higher. Nevertheless, as it was

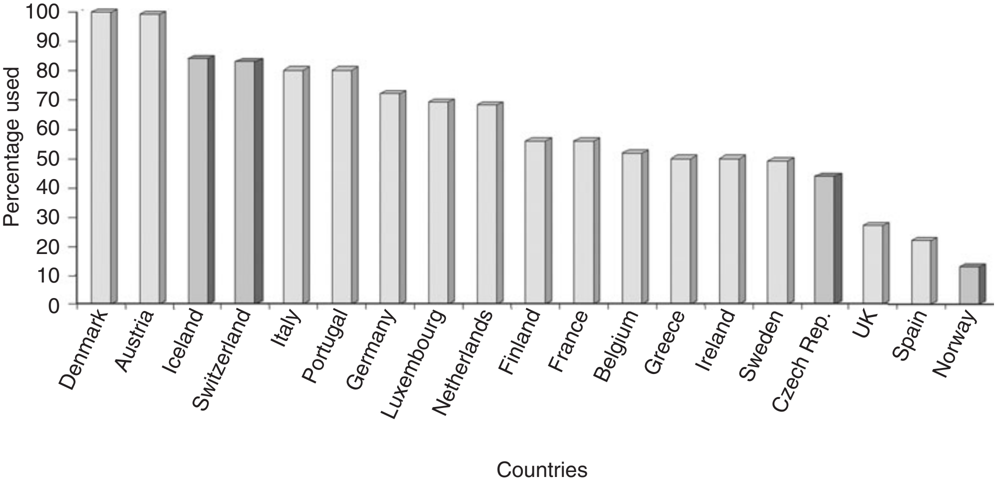

Fig. 13.6. Percentage of groundwater used for urban supply in several European countries. (From Llamas *et al*., 2001.)

previously mentioned, Spain is one of the European countries with the lowest proportion of groundwater uses for public urban water supply to large cities. Llamas (1985) explains the historical roots of this situation. There were two main causes. The first was that there was a very centralized government system where all the decisions in relation to water policy were taken by a small and selected group of civil engineers working for the Ministry of Public Works. The second was the failure in the 1850s of a proposal of another selected group of mining engineers who also worked for the government. Between the two social groups there existed a certain professional concurrence. Mining engineers supported the use of groundwater to solve Madrid's serious water problems in the latter half of the 19th century. They failed because neither the geology nor the water well technology at that time allowed sufficient understanding about the functioning and potential development of the nearby aquifers.

Irrigation

In Spain, as in many arid and semiarid countries, the main groundwater use is for agriculture. Although few studies have looked at the role that groundwater plays in irrigation, those that do exist point to a higher socio-economic productivity of irrigated agriculture using groundwater than that using surface water. A 1998 study of Andalusia (south Spain) showed that irrigated agriculture using groundwater is significantly more productive than agriculture using surface water, per volume of water used (Hernández-Mora *et al.*, 2001). Table 13.2 shows the main results of the Andalusia study. It is important to note that these results were based on the average water volumes applied in each irrigation unit (or group of fields). The water losses from the source to the fields were not estimated, but are significant in surface water irrigation. Other studies have calculated the volumes used in surface water irrigation as the water actually taken from the reservoirs. For example, the White Paper of Water in Spain (MIMAM, 2000) estimated an average use of 6700 m^3/ha/year and 6500 m^3/ha/year for the two catchments that are the subject of the Andalusia study without differentiating between surface and groundwater irrigation. Using these new figures and the volumes given for irrigation with groundwater in the Andalusia study, a more realistic average volume used for irrigation with surface water of 7400 m^3/ha/year can be estimated. Table 13.2 shows that productivity of groundwater irrigation is five times greater than irrigation using surface water and generates more than three times the employment per cubic metre used. It could be argued that the greater socio-economic productivity of groundwater irrigation in Andalusia can be attributed to the excellent climatic conditions that occur in the coastal areas. While good climatic conditions may influence the results, the situation is similar in other continental regions of Spain (Hernández-Mora and Llamas, 2001). The updated data presented by Vives (2003) about the Andalusian irrigation confirm the previous assessment about the greater social and economic efficiency of groundwater irrigation.

Table 13.3 provides an overview of Spanish irrigation, indicating the water sources and irrigation technologies. In general, drip irrigation and sprinkler systems are more common in the regions where groundwater is used more intensively.

When examining this section it is important to keep in mind the uncertainties of hydrologic data. However, the results are indicative of the greater productivity of irrigation using groundwater. This should not be attributed to any intrinsic quality of groundwater. Rather, causes should be found in the greater control and supply guarantee that groundwater provides mainly during droughts (see Llamas, 2000), and the greater dynamism that has characterized the farmers who have sought their own sources of water and bear the full (direct) costs of drilling, pumping and distribution (Hernández-Mora and Llamas, 2001).

Table 13.2. Comparison of irrigation using surface and groundwaters in Andalusia. (From Hernández-Mora *et al*., 2001.)

	Origin of irrigation water			
Indicator for irrigation	Groundwater	Surface water	Total	Relation groundwater/ surface water
Irrigated surface (10^3 ha)	210	600	810	0.35
Average use at origin (m^3/ha/year)	4000	7400	6500	0.54
Water productivity (€/m^3)[a]	2.16	0.42	0.72	5.1
Employment generated (EAJ/10^6 m^3)[b]	58	17	25	3.4

[a] €1 ≅ \$1.3.

[b] EAJ ~= equivalent annual job, which is the work of one person working full-time for 1 year.

Hydrologic benefits

Another potential benefit of groundwater development is the increase in net recharge in those aquifers that, under natural conditions, have the water level close to the land surface. The drawdown of the water table can result in a decrease in evapotranspiration, an increase in the recharge from precipitation that was rejected under natural conditions and an increase in indirect recharge from surface water bodies. Johnston (1997) analysed 11 American regional aquifers, showing that intensive groundwater development in 9 of these aquifers has resulted in significantly increased recharge.

Shah *et al.* (2003) studied seasonal recovery of groundwater levels for the whole of India after the monsoon rain. They concluded that the depletion of the water table due to groundwater abstraction increases significantly the precipitation recharge. This is quite in agreement with the general hydrogeological principles. There is ample evidence showing that extractions increase the recharge rates augmenting the sustainable use level.

A clear example of this situation is the increase in available resources for consumptive uses that followed intensive groundwater pumping in the Upper Guadiana basin in central Spain (see Bromley *et al.*, 2001). It has been estimated that average renewable resources may have increased between one-third and one-half under disturbed conditions. Figure 13.7 illustrates these results. Prior to the 1970s, groundwater pumping in the Guadiana basin did not have significant impacts on the hydrologic cycle. Intensive pumping for irrigated agriculture started in the early 1970s and reached a peak in the late 1980s. As a result, wetlands that, under semi-natural conditions, had a total extension of about 25,000 ha, cover only 7000 ha today. In addition, some rivers and streams that were naturally fed by the aquifers have now become net losing rivers.

The results of the decline in the water table have been twofold. On one hand, a significant decrease in evapotranspiration from wetlands and the water table, from about 175 million cubic metres per year under quasi-natural conditions to less than 50 million cubic metres per year today. On the other hand, there has been a significant increase in induced recharge to the aquifers from rivers and other surface water bodies. Consequently, more water resources have become available for other uses, mainly irrigation, at the cost of negative impacts on dependent natural wetlands. These impacts are highlighted later.

Disadvantages of Groundwater Use

Groundwater level decline

The observation of a trend of continuous significant decline in groundwater levels is frequently considered an indicator of imbalance between abstraction and recharge. While this may be most frequently the case, the approach may be somewhat simplistic and misguided. Custodio (2000) and Sophocleous (2000) remind us that any groundwater withdrawal causes an increasing piezometric depletion until a new equilibrium is achieved between the pumpage and the

Table 13.3. Descriptive elements of Irrigation in Spain (in hectares). (From MAPYA, 2001.)

								Predominant irrigation technique (%)		
Autonomous Community	Surface water	Groundwater	Inter-basin transfers	Water returns	Reuse	Desalinized	Total	Flood	Sprinkler	Drip irrigation
Andalusia	546,703	224,670	2,783	85	5,639		779,880	42	21	37
Aragón	373,886	20,315		21			394,222	80	18	2
Castilla-León	361,055	113,164		12,428	29		486,676	61	39	–
Castilla-La Mancha	124,262	228,528	1,011				353,801	32	55	13
Cataluña	205,031	53,043		6,377	342		264,793	69	12	19
Extremadura	207,337	3,151					210,488	69	26	5
Galicia	85,061	92					85,153	64	36	–
Murcia	42,553	93,810	51,104	360	1,600	271	189,698	60	3	37
Navarra	79,941	1,682		50			81,673	89	10	1
Rioja	45,771	3,564					49,335	66	29	5
C. Valenciana	146,691	154,821	40,258	4,178	4,534		350,482	80	1	19
Total	2,218,291	896,840	95,156	23,499	12,144	271	3,246,201	59	24	17

new recharge (or capture). This transient situation can be long depending on aquifer characteristics.

With respect to the climatic cycles, in arid and semiarid countries significant recharge can occur only after a certain number of years, which may easily be from 5 to 10 years. Therefore, continuous decline in the water table during a dry spell of a few years, when recharge is low and abstraction is high, may not be representative of long-term trends. Declines in water levels should indicate the need for further analysis. In any case, declines in the water table can result in a decrease in the production of wells and in pumping costs. This economic impact can be more or less significant depending on the value of the crops obtained. For instance, in some zones of Andalusia, the value of crops in greenhouses may reach \$50,000–70,000/ha/year. The water volume used is between 4000 and 6000 m^3/ha. The energy needed to pump 1 m^3 100 m high is 0.3–0.4 kWh. If a \$0.03 kWh energy cost is assumed, this means an increase in energy costs in the order or \$0.01–0.02/m^3.

Analyses on water irrigation costs are rather scarce. The WFD mandates that Member States should collect these and all relevant economic information related to the water services. A preliminary assessment has been done in Spain, which is mentioned by Estrela (2004). Table 13.4 compiles a few studies that have attempted to evaluate the impact of tariff increases as a result of the implementation of Article 9 of WFD.

Table 13.4 provides indication that the application of the full cost recovery (FCR) water rates may have a significant impact in farmers' rents and water demand. Yet, by no means should it be expected that the WFD would entail catastrophic results to the farming sector. This is proven by the evidence supported by the irrigation sector relying on groundwater resources. Generally, water costs are much closer to the FCR prices indicated in Table 13.4 than to the current prices of surface water. Yet, irrigation relying on surface sources will need to adopt more efficient water conveyance and application technologies.

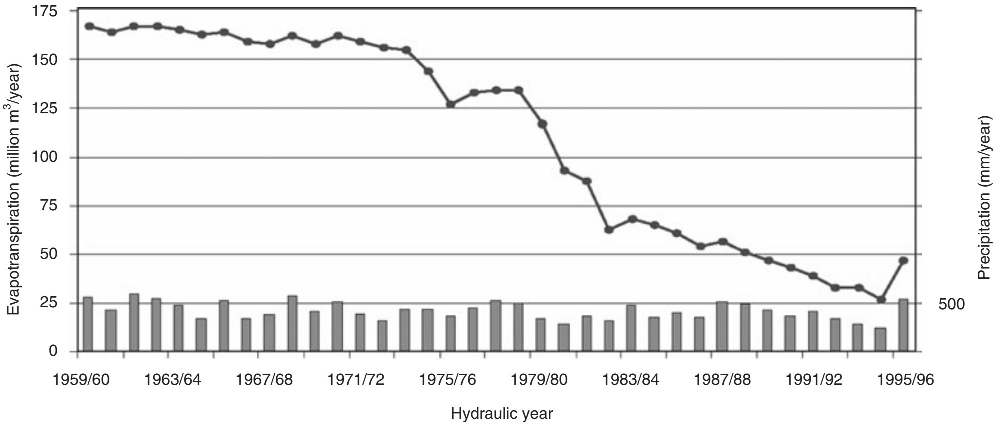

Fig. 13.7. Temporal evolution of evapotranspiration from the water table in the Upper Guadiana basin, caused by water table depletion. (From Martínez-Cortina, 2001, as cited in Llamas *et al.*, 2001.)

Table 13.4 also shows the relevance of water conservation, resulting from FCR prices. Conventional wisdom about water demand for irrigation in Spain should be profoundly revised, in view of the likely reductions that will be achieved by better pricing.

In 2003 the Ministry for the Environment (MIMAM, 2004), in agreement with Article 5 of the WFD, did a preliminary analysis of the cost of groundwater in Spain. This preliminary analysis estimates the cost of groundwater for irrigation and for urban water supply in each of the 400 Spanish hydrogeologic units. The average groundwater irrigation cost for the whole of Spain is about \$0.15/m^3, but there exists a great dispersion of values from \$0.04/m^3 to \$0.40/m^3. This assessment has been done without specific field surveys, and should therefore be considered only as a preliminary approach. The analysis does not include an estimation of the average value of the crops guaranteed with the groundwater abstraction. Experience shows that in Spain the ratio between the value of the crop and the cost of groundwater irrigation is usually very small, usually smaller than 5–10%. In other words the silent revolution of groundwater intensive use is mainly driven by output markets (Llamas and Martínez-Santos, 2005a,b), and will not be deterred by the increasing pumping costs of lower water tables.

A significant fact is that a large sea water desalination plant (40 million cubic metres per year) has been completed in Almería (south Spain) in 2004. The main use of this treated water was supposed to be greenhouse irrigation. The price of this desalinated sea water offered by the government to the farmers is in the order of \$0.40/m^3. This is a political price subsidized by the EU and by the Spanish Government. The real cost might be about double. The farmers are reluctant now to accept the price of \$0.40/m^3, although in that area the value of the greenhouse crops obtained is in the order of \$60,000/ha/year and the cost of the necessary 4000–6000 m^3/ha/year would be smaller than \$2000–3000/ha/year or less than 5% of the crop value. Probably the main reason for their reluctance is that in some cases they can buy or obtain groundwater at an even lower price. They do not care about the right to abstract such groundwater because, as it has been previously stated, the administrative and legal situation of groundwater rights is usually chaotic; in other words, most of the water wells in operation are illegal and the government is unable to control them. The preliminary economic analyses in the Jucar basin (Estrela, 2004) seem to confirm that the market drives the silent revolution of groundwater intensive use. For instance, in the small aquifer Crevillente in that basin, farmers are pumping their groundwater from a depth of almost 500 m at a cost of \$0.40/m^3. They grow special grapes for export with a value of about \$20,000–30,000/ha. They use groundwater at about 3500 m^3/ha/year. Therefore the ratio of groundwater irrigation cost to the crop is less than 5%. The sustainability of this groundwater abstraction is not threatened by the groundwater level depletion but because of groundwater quality degradation.

Degradation of groundwater quality

Groundwater quality is perhaps the most significant but not the most urgent challenge to the long-term sustainability of groundwater resources. Yet, accord-

Table 13.4. The effects of the WFD on the irrigation sector. (From Garrido and Calatrava, 2006.)

	Present rate		Tariff increase		Results		
RBA	Type	Levels[a](€/cm)	Medium	FCR[b]	Farm income	Water demand	Other results
Duero	Per hectare	0.01	0.04	0.06	–40% to –50%	–27% to –52%	Great influence of agricultural policies
Guadalquivir	Per hectare and volume	0.01–0.05	0.05	0.1	–10% to –19%	0% to –10%	Same
Duero	Per hectare and volume	0.01	0.04	0.1	–10% to –49%	–5% to –50%	Technical response
Guadalquivir	Per hectare and volume	0.01–0.05	0.06	0.12	–10% to –40%	–1% to –35%	Technical and crop response
Guadalquivir	Per hectare and volume	0.01–0.05	0.03	0.09	–16% to –35%	–26% to –32%	Technical and crop response
Guadiana	Per hectare	0.005	0.03	0.06	–15% to –20%	–30% to –50%	Technical and crop response
Júcar	Per hectare, volume and hourly rates	0.03–0.15	0.06	0.15	–10% to –40%	0% to –40%	Technical response
Segura	Per hectare, volume and hourly rates	0.05–0.30	0.10	0.25	–10% to –30%	0% to –10%	Very inelastic demand

[a] Equivalent measure.
[b] FCR = Full cost recovery rates.

ing to the Kuznet's curve, countries implicitly accept a degradation of their environmental quality in return of higher living standards, up to a point where the preferences are reversed. This point has been empirically estimated to be in the range of $6000–10,000 of per capita income.

Restoration of contaminated aquifers can be a very costly and difficult task. Most often, degradation of groundwater quality is primarily related to as point or non-point source pollution from various sources such as return flows from irrigation, leakage from septic tanks and landfills or industrial liquid wastes. These problems are not exclusive to industrialized countries but also may be serious in developing countries. The WFD emphasizes the recovery of groundwater quality in the EU but pays little attention to groundwater quantity problems. This situation may be caused by the insufficient participation of European Mediterranean experts in the preparation of the WFD. Therefore, other arid and semiarid countries should be very prudent in taking the WFD as a good paradigm for their water policy. Groundwater abstraction can also cause changes in groundwater quality. Some indicators of the susceptibility of an aquifer to water quality degradation are given in Custodio (2000). Although groundwater pollution is possibly the most serious problem from a long-term perspective, the quantitative issues may be the more urgent and politically pressing ones. In these cases, the problem is often related to inadequate well field location and not necessarily to the total volumes abstracted. Technical solutions to deal with problems of saline or lower-quality water intrusion have been developed and applied successfully in some places such as California and Israel. Unfortunately, the public awareness in Spain about groundwater pollution problems is still weak, mainly due to the scarcity of government reports and action to assess and to abate groundwater pollution.

Susceptibility to subsidence and/or collapse of the land surface

Aquifers in young sedimentary formations are prone to compaction as a result of water abstraction, and therefore the decrease in intergranular pore pressure. For example, this has been the case in the aquifers underlying Venice or Mexico City. More dramatic collapses occur commonly in karstic landscapes, where oscillations in water tables as a result of groundwater abstractions can precipitate the occurrence of karstic collapses. In both cases, the amount of subsidence or the probability of collapses is related to the decrease in water pressure. Fortunately, these types of geotechnical problems are not relevant in Spain.

Interference with surface water bodies and streams

Decline in the water table as a result of groundwater withdrawals can affect the hydrologic regime of connected wetlands and streams. Loss of base flow to streams, desiccation of wetlands and transformation of previously gaining rivers to losing rivers may all be potentially undesirable results of groundwater abstraction and serve as indicators of possible excessive abstraction. The already mentioned Upper Guadiana catchment in Spain is a typical example of this type of situation, which will be dealt with in more detail later. According to the WFD most groundwater abstraction in the Upper Guadiana basin in Spain must be cancelled because of its evident interference with the surface waters and its ecological impacts. However, the WFD states that when this solution implies serious social problems, the corresponding Member State may ask for derogations based on the hydrological, economic and social consequences. Most likely Spain will request derogations to the EU not only in the Upper Guadiana basin but also in many other aquifers where an intensive use of groundwater exists.

Ecological impacts on groundwater-dependent ecosystems

The ecological impacts of drawdown of the water table on surface water bodies and streams are increasingly constraining new groundwater developments (Llamas, 1992). Drying up of wetlands, disappearance of riparian vegetation because of decreased soil moisture and alteration of natural hydraulic river regimes can all be used as indicators of overexploitation. Reliable data on the ecological consequences of these changes are not always available, and the social perception of such impacts varies in response to the cultural and economic situation of each region. The lack of adequate scientific data to evaluate the impacts of groundwater abstraction on the hydrologic regime of surface water bodies makes the design of adequate restoration plans difficult. For instance, wetland restoration programmes often ignore the need to simulate the natural hydrologic regime of the wetlands, i.e. not only restore its form but also its hydrological function. Similar problems result in trying to restore minimum low flows to rivers and streams. Oftentimes minimum stream flows are determined as a percentage of average flows, without emulating natural seasonal and year-to-year fluctuations to which native organisms are adapted.

The social perception of the ecological impacts of groundwater abstraction may differ from region to region and result in very different management responses. GRAPES, an EU-funded project previously mentioned, looked at the effects of intensive groundwater pumping in three different areas: Greece, Great Britain and Spain (Acreman, 1999). In the Pang River in Britain, conservation groups and neighbourhood associations with an interest in conserving the environmental and amenity values of the river that had been affected by groundwater abstraction mainly drove management decisions. In the Upper Guadiana basin, dramatic drawdown in the water table (30–40 m) caused jointly by groundwater abstraction and drought (see Fig. 13.8) resulted in intense conflicts between nature conservation officials and environmental non-governmental organizations (NGOs), irrigation farmers and water authority officials. The conflicts have been ongoing for the last 20 years and have not yet been resolved. Management attempts to mitigate the impact of water level drops on the area's wetlands have so far had mixed results (Fornés and Llamas, 1999; Bromley *et al.*, 2001). On the other hand, in the Messara Valley in Greece, the wetland degradation caused by decline in the water table has not generated any social conflict. This situation seems to confirm that ecological awareness is deeply related to economic value of water and to the cultural background of each region.

Stakeholders' Participation in Groundwater Management

Spain has a long tradition of collective management of common pool resources. Probably the *Tribunal de las Aguas de Valencia* (Water Court of Valencia) is the most famous example. This Court has been meeting at noon every Thursday for many centuries at the entrance of Cathedral of Valencia to solve all the claims among the water users of a surface irrigation system located close to Valencia. All the members of the Court are also farmers. The decisions or settlements are oral and cannot be appealed to a higher court. The system has worked and it is a clear proof that 'the tragedy of commons' is not always true. Further evidence of social cooperation in Spain is the nearly 6000 *Comunidades de Regantes* (Irrigation Communities of Surface Water Users Associations). Some of them have been in operation for several centuries. Currently these communities are legally considered entities of public right. They are dependent on the Ministry for the Environment and are traditionally subsidized with public funds, mainly for the maintenance of the irrigation infrastructures.

The 1985 Spanish Water Act preserved the traditional *Comunidades de Regantes* that existed before its enactment and recommended these institutions for surface water management. It also extended this type of collective institution to groundwater management, and required the compulsory formation of *Comunidades de Usuarios de Aguas Subterráneas* (Groundwater Users Communities) when an aquifer system was legally declared overexploited. A short description of these institutions is contained in Hernández-Mora and Llamas (2000).

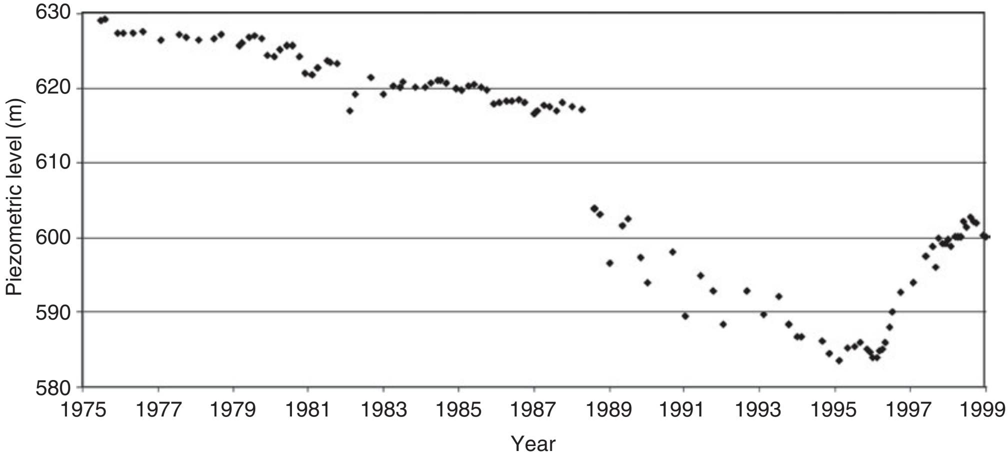

Fig. 13.8. Water table evolution in Manzanares (Upper Guadiana catchment, Spain). (From Martínez-Cortina, 2001, as cited in Hemández-Mora *et al.*, 2001.)

A more detailed description of the nature and evolution of some of these new groundwater user associations and communities can be found in López-Gunn (2003). The current situation can be summarized as follows:

1. It seems clear that the key issue for the acceptable functioning of these institutions is a bottom-up approach from the outset on the part of the governmental water authorities. This explains the almost perfect functioning of the Llobregat delta groundwater user association, which has been in operation since the 1970s under the previous 1879 Water Act. In that Water Act groundwater was legally privately owned but the corresponding Water Authority officers and the groundwater users (mainly water supply companies and industries) were able to work jointly. Something similar has occurred in the implementation of the Groundwater User Community for the eastern La Mancha aquifer located in the continental plateau. In this case, the groundwater users are mainly farmers and the irrigated surface covers about 900 km^2. This aquifer has never been declared legally 'overexploited' by the corresponding Water Authority.

2. In two important aquifers the situation has been the opposite. The western La Mancha and the Campo de Montiel aquifers are also located in the continental plateau in Spain. Their total area is about 7500 km^2 and their irrigated area is about 2000 km^2. The Guadiana River Water Authority legally declared both aquifers overexploited in 1987, in a typical top-down and control-and-command approach. Only in 1994 the corresponding groundwater user communities were implemented. And this was only possible thanks to a generous economic subsidies plan (paid mainly by the EU) to compensate the decrease in the groundwater abstraction. Nevertheless, a good number of farmers have continued to drill illegal water wells and they are not decreasing their pumpage. On the other hand, after 10 years the economic incentives from the EU have been discontinued. The Spanish Parliament asked the Government in July 2001 to present a plan for the sustainable use of water in this area by July 2002. This requirement has not been accomplished yet by Sophocleous (2000).

As the chief engineer for groundwater resources in the Ministry for Environment stated, serious difficulties have been faced in enforcing the setting up of the groundwater users associations in the aquifers legally declared 'overexploited' (Llamas, 2003). Only 2 out of 17 groundwater user communities that have to be implemented in the corresponding legally declared 'overexploited aquifers' are operative (Hernández-Mora and Llamas, 2001; Llamas *et al.*, 2001, ch. 9). As recognized in the White Paper on Water in Spain (MIMAM, 2000), the main cause is that these new groundwater user communities were established top-down, i.e. the water authorities imposed their implementation without the agreement of the farmers who are the main stakeholders. The 1999 amendments to the 1985 Water Act and the 2001 Law of the National Water Plan have provisions to overcome these difficulties and to foster the implementation of institutions for collective management of aquifers with ample participation of the stakeholders under a certain control of water authorities. It is too early to assess the results of these provisions.

In Spain, in addition to the communities born under the auspices of the 1985 Water Act, there are a large number of private collective institutions or associations to manage groundwater. Only a few years ago a group of them set up the Spanish Association of Groundwater Users. This is a civil (private) association that is legally independent of the Ministry for the Environment. Despite the wide recognition of the benefits of this type of associations, it is early to ascertain whether the needed economic, tax, and operational incentives are in place.

Hydrosolidarity and Groundwater Management in Spain

Overview

In Spain, like everywhere else, ethical factors play a crucial role in water uses and water management. Several recent publications address this topic (see Delli Priscoli and Llamas, 2001; Selborne, 2000; Llamas, 2003b). Human solidarity is one of the ethical principles that underlay most water policy agreements or treaties. One of the meanings of the concept of solidarity, as it applies to the use of natural resources, is that a person's right to use those resources should be constrained or limited by the rights or needs of other human beings now or in the future, including protection of the natural environment.

Nowadays, few people would dare to speak openly against hydrosolidarity (the need to share water resources). In practice, however, it might be difficult to find constructive ways to facilitate an equitable and fair sharing of water resources among concerned stakeholders, particularly in densely populated arid and semiarid regions. Lack of knowledge, arrogance, vested interests, neglect, institutional inertia and corruption are some of the obstacles frequently encountered to achieve hydrosolidarity (Llamas and Martínez-Santos, 2005b). The noble and beautiful concept of hydrosolidarity may also be used in a corrupt or unethical way by some lobbies in order to pocket *perverse subsidies*, which are bad for the economy and the environment (Delli Priscoli and Llamas, 2001). An example of the improper use of hydrosolidarity is that of the Segura catchment area. It has influenced the approval of the large aqueduct for the Ebro River water diversion included in the first National Water Plan in Spain, which was approved as a Law in July 2001 by the Spanish Parliament, and rebuffed after the general election of March 2004.

The Segura catchment

This section is mainly taken from an invited paper presented by Llamas and Pérez Picazo in the 2001 Stockholm World Water Week. The term 'hydrosolidarity' has been coined mainly by professors Falkenmark and Lundquist who were the organizers of this water week.

Hydrology

The Segura catchment is located in south-eastern Spain. Its main features are: (i) surface area 19,000 km^2; (ii) average annual precipitation: 400 mm, ranging from 800 mm in the headwater to 200 mm in the coastal plain; (iii) annual potential evapotranspiration: 800–900 mm; (iv) average streamflow: 1000 million cubic metres. The relief is abrupt with mountains that reach an altitude of 2000 m. The geology is complex with numerous faults and thrusts. Calcareous aquifers cover about 40% of the catchment's surface. Natural groundwater recharge is estimated at about 600 million cubic metres per year (about 60% of the total stream flow). The climate is typical of Mediterranean regions: hot summers, frequent flash floods and long droughts.

Water development until the 1960s

As much as 60% of the Segura River basin is within the Murcia Autonomous Region and the remaining 40% divided between the autonomous regions of Valencia and Castilla-La Mancha. The mild climate and the important base flow (typical of a karstic catchment) of the Segura River encouraged the development of an important agricultural economy in the region. It was based on an irrigation network on the flood plains of the middle and lower part of the catchment area, which dates as far back as the Muslim occupation 1200 years ago. Vegetables, citrus and other fruits have been cultivated in the region for many centuries. Agro-industry (food processing) has also been significant at least since the beginning of the 20th century. Collective systems to manage surface irrigation were implemented several centuries ago.

Until recently, agriculture was the main revenue-generating activity in the Segura catchment area. Murcia was considered the orchard of Spain. Since the integration of Spain in the EU (1986), the demand for its agricultural products increased significantly. The scarcity and/or variability in the availability of surface water resources have motivated the construction of 24 reservoirs that provide total storage of about 1000 million cubic metres. Although good at preventing floods, they have not satisfied the farmers' water demands for irrigation at a nominal price. Politicians and engineers who have advocated for the transfer of water resources from 'humid' Spain to 'dry' Spain have backed the old paradigm, with intense reliance on subsidies. In 1933, the first formal proposal to transfer water from the Tagus River headwaters (in central Spain) to the Segura River was formally made, but became operative only in 1979.

Groundwater abstraction boom

In the 1950s and 1960s, the Spanish Ministry of Agriculture launched a significant effort to promote groundwater irrigation in Spain. This promotion can be said to be totally independent of the National Water Policy that, as mentioned earlier, was driven by the corps of civil engineers of the Ministry of Public Works. This initial activity, heavily subsidized with public funds, soon became a catalyst that promoted intensive water well drilling by many private farmers in many regions of Spain. The most active region in this respect was the Segura catchment area. There were several reasons for the special development of groundwater abstraction in this region: (i) the area had a long tradition of irrigation with surface water and a traditional capacity to market high-value crops in Spain and abroad; (ii) many farmers had the expectation that these groundwater-irrigated areas would have some kind of preference in the allocation of surface water coming from the Segura reservoirs, from the Tagus River water transfer or from the future Ebro River water transfer project. In 1976, several years before the arrival of the first Tagus water, the new areas irrigated with groundwater required more water than the total theoretical volume to be transferred to the Segura catchment in the 1980s.

In Spain, according to the Water Law of 1879, groundwater was private-owned. The landowner could drill a water well in his or her land and pump as much groundwater as he or she wished, unless a third person was affected. Nevertheless, in the 1950s special regulations were enacted by the government that theoretically made groundwater a part of the public domain in the *Vegas del Segura* (Segura flood plains). The lack of experts in hydrogeology in the Segura Water Authority made this regulation difficult to enforce.

Even after the enactment of the 1985 Water Act the control of the old and new water wells in the Segura catchment area is rather scarce. The situation can accurately be described as one of administrative and legal 'chaos' (see Llamas and Pérez Picazo, 2001). For example, the official White Paper on Spain's Water (MIMAM, 2000, p. 343) admits that in this region only about 2500 water wells out of more than 20,000 drilled are legally inventoried by the Segura Water Authority.

The Tagus River water transfer and the future Ebro River water transfer

In 1979, almost 50 years after the first formal proposal, water from the Tagus River was transferred to the Segura catchment through a 300 km long aqueduct. The capacity of this aqueduct is about 33 m^3/s or 1000 million cubic metres per year, but the maximum volume approved for transfer during the first phase was only 600 million cubic metres per year. The reality is that the average volume transferred during the first two decades of operation of the aqueduct has been about 300 million cubic metres per year. The theoretical 600 million cubic metres to be transferred was distributed thus: 110 million cubic metres for urban water supply, 400 million cubic metres for irrigation and 90 million cubic metres as estimated losses during transfer. It was also stipulated that when the volume of water transferred is smaller that this theoretical amount, urban water supply had a clear priority. One interesting aspect of this project is that the beneficiaries of the transferred Tagus water pay a tariff for the water that is significantly higher than that usually paid by surface water farmers in Spain (approximately €0.005/m^3). In this case, they pay an average of about €0.1/m^3, although water for urban supply has a higher tariff than water for irrigation. The Law of the National Water Plan enacted in 2001 approved a new water transfer of 1050 million cubic metres per year from the Ebro River in northern Spain to several regions along the Mediterranean coast. Almost 50% of this volume was for delivery to the Segura catchment area. The planned aqueduct was almost 900 km long. Out of the total volume transferred, about 50% is for urban water supply and the rest for supplying water to areas in which groundwater abstraction has been excessive and has impacted the storage and groundwater quality of the aquifers. The Ebro water transfer met strong opposition among many different groups, parties and area-of-origin regional governments. Demonstrations summoned hundreds of thousands of people Valencia (for) and Zaragoza (against) the transfer. According to the government, the real cost of the Ebro water transfer would be about €0.30/m^3, but analysts argued it would be much higher.

The conflict about the Ebro water transfer: lack of hydrosolidarity or false paradigms?

In 2001 a poll was held to assess the social perception of the Ebro water transfer. Of those interviewed, 50% were in favour of the transfer, 30% were against it and the remainder had no opinion on the issue. One could conclude that those who were against the Ebro transfer lacked solidarity with the Mediterranean regions because they denied water to *thirsty areas*, while the Ebro River has a surplus of water, which is 'wasted uselessly' into the Mediterranean Sea. Most people, in every culture or religion think that it is a good action to give fresh water to the thirsty. In Western civilization this is a biblical tenet. But are the people in the Segura catchment region really thirsty? Certainly not. Almost 90% of the water used in this area is for irrigation of high-value crops and not for urban water supply. The irrigation economy in Segura is flourishing and very efficient. Table 13.5 shows the evolution of irrigated lands in the Segura catchment region, which has almost tripled since 1933, when the use of surface water reservoirs and groundwater was minimum.

The second old and current false paradigm is that farmers cannot (and should not) pay the *full cost* of the infrastructures to bring them water from the Ebro River. Most authors consider that if the full cost of the transfer were passed on to the farmers and urban users through water use fees, they would not support the Ebro water transfer or be willing to pay for it, since there are cheaper and faster solutions to meet their water needs. As discussed earlier, detailed studies undertaken in Andalusia, Spain, have shown clearly that groundwater irrigation is much more efficient than surface water irrigation: it produces about five times more cash per cubic metre used, and three times more jobs per cubic metre. The analysis done for Andalusia (a sample of almost one million hec tares), and the conclusions drawn from it, can be applied to most irrigated areas of Spain (3.5 million hectares). Other studies shown in Table 13.4 support this conclusion.

Llamas and Pérez-Picazo (2001) considered that both paradigms are now obsolete. However, some time will be necessary to change the mentality of the general public. These false paradigms are also frequent in other countries, as it is mentioned in Llamas and Martínez-Santos (2005b). It seems probable that the conflicts between the farmers and the conservation lobbies will increase in the near future. To avoid or mitigate such conflicts a stronger policy of transparency, accountability and general education (without obsolete paradigms) seems important.

Table 13.5. Evolution of irrigated area in the Segura catchment area. (From Llamas and Pérez Picazo, 2001.)

Year	Area (ha)
1933	90,000
1956	104,000
1963	115,000
1983	197,000
1993	235,000
2000	252,000

Conclusions

In Spain, like everywhere else, complexity and uncertainty characterize water management problems in general, and more so in the case of groundwater. Uncertainty is an integral part of water management. This uncertainty relates to scarcity of data, strong non-linearities in groundwater recharge values, scientific knowledge and changing social preferences. Honesty and prudence in recognizing current uncertainties is necessary. At the same time, there needs to be a concerted effort to obtain more and better hydrological data on which to base management decisions.

Intensive groundwater development is a new situation in most arid and semiarid countries. Usually, it is less than 30–40 years old. Four technological advances have facilitated this: (i) turbine pumps, (ii) cheap and efficient drilling methods, (iii) scientific hydrogeology advance, and (iv) cheap and accessible energy. Full cost (financial, operation and maintenance) of groundwater abstraction is usually low in comparison to the direct benefits obtained.

Mainly individual farmers, industries or small municipalities have carried out groundwater development. Financial and technical assistance by conventional Water Authorities has been scarce. This is why the new situation can be properly described as a *silent revolution* by a great number of modest farmers at their own expense.

The lack of planning and control of groundwater development has resulted in ecological or socio-economic impacts in a few regions. Property rights and institutional uncertainty is now worrying the beneficiaries; despite this none seems to be withdrawing and many others risk becoming users beyond the law and the public control.

Aquifer overexploitation is a complex concept that needs to be understood in terms of a comparison of the social, economic and environmental benefits and costs that derive from a certain level of water abstraction. It is meaningless and misleading to define overexploitation in purely hydrogeological terms given the uncertainties in recharge and abstraction values and the fact that the amount of available resources in a catchment area is variable and can be influenced by human actions and management decisions. The assumption that a long trend (e.g. 10 years) of decline in groundwater levels implies real overexploitation or overdraft may be too simplistic and misleading. This concept has been used in Spain to provide grounds for public action, igniting a top-down sort of policy that has failed to deliver significant benefits.

Increasing emphasis on cost-effective and environmentally sensitive management practices places a new thrust on broad public involvement in any water management decision-making process. But guaranteeing effective public participation in management processes requires informing and educating the public on increasingly complex scientific and technical issues. Effective information and education campaigns are therefore essential. The conflicts that are often a part of water management processes require the use of innovative conflict resolution mechanisms, which will allow for the discovery of feasible solutions that are accepted by all and can be successfully implemented. Up to now very little has been done in this direction in Spain.

Because of the persistence of obsolete paradigms, the wonderful concept of hydrosolidarity was recently improperly used in Spain to promote perverse subsidies mainly through the Ebro River water transfer to the Mediterranean regions. In the opinion of these authors, fortunately, the construction of the Ebro River diversion has been cancelled because it would be a wasteful use of public money. However, the initial solution proposed by the new government is equally prone to 'perverse subsidies'. The difference is that the public funds will be employed in the construction of more than a dozen large desalinating plants. The probability that farmers accept this solution is small. The main reason for this rejection is that abstracting or buying groundwater is significantly cheaper than paying for desalinized water. Probably, in most cases this abstraction of groundwater may not be sustainable and it is against the spirit and the provisions of the WFD. However, logically under the current administrative and legal chaos in groundwater development farmers are not very concerned about the need for achieving an environmentally sustainable groundwater development. They are much more concerned with the economic and social sustainability of groundwater development. Yet the amended law of the National Water Plan includes a certain number of articles, which, if actively enforced, would contribute efficiently to introduce a new water culture in Spain.

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