Lessons Learnt from the Impact of the Neglected Role of Groundwater in Spain's Water Policy

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ABSTRACT: Spain is the most arid country in Europe. Issues and conflicts related to water management are more relevant to the country's development than that of in other European countries. In July of 2001 the Spanish Parliament enacted the Law of the National Water Plan. This Plan has induced considerable controversy among diverse social sectors and lobbies: political parties, farmers associations, large construction firms, conservation groups, scholars, and others. The real role of groundwater in Spain was practically ignored in the initial proposal for the National Water Plan (NWP). The approved bill included a series of provisions about groundwater which, if they are enforced, will make it difficult to maintain some old paradigms. One of these is the need to continue the large subsides to build large hydraulic structures. One such structure is the aqueduct of the Ebro River, designed for the transfer of water to several Mediterranean regions. Spain is the country -except four small countries- with the largest number of large dams per person. It is also the country of the European Union which uses the lowest proportion of groundwater for urban water supply. This may be the result of the central government's policy in the nineteenth Century which restricted the use of groundwater as the source of supply for Madrid. This policy later spread trough out the rest of the country.

Nevertheless, farmers do not usually follow the government's paradigms and during the last 30 to 40 years they have considerably increased the use of groundwater for irrigation. Today about one million hectares, out of a total of 3.5 million hectares, are irrigated with groundwater. The economic value of the crops and the employment generated by the use of groundwater irrigation is higher than that from surface water irrigation. It can be said that groundwater irrigation has produced significantly "more crops and jobs per drop". Most of this spectacular agricultural development has been made with scarce planning and very limited control by the government water authorities. This has induced legal and ecological chaos in a few regions. The National Water Plan is a blend of new and old paradigms. The lobbies of the followers of the old paradigms are still powerful and it is presently difficult to foresee which will be the practical results of this plan.

1. INTRODUCTION

1.1. Background

Spain is the most arid country in Europe. Groundwater development has significantly increased during the last half century in most semiarid or arid countries of the world. This development has been mainly undertaken by a large number of small (private or public) developers and often the scientific or technological control of this development by the responsible regulatory agencies has been minor, if any at all. 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 entities which normally manage or control the operation of such irrigation or urban public water supply systems. This historical situation has often produced two effects: 1) most regulators have limited understanding and poor data on the groundwater situation and value; 2) in some cases the lack of control on groundwater development has caused problems such as decline of the water level in wells, decrease of well yield, degradation of water quality, land subsidence or collapse, interference with streams and/or surface water bodies, and ecological impact on wetlands or riparian forests.

In Spain, and almost everywhere, these problems have been frequently magnified or exaggerated by groups with lack of hydrogeological know-how, professional bias or vested interests. For instance, the World Water Council (2000, page 13) states that: *"Aquifers are being mined at an unprecedent 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 kind of *hydromyth* that has flooded the water resources literature. A usual axiom derived from this pervasive *hydromyth* is that groundwater is an unreliable and fragile resource that should only be developed if the conventional large surface water

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projects are not feasible. This groundwater resource fragility concept has been dominant in Spain during the last twenty years (Llamas, 1985; López-Gunn and Llamas, 2000). In the last decade a good number of authors have also voiced this fragility as a common issue (Postel, 1999; Secler *et al*., 1998).

Another usual *hydromyth* is to consider that groundwater mining, that is the development of non-renewable groundwater resources, is always overexploitation. The implication of this word is that groundwater mining goes against basic ecological and ethical principles. Some authors (Selborne, 2001; Llamas, 2001; Llamas and delli Priscoli, 2000) have shown that such *hydromyth* may always not be correct.

1.2. Purpose

This article describes the intense groundwater development in Spain during the last three or four decades And the positive and negative aspects of such development. 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 which are undergoing or will undergo this change. The Spanish Water Code of 1985 is one of the few in the world which has regulated the concept of *overexploited aquifer*. Based mainly in the Spanish experience, the main aim of this paper is to present and discuss: 1) the many meanings of the terms groundwater (or aquifer) overexploitation and sustainability; 2) the main factors to take into consideration in analyzing the pros and cons of intensive groundwater development; and 3) the strategies to prevent or correct the unwanted effects of intensive groundwater development.

What is an intensively used or stressed aquifer? During the last decade the expression *water stressed regions* has become pervasive in the water resources literature. Usually this means that those regions are prone to suffer now or in the near future serious social and economic problems because of water scarcity. Some authors insist on the probable outbreak of violent conflicts, that is**,** water wars among water stressed regions. The usual threshold to consider a region under water stress is 1000 m^3/person/year (United Nations, 1997, page 10-13), but some authors increase this figure to 1700 m3/person/year. If this ratio is only 500 m^3/person/year the country is considered in a situation of absolute water stress or water scarcity (Seckler *et al.*, 1998; Postel, 1999). This simplistic approach of considering only the ratio between water resources and population has scarce practical application and may be misleading. Most water problems are related to its quality degradation and not its relative scarcity. As an example, a good number of Spanish regions with a ratio lower than 500 m^3/year/person, are regions with high economic and social standard of living.

In its last 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 ratio water/population but also the Gross National Product per capita (United Nations, 1997, page 138). Other experts are also beginning to use other more sophisticated indices or concepts in order to diagnose the current or future regions with water problems. The result of these analyses will probably show that a certain *water-stress* may be an incentive to promote the development of these regions. In this case, it could be defined as an *eu-stress*, that is, a good stress. For example, during the last few decades in a good number of semi-arid or arid regions, tourism or the production of high value crops have significantly intensified. The scarcity of precipitation has been fully compensated by the great amount of sunny days and the high solar energy received. Examples of these developments are the sun *belt* in the USA and most of the European Mediterranean coast. The necessary water for these activities may be from different sources. Groundwater is probably the most frequently used, but it also may be imported, recycled or desalinated water. An example described later is a desalination plant (40 Mm^3/year) that will be completed in 2002 southeastern Spain, for use in greenhouse irrigation.

This article will show that groundwater development during the last decades has significantly contributed to Spanish agricultural development and to alleviate poverty as well as and to improve public health in developing countries. These improvements should be maintained and increased but not in the same way. The generally uncontrolled and unplanned groundwater development has to be rationalized and the externalities of groundwater extraction and the temporary or intrinsic uncertainties related to water management considered. The implementation of this groundwater sustainable use requires, as a *conditio sine qua non*, the participation of educated and informed groundwater users and other stakeholders in groundwater management decisions. This demands urgently the development of institutional arrangements for groundwater management where users can work jointly with the corresponding water authorities.

2. WHAT DOES SUSTAINABILITY MEAN?

During the last decade, the concept of sustainability has been proposed by many as a philosophy to solve most water problems or conflicts. In 1987, the United Nations Commission on Environment and Development defined sustainability as "*the ability to meet the needs of the present generations without compromising the ability of future generations to meet their needs*". The European Union Water Framework Directive, enacted in December 2000, states that it is necessary to promote or foster a sustainable water use. Probably, most people agree with this general principle, but its practical application in natural resources management is challenging. For instance, in terms of water resources management even the concept of minimum basic water needs, often estimated in 20 to 50 litters per day per person, is very controversial.

Another terminological problem is related to the concept of future generations. Are we talking about the people that will live in this planet in the 22nd century, in the whole third millennium or only in two generations, that is, within the next fifty years? No scientist is able to predict the situation one thousand 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 fifty years from now. The U.S. Geological Survey (1999) has published an interesting circular on the topic of groundwater sustainability but, in it the issue is considered almost exclusively from a hydrological point of view. It is clear that environmental problems have a natural science foundation but also, and even mainly, a social science foundation. There is no doubt that the issue is complex. Some authors consider different types of sustainability: ecological, social, economic, and political. In some regions there is plenty of water and other natural resources and by all the ecological indicators the people in those regions are *rich*. Nevertheless, because of the economic, social and political situation their sustainable development is in jeopardy. Wood (2001) points out the complexity of the sustainability concept and introduces the concept of "renewability" based on water balance to separate science and engineering aspects from those of water management strategies.

For many years, this author has put forth the idea that in Spain and in many other countries water scarcity is not usually the problem (Llamas, 1992). The real issue is widespread water mismanagement which very frequently results in the very serious problem of water quality degradation

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 Kessler, 1998; The Economist, 1998; Asmal, 2000; World Humanity Action Trust, 2000) but to improve its management.

3. THE MANIFOLD COMPLEX, AND THE PRACTICALLY USELESS CONCEPT OF OVEREXPLOITATION: OVERVIEW

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) and Sophocleous (2000) have most recently dealt with this topic in detail.

A number of terms related to overexploitation can be found in the water resources literature. Some examples are: safe yield, sustained yield, perennial yield, overdraft, groundwater mining, exploitation of fossil groundwater, optimal yield and others (see glossaries in Todd, 1980, 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* depends mainly on the social perception of the issue. This social perception is more related to the legal, cultural and economic background of the region than to hydrogeological facts.

For example, in a research study on groundwater fed catchments, called 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 caused a serious conflict between farmers and conservationists which has not been settled yet (see Llamas *et al.*, 2001; Bromley et al., 2001).

The Spanish Water Code of 1985 does not mention specifically the concept of sustainability in water resources development but frequently indicates that this development has to be in balance with nature. It basically considers an aquifer *overexploited* when the pumpage is close or larger than the natural recharge.

The Regulation for the Public Water Domain that developed 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. Also according to the law, strict regulatory measures have been designed to deal with these situations of stress. 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, as is implicitly recognized in the White Paper on Water In Spain (MIMAM, 2000).

The misconception of considering that *safeyield* is practically equal to natural recharge, already shown by Theiss in 1940, has been voiced by many other hydrogeologists (see Custodio, 2000; Sophocleous, 2000; Hernández-Mora *et al.*, 2001). Bredehoeft *et al.* (1982, pages 53, 54 and 56) describe the issue in the following way: "*Water withdrawn artificially from an aquifer is derived from a decrease in storage in the aquifer, a reduction of the previous discharge from the aquifer, an increases in the recharge, or a combination of these changes. The decrease in the discharge plus the increase in recharge is termed capture. Capture may occur in the form of decreases in the groundwater discharge into streams, lakes, and the ocean, or from decreases in that component of evapotranspiration derived from the saturated zone. After a new artificial withdrawal from the aquifer has begun, the head of the aquifer will continue to decline until the new withdrawal is balanced by capture". "In many circumstances the dynamics of the groundwater system are such that long periods of time are necessary before any kind of an equilibrium conditions can develop".*
As an example of the change in the social perception of water values it is interesting to remark that in 1940, according to Theiss, the water *was gained* by lowering the water table in areas of rejected recharge or where the recharge was *lost* through transpiration from *non-beneficial vegetation* (phreatophytes). During the period of time when Theiss addressed these issues *wetlands were wastelands*.

Bredehoeft *et al.* (1982) present some theoretical examples to show that the time necessary to reach a new equilibrium or steady state between groundwater extraction and capture may take decades or centuries. Custodio (2000) and Sophocleous (2000) have also presented illustrations to show the relationship between the size of the aquifer, its difussivity and the time necessary to reach a new steady state after the beginning of a groundwater withdrawal.

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

It was suggested that a possible definition is to consider an aquifer overexploited when the economic, social and environmental costs that derive from a certain level of groundwater abstraction are greater than its benefits (Llamas *et al.*, 1992). Given the multi-faceted character of water, this comparative analysis should include hydrologic, ecological, socioeconomic and institutional variables. While some of these variables may be difficult to measure and compare, they must be explicitly included in the analysis so they can inform decision-making processes. Following and expanding on to the ideas discussed in Hernández-Mora *et al.* (2001), the criteria that can be used to evaluate the benefits and costs related to groundwater abstraction will be presented, after describing the Spanish situation in water resources and uses. In this article the so-called Total Economic Value (TEV) of groundwater, as defined by the U. S. National Research Council, has not been explicitly considered. Nevertheless, 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.

4. WATER RESOURCES OF SPAIN

4.1. Climatic and Hydrologic Setting

Spain has a surface of approximately 500,000 km^2. The average precipitation is 700 mm/year. However, this average has considerable spatial deviation. From 100 mm/year in some islands in the Canary Archipelago to more than 2,000 mm/year in the humid North. The average annual temperature is 14 ºC. Average potential evapotranspiration is about 700 mm/year. In most of Spain evapotranspiration is higher than precipitation. The average streamflow is about 110 km^3/year. From this amount about 80 km^3/year is surface runoff and about 30 km^3/year is groundwater discharge. At least one third of Spain is endowed with good aquifers. These aquifers may be detrital, calcareous or volcanic (figure 1). The Water Administration has formally identified 411 aquifer systems or hydrogeological units (see Llamas *et al.*, 2001, table 4.1) which cover an area of 180,000 km^2, approximately.

The estimated *natural* recharge of these aquifers averages 30 km^3/year but varies with weather conditions between 20 and 40 km^3/year (figure 2).

4.2. Water uses

Spain's current total water uses are about 33 km^3/year or about one third of this total water resources (110 km^3/year).These uses are distributed as follows (in km^3/year):

Irrigation	24
Urban Water supply and connected industrial	5
Independent industrial uses and cooling	7
Total	36

Spain has about 40 million inhabitants. This means an average of almost 3,000 m^3/person/year, considering the whole country. Nevertheless, this average may be misleading because in some areas this indicator is smaller than 200 or 300 m^3/person and year.

Table 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 ground water during the last forty years is illustrated in figure 3.

This groundwater use growth has been the result of groundwater development by individuals, small municipalities and industries. It has not been promoted or planned by government agencies. As a matter of fact, Spain is a serious case of *hydroschizophrenia*; that is of a almost complete separation of surface and groundwater in the mind of water planners (Llamas, 1985). As a result of this *disease*, Spain is among the countries with the highest number of large dams per person: 30 large dams per million inhabitants. Only four countries have a higher ratio: Norway, Cyprus, Iceland and Albania (figure 4). The rhythm of large dams construction in Spain during the last fifty years has been almost 20 large dams per year (figure 5).

Table 1. Spain's groundwater use summary (estimated from several sources).

Activity	Volume applied (Mm^3/year)	Percentage of total water (surface + ground water)
Irrigation	1,000-1,5000	~ 20%
Urban	4,000-5,000	~ 25%
Industrial and cooling	300-400	~ 5%
Total	5,500-6,500	15-20%

Source: Llamas et al. (2001, table 5.16).

Inside the European Union, Spain is the country with the least percentage of groundwater uses for urban water supply. It is about 25% (see figure 6). The explanation of this anomaly is not the lack of aquifers, like in Norway's case, but the previously mentioned *hydroschizophrenia* of the government water planners who were the persons making decisions on the use of public funds for the water supply to large cities and for large surface water irrigation schemes.

4.3. Groundwater ownership and markets

Until the 1985 Water Code took effect, 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 Code declared all groundwater in Spain of public domain. Every new groundwater abstraction requires a permit by the corresponding water authority.

The groundwater developments made before the 1st January 1986 may continue as private domain, using the same amount of groundwater that they were using previously. All these wells, galleries or springs have to be inventoried and registered with the corresponding water agencies. The main problem is that the legislators and the water authorities underestimated the relevance and number of groundwater abstractions and did not provided the economic means and the man-power to register all the grandfathered groundwater rights. Sixteen years after the enactment of the Water Code the number of private groundwater abstraction rights remains uncertain. Llamas *et al.* (2001, chapter 8) have estimated that probably 90% of the private groundwater developments have an illegal or a-legal status. And what is worse, it seems that the number of illegal wells drilled after the 1st January 1986 is very large. In other words, the 1985 Water Code groundwater provisions have been scarcely enforced. This has created a situation which may be considered as legal and administrative chaos. The 1985 Water Code was partly amended in 1999, mainly to introduce in some way the water markets. 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 still most groundwater resources are private ownership and they can be sold or bought like any other commodity. The importance of these groundwater market varies according to the different Spanish regions. For example, in the Canary Islands organized water markets have been in operation for more than a century. A detailed description of the Spanish groundwater markets can be read in Hernández-Mora and Llamas (2001).

5. BENEFITS OF GROUNDWATER DEVELOPMENT

The concept of groundwater overexploitation or sustainability must necessarily take into account the numerous socioeconomic and even ecological benefits that can derive from groundwater use. Socioeconomic benefits range from water supply to economic development, as a result of agricultural growth in a region. With respect to 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).

5.1. Potable Water Supply

Groundwater is a key source of drinking water, particularly in rural areas and in island environments. 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 Spain is one of the European countries that less proportion of groundwater uses per public urban water supply to large cities. This situation has the historical roots explained in Llamas (1985). The failure in the 19th century in continuing the water supply to Madrid by groundwater (Khanat systems) induced one of the most serious cases known of *hydroschizofrenia*. This neglect of groundwater role is the basic cause of today's most current water conflicts in Spain (Llamas and Pérez Picazo, 2001).

5.2. Irrigation

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 1999 study done for Andalucía, in Southern Spain shows 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 2 shows the main results of the Andalucia 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. Nevertheless, these losses in surface water irrigation are significant. 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 consumption of 6,700 m3/ha/year and 6,500 m3/ha/year for the two catchments that are the subject of the Andalucía study without differentiating between surface and groundwater irrigation. Using these new figures and the volumes given for irrigation with groundwater in the Andalucía study, a more realistic average volume used for irrigation with surface water of 7,400 m3/ha/year can be estimated. Table 2 shows that productivity of groundwater irrigation is 5 times greater than irrigation using surface water and generates more than 3 times the employment per m^3 used. It could be argued that the greater socio-economic productivity of groundwater irrigation in Andalucía 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).

A literature search did not reveal similar studies in other parts of Europe. Studies in India show similar results. For instance, Dains and Pawar (1987) estimate that groundwater constitutes 30% of all water used for irrigated agriculture in India but is responsible for 70-80% of all agricultural production. According to Dhawan (1995), in India research indicates that yields in groundwater irrigated areas are higher by one third to one half more than in areas irrigated from surface waters. First Postel (1999) and later the World Water Council (2000) and Rijsberman and Cosgrove (2000), consider that intensive groundwater use in India has been decisive in order to feed that country's current population of one billion people. Nevertheless, this *miracle*, as Postel describes it, is not sustainable because it has been mainly done mining groundwater, that is, using about 100 km^3/year of non-renewable groundwater resources. This figure is based on an undated and unpublished report, and does not fit the data provided by the Indian Water Resources Society (2000), or the estimation of groundwater recharge by Rangarajan and Athavale (2000). India seems to be the country which has most intensively developed groundwater irrigation during the last three or four decades (more than 20 million hectares developed). A thorough analysis of the benefits and costs of this phenomenon would be useful for the whole humanity. When examining the data included in this section it is important to keep in mind the strong uncertainties that are attached to hydrologic data. However, the results obtained 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 2. Comparison of irrigation using surface and groundwater in Andalucía.

Indicator for irrigation	Origin of irrigation water			Relation groundwater surface water
	Ground-water	Surface water	Total	
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) [1]	2.16	0.42	0.72	5.1
Employment generated (EAJ/10^6 m^3) [2]	58	17	25	3.4

Source: Llamas et al. (2001).

[1] 1 € ≅ 0.9 US$
[2] EAJ stands for Equivalent Annual Job which is the work of one person working full-time for one year.

5.3. Hydrologic benefits

Other 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. This process was already described by the American hydrogeologist Theis in 1940 and was later developed by Bredehoeft *et al.* (1982). Johnston (1997) analyzed eleven American regional aquifers. He shows that intensive groundwater development in nine of these aquifers has resulted in significantly increased recharge.

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). Cruces and Martínez (2000) have estimated that average renewable resources may have increased between one third -and one half- under disturbed conditions. Figure 7 illustrates some results from this monograph. 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, today only cover 7,000 ha. In addition, some rivers and streams that were naturally fed by the aquifers, now have become net losing rivers.

The results of the decline of the water table have been two-fold. On one hand, a significant decrease in evapotranspiration from wetlands and the water table, from about 175 hm^3/year under quasi-natural conditions to less than 50 hm^3/year today. At the same time, 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. Clearly, it is important to keep in mind the associated negative impacts that the drawdown of the water table has had on dependant natural wetlands.

6. DISADVANTAGES OF GROUNDWATER USE

6.1. 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. Management decisions based on this simplistic approach may sometimes be misguided. Custodio (2000) and Sophocleous (2000) agree that every groundwater withdrawal causes an increasing piezometric depletion until a new equilibrium is achieved between the pumpage and the new recharge (or capture). This transient situation can be however long depending on aquifer characteristics such as storage capacity, transmissivity, degree of stratification and heterogeneity. For instance, in large unconfined aquifers, the time necessary to reach a new equilibrium state in water table levels can of decades or centuries when transmissivity is low. On the other hand, in large confined aquifers, water level declines do not necessarily imply a significant decline in storage but, rather, a change in the elastic conditions of the system.

With respect to the climatic sequence, in arid and semiarid countries significant recharge can occur only every 5 to 10 years. Therefore, continuous decline in the water table during a dry climatic sequence of a few years, when recharge is low and abstraction high, may not be representative of long-term trends. Declines in water levels should indicate the need for further analysis. Whether they indicate possible abstraction greater than recharge is something that needs to be studied on a case-by-case basis, always taking into consideration the hydrogeological characteristics and the size of the aquifer, as well as the climatic sequence. In any case, declines in the water table can result in a decrease in the production of wells as well as increases 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 Andalucía, the value of crops in greenhouses may reach 40,000 to 60,000 US$/ha/year. The water volume used is between 4,000 and 6,000 m^3/ha. The energy needed to pump one cubic meter 100 m high is about 0,3 kWh. This means that the increase on the costs of pumping in the event of a drawdown of 100 m is almost irrelevant for the agribusiness. As previously described, a significant fact is that a large sea water desalination plant (40 Mm^3/year) will be completed in Almería (South Spain) in 2002. The main use of this treated water will be green-house irrigation. On the other hand, if the value of the crops is only about 1,000 US$/ha/year, and the water needed is about 10,000 m^3/ha, the increase in the cost of energy of a drawdown of 100 m can render those crops uneconomic.

The socio-economic situation created by water table depletion in rural areas of poor developing countries may be more complex and prone to social inequity. For instance, according to Moench (1999), this may occur in some poor rural regions of India. A similar situation may occur when a fragmentation of well ownership exist, as in Tamal Nadu, India, such as it is described (Janakarajan,1999). In both cases, a possible solution would be to require that the person causing the water table depletion compensate in money or water the person whose well becomes dry or sees its yield reduced. Perhaps in such regions, the main problem may be that the officers of the corresponding water authority have neither the knowledge nor the necessary means to enforce groundwater regulations. Then, probably the impacted *farmers* will emigrate to some urban area. Can this frequent migration towards urban areas be stopped or significantly reduced by forbidding groundwater development in order to avoid such aquifer depletion?

It seems clear that, before trying to extrapolate Spanish solutions to developing countries situations, a thorough assessment of the hydrogeological and socio-economic situation of these countries is required. The adequate solutions in a country where the average income per person and year is smaller than US$ 500, should usually be very different from those adequate for countries industrialized.

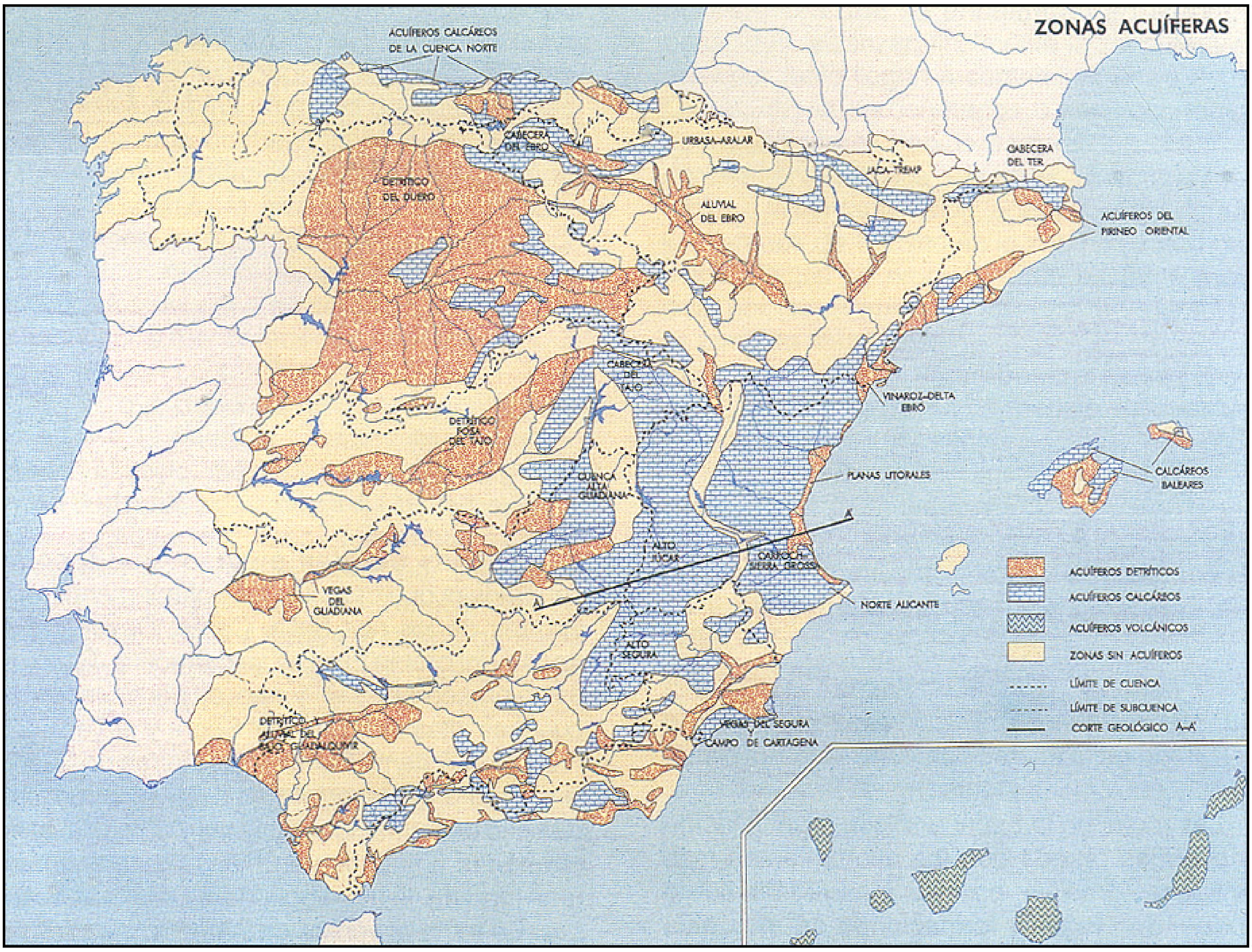

Figure 1. Spain's location and types of main aquifers. Source: MIMAM (2000, figure 2).

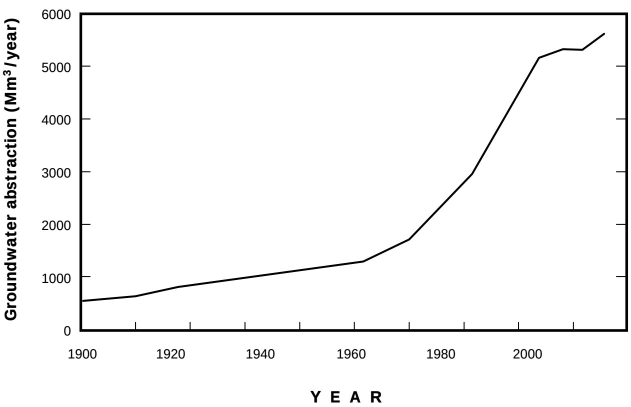

Figure 3. Groundwater consumption development of groundwater in Spain, showing its rapid increase from the 1960s to date. Source: MIMAM (2000, figure 339).

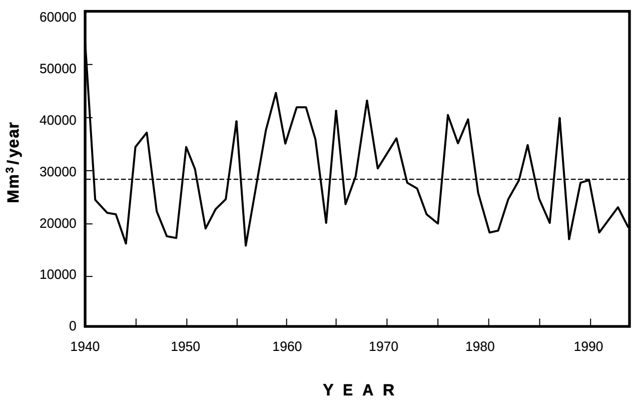

Figure 2. Estimated natural groundwater recharge in Spain from 1940 to 1995. Source: MIMAM (2000, figure. 124).

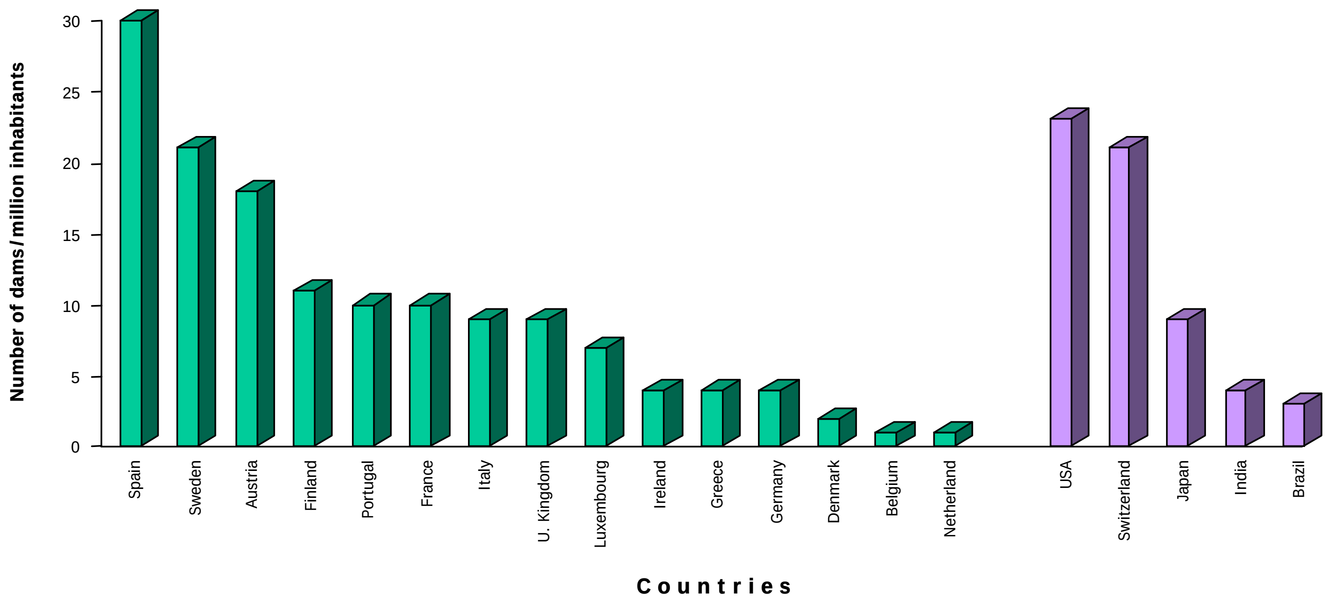

Figure 4. Number of dams per capita in different countries. Source: Llamas et al. (2001, figure 5.7).

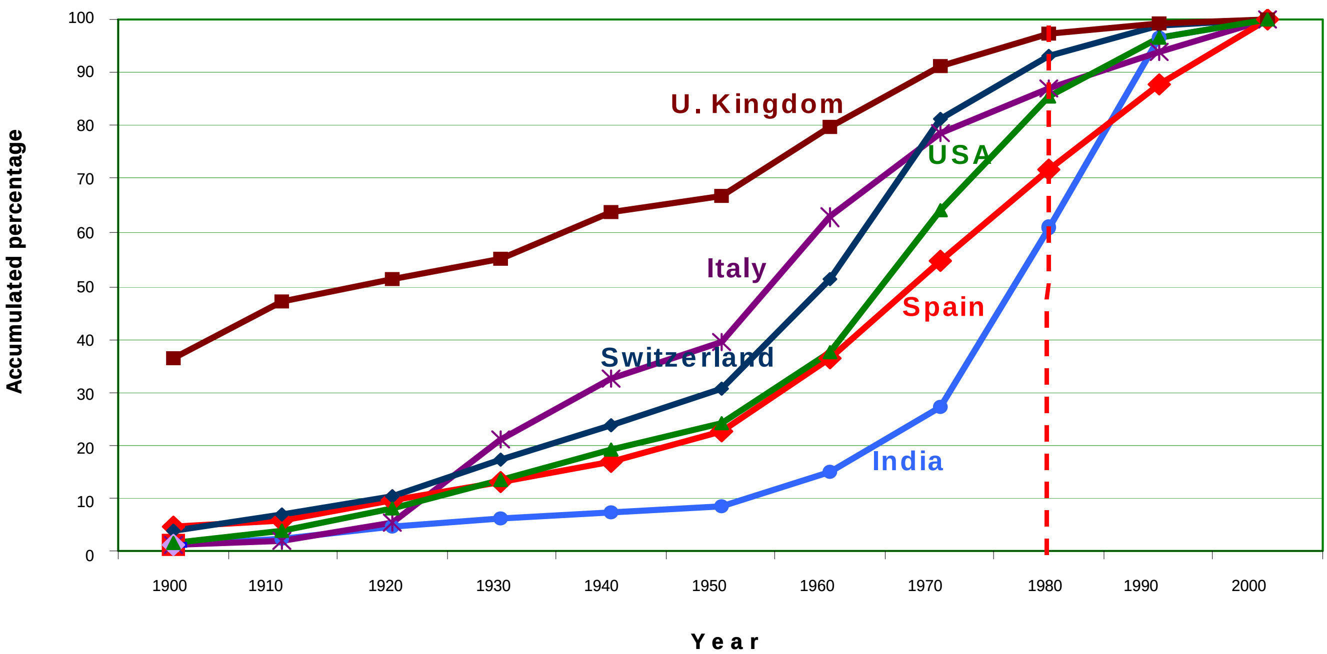

Figure 5. Temporal dam construction rhythm in several representative countries. Source: Llamas *et al.* (2001, figure 5.8).

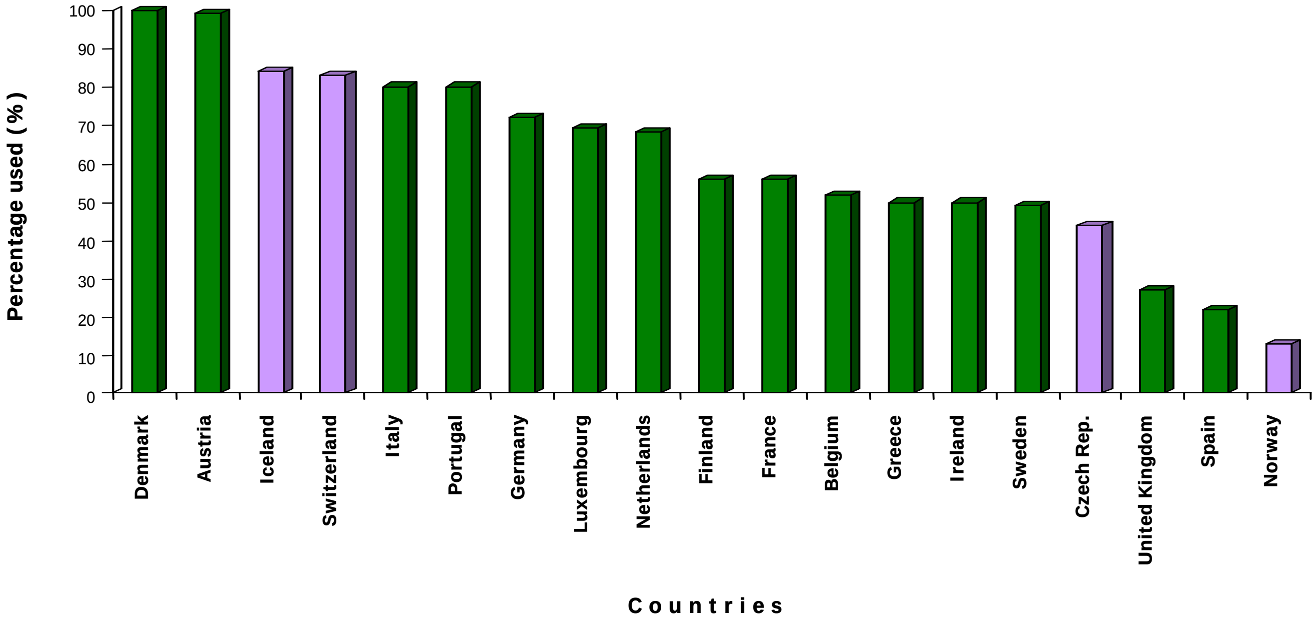

Figure 6. Percentage of groundwater used for urban supply in several European countries. Source: Llamas *et al.* (2001, figure 5.3)

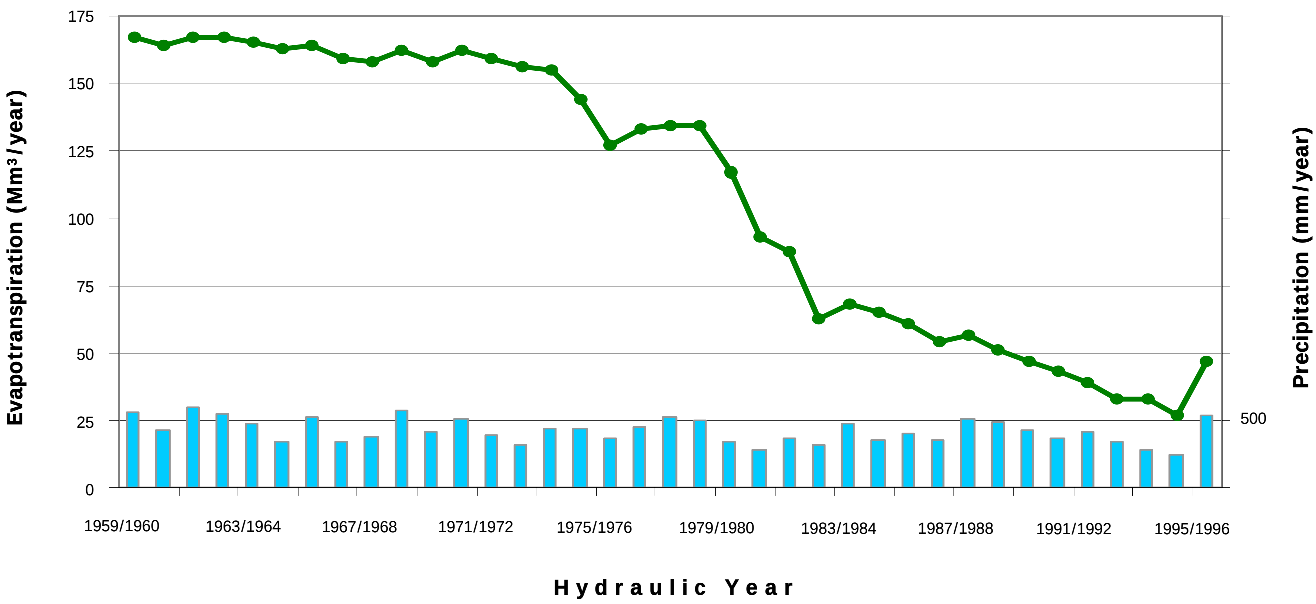

Figure 7. Temporal evolution of evapotranspiration from the water table in the Upper Guadiana basin, caused by water table depletion. Source: Martínez Cortina as cited in Llamas *et al.* (2001, figure 4.7).

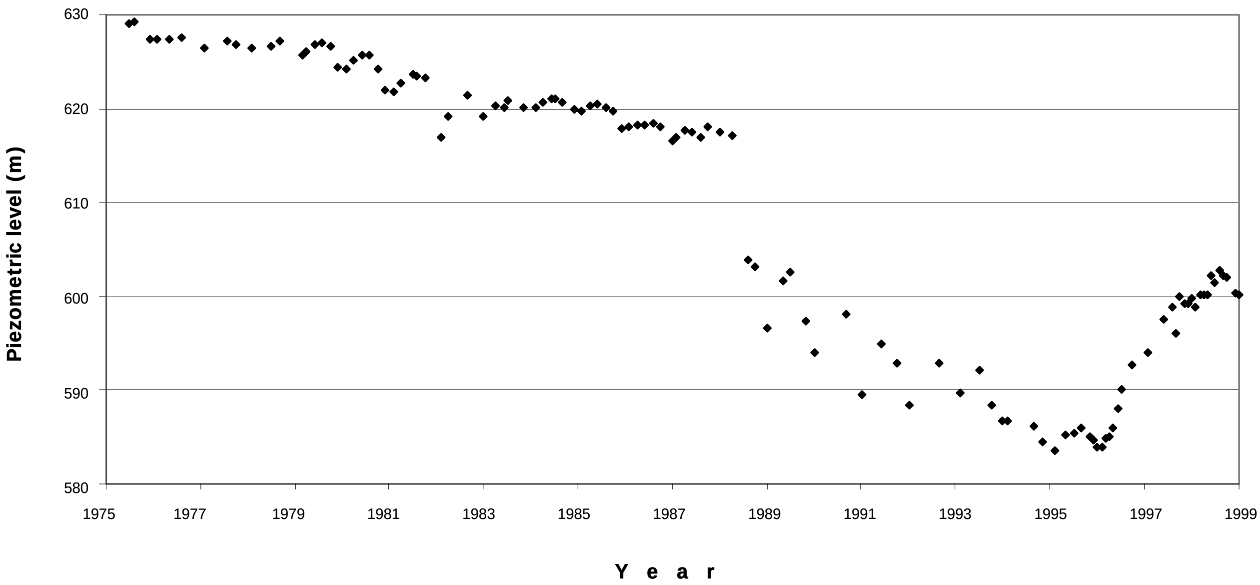

Figure 8. Water table evolution in Manzanares (Upper Guadiana catchment, Spain). Source: Martínez Cortina (2001) as cited in Hernández-Mora et al. (2001)

6.2. Degradation of groundwater quality

Groundwater quality is perhaps the most significant challenge to the long-term sustainability of groundwater resources. Restoration of contaminated aquifers can be a very costly and difficult task. Most often, degradation of groundwater quality is not a result of excessive abstraction, but is related to other causes such 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 of industrialized countries but also may be serious in developing countries (Burke and Moench, 2000; Janakarajan, 1999).

Groundwater abstraction can also cause changes in groundwater quality. Some indicators of the susceptibility of an aquifer to water quality degradation are the following (Custodio, 2000):

1. Proximity to saline water bodies: risk of saltwater intrusion which not only depends on the amount of abstraction relative to recharge, but also on the well field location and well design and on the geometry and hydrogeological parameters of the aquifer.
2. Hydraulic connection to low quality surface or groundwater bodies. Changes in the hydraulic gradient as a result of groundwater abstraction may result in the intrusion of poor quality water into the aquifer from adjacent water bodies.

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 the groundwater pollution problems is still weak. The situation is improving but very slowly. Spain is not a region to imitate in this respect.

6.3. Susceptibility to subsidence and/or collapse of the land surface

Aquifers formed in young sedimentary formations are prone to compaction as a result of water abstraction and the resulting decrease in intergranular pore pressure. For example, this has been the case in the aquifers underlying Venice or Mexico City. More dramatic collapses are a common occurrence in karstic landscapes, where oscillations in water table 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. This is a result not only of the amount of groundwater withdrawal, but also of well field location and design. Fortunately, these type of geotechnical problems are not relevant in Spain.

6.4. 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 baseflow to streams, dissecation 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.

6.5. Ecological impacts on groundwater-dependant ecosystems

The ecological impacts of drawdowns 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, or alteration of natural hydraulic river regimes, can all be used as indicators of overexploitation. Reliable data on the ecological consequences of these changes is 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 programs often ignore the need to simulate the natural hydrologic regime of the wetlands, that is, 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 streamflows 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. A European Union-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 neighborhood 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 drawdowns in the water table (30-40 m) caused jointly by groundwater abstraction and drought (see Figure 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 past 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. Conservation interests do not seem to be strong in Crete.

7. 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 sentences are oral and can not be appealed to a higher court. The systems has worked and it is a clear proof that *The Tragedy of Commons* is not always true. Further evidence of social cooperation in Spain are the thousands of *Comunidades de Regantes* (Irrigation Communities or Water Users Associations). Some of them have been in operation for several centuries.

The 1985 Spanish Water Code preserved the traditional *Comunidades de Regantes* that existed before its enactment and recommended these institutions for surface water management. It is also extended these 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 description of these institutions is contained in Hernández-Mora and Llamas (2000). It has been difficult to enforce the formation of the groundwater users associations in overexploited aquifers and sixteen years after the enactment of the Water Code only a few are operating at this time (Llamas *et al.*, 2001, chapter 9; Hernández-Mora and Llamas, 2001). As recognized in the White Paper on Water in Spain

(MIMAM, 2000), the main cause is that these new groundwater users communities were established top-down, that is the water authorities imposed their implementation without the agreement of the farmers who are the main stakeholders. Both, the 1999 amendments to the 1985 Water code 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.

In Spain, independently of these officially created groundwater user communities, there are a large number of private collective institutions to manage groundwater. Some of them have been in operation for many years. There is a general consensus on the crucial need to implement these institutions but it will be necessary to wait a few years to know if the incentives (economic, fiscal, operational) offered to the stakeholders are the right ones to achieve this goal.

8. HYDROSOLIDARITY AND GROUND-WATER MANAGEMENT IN SPAIN

8.1. Overview

In Spain, like everywhere, ethical factors play a crucial role in water uses and in water management. Many recent publications address this topic (see Selborne, 2001; Llamas, 2001, a; Llamas and Priscoli, 2000; Burke and Moench, 2000). An analysis of this scenario in Spain is described by Llamas (2001 b). Human solidarity is one of the ethical principles that underlies 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 or future human beings. These rights or needs should also include the water needed for care of the natural environment.

Nowadays, few people would dare to speak openly against hydrosolidarity (the need to share water resources), that is, the application of the principle of solidarity to water resources management. In practice, however, it might be difficult to find constructive ways to facilitate an equitable and fair share of water resources among concerned stakeholders, particularly in densely populated arid and semi-arid regions. Lack of knowledge, arrogance, vested interests, neglect, institutional inertia, corruption, are some of the obstacles frequently encountered to achieve hydrosolidarity (Llamas and Perez-Picazo, 2001). The noble and beautiful concept of hydrosolidarity may also be used in a corrupt or unethical way by some lobbies in order to withdraw public money, that is *perverse subsidies*, which are bad for the economy and the environment (Llamas and Delli Priscoli, 2000). An example of the improper use of hydrosolidarity is that of the Segura catchment area. It has influenced the first National Water Plan in Spain, which was approved as a Law in July 2001 by the Spanish Parliament.

8.2. The Segura Catchment

Hydrology

The Segura catchment is located in southeastern Spain. Its main features are: a) surface area 19,000 km^2; b) average annual precipitation of 400 mm, ranging from 800 mm in the headwater to 200 mm in the coastal plain.; c) annual potential evapotranspiration: 800-900 mm; d) average streamflow: 1000 Mm^3. 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 recharge is estimated at about 600 Mm^3/year (about 60% of the total streamflow). The climate is typical of Mediterranean regions: hot summers, frequent flash floods and long droughts.

Water Development Until the 1960s

Sixty percent of the Segura river basin is within the Murcia Autonomous Region with the reminder 40% divided between the Autonomous Regions of Valencia and Castilla-La Mancha. The mild climate and the important baseflow (typical of a karstic catchment) of the Segura river, encouraged the development of an important agricultural economy in the region on the basis of an irrigation network on the floodplains of the middle and lower part of the catchment area, that dates as far back as the Muslim occupation twelve hundred years ago. Vegetables, citrus and other fruits have been cultivated in the region for many centuries. Agroindustry (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 European Union (1986), the demand of its agricultural products increased significantly. The scarcity and/or variability in the availability of surface water resources has historically been considered a serious drawback for the development of this region. After the Spanish Civil War (1936-1939), an important program to control the Segura River was designed and implemented. The total capacity of the two dozen reservoirs built since that time is about 1,000 Mm^3. These dams have served to mitigate the destructive consequences of former catastrophic floods, but have not satisfied the farmers' water demands for irrigation. In Spain, like in most countries, the expectation is that surface water supplies for irrigation should be delivered to the farmers at an almost nominal price. Consequently, the corresponding dams and other hydraulic infrastructures were financed with public funds. According to these predominant paradigms (almost free water for irrigation), and in response to the active lobby of the Segura farmers, ever since the early twentieth century, politicians and engineers have advocated for the transfer of water resources from the "humid" Spain to the "dry" Spain It has been often argued, that it was necessary to correct the natural hydrologic imbalance of Spain. The first formal proposal to transfer water from the Tagus river headwaters (in central Spain) to the Segura River dates back to 1933. This project was dormant for more than thirty years. It was proposed again in the sixties, implemented, and completed in the seventies.

The Groundwater Abstraction Boom

In the 1950s and 1960s, the Spanish Ministry of Agriculture launched a significant effort to promote groundwater irrigation in Spain. The officers of this Ministry, together with the experts of the Spanish Geological Survey, elaborated the first regional hydrogeological surveys of Spain, introduced modern drilling technologies for deep waterwells, and promoted the use of submersible pumps, invented a few decades before. This initial activity, heavily subsidized with public funds, was soon a catalyst that promoted intensive waterwell drilling by many private farmers in many regions of Spain. The most active region in this respect was probable the Segura catchment area. There were several reasons for the special development of groundwater abstraction in this region: a) the area had a long tradition of irrigation with surface water and a traditional capacity to market high value crops in Spain and abroad; b) 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 rivers water transfer or, more recent, from the future Ebro River water transfer project(all these infrastructures built by the Government with public funds). 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 water to be transferred to the Segura catchment in the eighties.

In Spain, according to the Water Law of 1879, groundwater was private ownership. The landowner could drill a waterwell in his/her land and pump as much groundwater as he/she wished, unless a third person was affected. Nevertheless, in the 1950's special regulations were enacted by the Government that theoretically made groundwater a part of the public domain in the "Vegas del Segura" (Segura floodplains). The lack of experts in hydrogeology inside the Segura Water Authority made this regulation difficult to enforce.

Even after the enactment of the 1985 Water Code 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 et al., 2001). For example, the official White Paper on Spain's Water (MIMAM, 2000, page 343) admits that in this region only about 2,500 waterwells -out of more than 20,000 drilled- are legally inventoried by the Segura Water Authority.

8.3. The Tagus River Water Transfer and the Future Ebro River Water Transfer

In 1979, almost fifty 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/second or 1,000 Mm^3/year, but the maximum volume approved for transfer during the first phase was only 600 Mm^3/year. The reality is that the average volume transferred during the first two decades of operation of the aqueduct has been about 300 Mm^3/year, that is, half of the maximum volume authorized and one third of the total capacity of the aqueduct. The theoretical 600 Mm^3 to be transferred were distributed in the following way: 110 Mm^3 for urban water supply, 400 Mm^3 for irrigation and 90 Mm^3 as estimated losses during transfer. It was also stipulated that when the 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 the tariff usually paid by surface water farmers in Spain (~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. In June of 2001 the Spanish Parliament enacted the Law of the National Water Plan. The most relevant aspect of the Law is that it approves a new water transfer of 1,050 Mm^3/year from the Ebro River in Northern Spain to several regions along the Mediterranean coast. Almost 50% of this volume is for delivering to the Segura catchment area. The planned aqueduct is almost 900 km long. Out of the total volume transferred, about 50% is for urban water supply and the rest to supply water to areas in which groundwater abstraction has been excessive and has impacted the storage and groundwater quality of the aquifers . Most of these *degraded* aquifers are located inside the Segura catchment region.

The Ebro water transfer has met strong opposition among many and different groups. The principal one is the Government of the Aragon autonomous region, located on the Ebro basin. Other interests opposed to the proposal include the people of the Ebro delta region, many environmental groups, a good number of scholars, and others that have shown their partial or total rejection to the transfer. Several massive demonstrations against the Ebro transfer have taken place. One of them in Zaragoza, the capital city of Aragon, with about 400,000 participants. Another in Brussels with more than 10,000 participants. According to the government, the real cost of the Ebro water transfer will be about 0,30 €/m^3. This figure has been contested by a good number of experts in economy, who consider that the real cost will be significantly higher. Some consider that sea or brackish water desalination is a better alternative both from an economic and an ecological point of view. In any case, the detailed technological and finantial design of the Ebro water transfer is going to take a certain number of years. The Socialist Party (now an opposition party), has announced that they will stop this water transfer if they win the next general elections (not later than May 2004).

8.4. The Conflict about the Ebro Water Transfer: Lack of Hydrosolidarity or False Paradigms?

In 2001 a poll was taken about the social perception of the Ebro water transfer. Fifty percent of those interviewed were in favor of the transfer, 30% were against and the reminder had no opinion on the issue. One could think 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 freshwater to the thirsty. In our western civilization this is an evangelical dogma. Nevertheless, are the people in the Segura catchment region really thirsty? Definitely, not. Almost 90% of the water used in this area is for irrigation of high value crops and not for urban water supply. Moreover, most of the people in Spain still think that the hydraulic infrastructures have to be financed with public funds, because the *poor farmers* cannot pay the full cost of water and they perform a task that is really essential and beneficial for the whole country. But irrigation in the modern Segura catchment area is essentially an economic activity.

Table 3 shows the evolution of irrigated lands in the Segura catchment region. It is shown that this surface has almost tripled since 1933, when the use of surface water reservoirs and groundwater was minimum. During the last twenty or thirty years, the increase in the irrigated surface has been done mainly through an excessive and uncontrolled (by the government) use of groundwater.

Table 3. Evolution of irrigated area in the Segura catchment area.

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

Source: Llamas and Pérez Picazo (2001).

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 was 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. Nevertheless, considering the prevalent paradigm, farmers are sure that a great part of the cost of these infrastructures will not be paid by them but with public funds. As discussed in

5.2 detailed studies undertaken in Andalucía, Spain, have shown clearly that groundwater irrigation is much more efficient than surface water irrigation: it produces about 5 times more cash per m^3 used; and three times more jobs per cubic meter. With groundwater irrigation the goal "*more crops and jobs per drop*" is usually achieved. The analysis done for Andalucía (a sample of almost one million hectares), and the conclusions drawn from it, can be applied to most irrigated areas of Spain (3,5 million ha).

The need to provide cheap water to *thirsty* areas and the belief in the need to subsidize water infrastructures are still today the predominant paradigms in Spain. Llamas and Pérez Picazo (2001) consider that nowadays both paradigms are obsolete. However, some time will be necessary to change the mentality of the general public. These false paradigms are also frequent in other countries.

9. THE ROLE OF GROUNDWATER IN THE NATIONAL WATER PLAN

The main goal of the Law of the National Water Plan is the Ebro water transfer but it has also included several articles that, if enforced, will act as a time bomb against the Ebro water transfer, and dramatically improve groundwater management in Spain. For example:

1) Article 18 established that not a single drop of the Ebro River can go to an *overexploited aquifer* if detailed studies of the situation are not previously performed and approved by the central government. Groundwater user communities have to be formally established on these aquifers and none had been established in the Segura catchment area until October 2001, when suddenly several groundwater user communities have been approved by the Segura Water Authority.
2) Article 29 establishes the need to perform a thorough study of groundwater in Spain, and to foster, in general, the formation of groundwater user communities.
3) Article 34 establishes that a relevant education campaign on water resources addressed to the general public, has to be promptly carried out.

10. SUMMARY

In Spain like everywhere, complexity and variability characterize water management problems in general and even 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 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 recent situation in most arid and semiarid countries. Usually, it is less than 30-40 years old. Three technological advances have facilitated this: 1) turbine pumps, 2) cheap and efficient drilling methods, and 3) scientific hydrogeology advance.

Full cost (finantial, operation and maintenance) of groundwater abstraction is usually low in comparison to the direct benefits obtained.

Groundwater development has been carried out mainly by individual farmers, industries, or small municipalities. Finantial and technical assistance by conventional Water Authorities has been scarce.

The lack of planning and control of groundwater development has resulted in ecological or socio-economic impacts in a few regions.

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 useless to define overexploitation in purely hydrogeological terms given 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 (10 years, for example) of decline in groundwater levels implies real overexploitation or overdraft may be too simplistic and misleading.

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 that will allow for the discovery of feasible solutions that are accepted by all and can be successfully implemented.

Because of the persistence of obsolete paradigms, the wonderful concept of Hydrosolidarity has been recently improperly-used in Spain to promote *perverse subsidies* mainly through the Ebro River water transfer to the Mediterranean regions.

The Law of the National Water Plan includes a certain number of articles that, if are actively enforced, would contribute efficiently to introduce a new water culture in Spain.

REFERENCES

Acreman, M.C. (compiler), 1999. Guidelines for the sustainable management of groundwater-fed catchments in Europe. Report of the Groundwater and River Resources Action Programme on a European Scale (GRAPES), *Institute of Hydrology*, Wallingford, UK., 82p.

Asmal, K., 2000. Water: from casus belli to catalyst for Peace. Address in the opening session in the Stockholm Water Symposium. 14 August 2000.

Bredehoeft, J.D., Papadopoulos, S.S. and Cooper, H.H., 1982. The water budget myth (Scientific basis of Water Management), *Studies in Geophysics, National Academy of Sciences*, 51-57.

Bromley; J., Cruces, J., Acreman, M., Martínez, L. and Llamas, M.R., 2001. Problems of Sustainable Management in an Area of Overexploitation: The Upper Guadiana Cathcment Central Spain. *Water Resources Development* 17: 379-396.

Collin, J.J. and Margat, J., 1993. Overexploitation of water resources: overreaction or an economic reality?. *Hydroplus*, nº 36, 26-37.

Cosgrove, W. J. and Rijsberman, F.R., 2000. World Water Vision, Earthscan Publications Ltd., London, 108p.

Cruces de Abia, J. y Martínez, L., 2000. La Mancha húmeda . Explotación intensiva de las aguas subterráneas en la cuenca alta del río Guadiana. Papeles del Proyecto Aguas Subterráneas, No. A3. Fundación Marcelino Botín, Santander, Spain, 66p.

Custodio, E., 2000. The Complex Concept of Groundwater Overexploitation. Papeles del Proyecto Aguas Subterráneas. No. A1. Fundación Marcelino Botín. Santander, Spain, 58p.

Custodio, E. and Dijon, R., 1991. *Groundwater overexploitation in developing countries*. *Report of an U. N. Interregional Workshop*, UN.INT/90/R43, 116p.

Dains, S.R. and Pawar, J.R., 1987. *Economic return to irrigation in India*, New Delhi. Report prepared by SDR Research Group Inc. For the U.S. Agency for International Development.

Dhawan, B.D., 1995. *Groundwater depletion, land degradation and irrigated agriculture in India*. Commonwealth Publisher. Delhi, India.

Fetter, C. W., 1994. Applied Hydrogeology. MacMillan, New York.

Fornés, J., and Llamas, M.R., 1999. Conflicts between Groundwater Abstraction for Irrigation and Wetlands Conservation: Achieving Sustainable Development in the La Mancha Húmeda Biosphere Reserve (Spain), in *Groundwater Ecology. A Tool for Management of Water Resources* (Griebler *et al.*, ed.). *European Commission. Environmental and Climate Programme*, 227-236.

Hernandez-Mora, N. and Llamas, M. R., 2000. "The Role of User Groups in Spain: Participation and Conflict in Grounwater Management", CD-ROM of the X World Water Congress (Melbourne, 12-16 March 2000), *International Association of Water Resources*, 9p.

Hernandez-Mora, N., Llamas, M.R. y Martinez, L., 2001. Misconceptions in Aquifer Overexploitation. Implications for Water Policy in Southern Europe. In: *Agricultural Use of Groundwater*. Towards Integration between Agricultural Policy and Water Resources Management (ed. C. Dosi), Kluwer Academic Publishers, 107-125.

Hernandez-Mora, N. y Llamas, M.R. (ed.), 2001. *La economía del agua subterránea y su gestión colectiva*. Fundación Marcelino Botín y Mundi Prensa, Madrid, 550p.

Indian Water Resources Society, 1999. Water: Vision 2050, New Delhi, 74p.

Janakarajan, S., 1999. Conflicts over the Invisible Resource in Tamil Nadu: Is there a way out?. In *Rethinking the Mosaic* (Moench *et al.*, ed.). The Institute for Social and Environmental Transition, Boulder, Colorado, p. 123-160.

Johnston, R.H., 1997. Sources of Water Supplying Pumpage from Regional Aquifer System of the United States. *Hydrogeology Journal*, 5(2): 54-63.

Kessler, E., 1998. Editorial, *Ambio* 27(6), p.427.

Llamas, M.R., 1985. Spanish Water Resources Policy: The Illogical Influence of Certain Physical and Administrative Factors. *Mem. of the 18th International Congress of the International Association of Hydrologists* XVIII (2): 160-168.

Llamas, M.R., 1992. Wetlands: An important issue in Hydrogeology. In *Selected Papers on Aquifer Overexploitation*, (Simmers *et al.*, de.), Heise, Hannover, 3: 69-86.

Llamas, M.R., 2000. Some Lessons Learnt during the Drought of 1991-1995 in Spain, in *Drought and Drought Mitigation in Europe* (Vogt and Somma, Ed.), Kluwer Academic Publishers, 253-264.

Llamas, M. R., 2001a. Considerations on Ethical Issues in Relation to Groundwater Development and/or mining , UNESCO Conference on International Aquifers Systems in Arid Zones - Managing non-renewable Resources. Tripoli, 20-24 November 1999. *Technical Documents in Hydrology*, V IHP, no. 42, UNESCO, París, 467-480.

Llamas, M.R., 2001b. "Cuestiones éticas en relación con la gestión del agua en España". Discurso de Ingreso en la Real Academia de Doctores, Madrid, 85p.

Llamas, M.R., Back, W. and Margat, J., 1992. Groundwater use: equilibrium between social benefits and potential environmental costs, *Applied Hydrogeology*, Heise Verlag, 1(2): 3-14.

Llamas, M.R. and Priscoli, J. Delli, 2000). Water and

Ethics, in Papeles del Proyecto Aguas Subterráneas, no. A5, Fundación Marcelino Botín, Madrid, 56-99.

Llamas, M.R. and Pérez Picazo, M.T., 2001. The Segura Catchment Management and the Debate on Hydrosolidarity in Spain. 2001 Seminar of the Stockholm International Water Institute, Stockholm 18 Augusts 2001. 18 pages, *in press*.

López Gunn, E. and Llamas, M.R., 2000. New and Old Paradigms in Spain's Water Policy, in *Water Security in the Third Millenium: Mediterranean Countries Towards a Regional Vision*. UNESCO Science For Peace Services (9): 271-293.

Ministerio de Medio Ambiente (MIMAM), 2000. Libro Blanco del Agua en España, Secretaría de Estado para Aguas y Costas, Madrid, 640p.

Moench, M., 1999. Addressing constraints in Complex Systems. Meeting the Water Management Needs of South Asia in the 21st Century in *Rethinking the Mosaic* (Moench et al, ed.). The Institute for Social and Environmental Transition. Boulder. Colorado, 1-56.

National Research Council, 1997. *Valuing Ground Water*. National Academy Press, Washington DC., 189p.

Postel, S. (1999), *The Pillar of Sand*, W.W. Norton and Co., New York, 313p.

Rangarajan, R. and Athavale, R.N., 2000. Annual Replenishable Ground Water Potential in India - An Estimate Based on Injected Tritium Studies, to be published in *Journal of Hydrology*, preprint, 30p.

Seckler, D., Amarashinge, U., Molden, D., de Silva, R. and Barker, R., 1998. World Water Demand and Supply, 1990 to 2025, *Scenarios and Issues*, Research Report 19, International Water Management Institute, Colombo, Sri Lanka, 42p.

Selborne, L., 2000. *The ethics of Freshwater Use: A Survey*. COMEST, UNESCO, Paris, 58p.

Simmers, I., Villarroya, F., and Rebollo, L.F. (editors), 1992. Selected papers on overexploitation. *Hydrogeology*, Selected Papers, Vol. 3, Heise, Hannover, 392p.

Sophocleous, M., 2000. From Safe Yield to Sustainable Development of Water Resources - The Kansas Experience . *Journal of Hydrology* 235: 27-43.

The Economist, 1998. *Environmental Scares*. December 20, 1998, 21-23

Tood, K.D. (1980). Ground Water Hydrology, 2nd Ed., McGraw Hill, New York.

United Nations, 1997. *Assessment of Global Water Resources*, New York.

U.S. Geological Survey, 1999. *Sustainability of Ground-Water Resources*. Circular 1186, 50p.

Wood, W.W., 2001. Water Sustainability-Science or Management, *Ground Water* 39(5): 641.

World Commissions on Dams, 2000. Dams and Developments. A New Frame for Decision-Making, *Earthscan*, 404p.

World Humanity Action Trust (WHAT), 2000. Governance for a Sustainable Future, Part IV. Working with Water, *Reports of WHAT*, London, 145-197.

World Water Council, 2000. A Water Secure World, *The Commission Report*.