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Groundwater problems in general and in Spain in particular

Groundwater is a reliable source of freshwater. Many favourable characteristics explain its widespread use, alone or jointly with other freshwater sources. However, groundwater exploitation causes also several inconveniences. Some are real, but many others are imagined, due to poor understanding of aquifer systems, or are created to diminish the importance of groundwater and to promote other aspects of the water cycle. Technical problems are the easiest to understand and to internalize from an economic point of view. Groundwater hydrodynamics explains water level drawdown, salinization and increasing exploitation costs. These problems become important for intensively exploited, large aquifer systems. Groundwater pollution is a serious hydrogeological problem, but also a land use related problem. Its solution needs a broader spectrum of elements than those provided by groundwater regulations alone. The same can be said for groundwater wetland dependent problems. Different but very important problems concern groundwater management. These are complex problems, since there are many actors and personal and collective attitudes as well as management and administrative vices involved. Groundwater problems depend on each region's or country's conditions. They come to light clearer when aquifers are intensively exploited. This is the case of Spain with respect to the European Union. It is difficult to comply with Directives mainly adapted to other hydrogeological conditions. In 1985 Spain changed its former, more than a century old, Water Act, to try to update obsolete concepts and regulations. Currently, groundwater is a public domain. To some extent it has been regulated as if it were an extension of surface water, which is a public domain since the last century. This, plus a series of miscalculations, lack of means, devotion to obsolete planning goals and excessive pervasion of politics into technical and managerial affairs has led to difficulties in enforcing and applying the new Water Act and its Regulations, as well as in drafting the mandatory Water Plans. In practice most extracted groundwater is still private. This situation leads to what are erroneously considered as difficult groundwater problems, and is used as an argument or excuse for paying more attention to problems of surface water and other water sources such as desalination and reuse. This paper comments on these negative aspects to show errors that should be avoided.

INTRODUCTION

For a long time groundwater has been an important source for human water supply. Its importance is currently increasing, both in developed and developing countries. Simultaneously, groundwater is essential for many environmental issues and plays a key role in many Earth processes.

Since groundwater is mostly out of sight, it has been the subject of speculation since antiquity. Engineering aspects were often quite well understood, but a long series of scientific misinterpretations coming from early times lasted until recently and persist in popular culture and in difficult to eradicate myths, which pervade managerial attitudes. They are the source of what are often called groundwater problems, as perceived by many of them. There is currently good scientific and engineering knowledge of groundwater — in some cases superior to the knowledge of other phases of the water cycle — but it has not been duly transferred yet to basic education and mass media. Thus groundwater is often still considered as something mysterious and unreliable, or plainly neglected by many managers of the water administration, in spite of its successful and intensive use, because many of them lack a background on groundwater science and engineering. Furthermore, mass media often produce distorted, biased and erroneous information on groundwater issues.

Fortunately things are changing little by little with the help of well established international postgraduate courses, many of them fostered by UNESCO, by the introduction of specific disciplines in training curricula and by the continuous pushing of some scientific and technical organisations, such as the International Association of Hydrogeologists.

This paper presents a selection of the most important technical and managerial problems related or attributed to groundwater exploitation, grouped in topics. Spain has been chosen as the basis to illustrate the diverse aspects involved. Thus, there is a bias towards problems common in continental and insular Spain. A background introduction will be given in the following section. Continental and insular Spain is an adequate reference country to describe real or assumed groundwater problems, because on average it is the most arid country of Europe [1,2], except Malta, and large enough to present a wide spectrum of situations, and because it has a long tradition of groundwater use and old water management arrangements. Some quantity and quality problems are not shared with other regions of Europe, especially of the European Union, where groundwater is often located in relatively well recharged, shallow, Quaternary formations. There water quality issues often dominate, because a large part of the extracted water is used for human supply, and cropland irrigation is often a minor issue, except in the Mediterranean area. Conversely, in Spain agriculture uses about 80% of available water resources and consumes 90% of it. Rivers are relatively small and highly variable, to the extent of becoming a rivulet or a dry channel in summer. This introduces difficulties for the compliance and application of some European Directives on groundwater.

Often continental Spain has been compared with California in terms of population, agriculture and water resources [3,4], to draw conclusions about groundwater management issues. Also, what concerns water, some Spanish regions along the Mediterranean Sea have some points in common with Arizona. Some of the issues at stake are intensive aquifer exploitation, overexploitation, water legislation, seawater encroachment (not in Arizona, of course), water salinity and public participation in management.

GROUNDWATER RESOURCES AND MANAGEMENT IN SPAIN

The Iberian Peninsula is highly varied as regards water resources [5]. Although the average rainfall is about 700 mm/a, the north and northwest are humid (more than 1300 mm/a). The Mediterranean area is predominantly semi-arid, with areas close to arid (less than 200 mm/a), with high potential evapotranspiration rates, a good climate for crops and fertile soils in the plains along the coast and the main valleys. Roughly, two-thirds of the territory drains into the Atlantic Ocean, partly through Portugal, which is more humid. The Ebro is the only large river basin draining into the Mediterranean Sea. Other Mediterranean basins are small, with seasonal rivers subjected to extreme water conditions. However, this area has important unconsolidated and carbonate aquifers. The Balearic Islands have the Mediterranean characteristics, with no significant surface water resources and relatively good carbonate aquifers. The volcanic Canary Islands are situated in the arid Atlantic Saharan belt of about 100 mm/a rainfall, but as some of them are very high, quite large orographic rainfall (up to 1000 mm/a) is derived from the humid trade winds, but this is restricted to the northern slopes of the highlands [5].

In Spain water rights and water organisations date from earlier times. The seven centuries old Water Court of Valencia is a good example [6]. Water legislation and usages were varying from site to site and appropriation rights were often sanctioned by the authorities. In 1866 the first Water Act for the whole country was drafted, intending to declare all water a public domain. However, when it was enacted in 1879 only surface water was declared a public domain and groundwater was declared the property of the extracter. Thus, the Public Administration lost interest in groundwater. The settlement of conflicts was committed to Civil Courts, unless groundwater extraction could affect public waters in rivers, lakes and canals. According to Llamas [7], the failure of deep, flowing wells for the public supply of Madrid, trying to replicate what was done earlier in Paris, played also a role in the scarce interest in groundwater of the engineers of the highly centralized Public Administration, ignoring what was done with good success in other areas of the country, mostly by private enterprises, and ignoring the advanced ideas of some scientists and engineers.

In 1926 the public water administration was organized into ten River Basin Water Agencies (Confederaciones Hidrográficas) in the peninsula and three island Water Services. The Confederaciones Hidrográficas were conceived as water management and investment organisations, with representatives of the surface water users in the governing and water management boards. However, soon they became poorly representative, techno-bureaucratic organisations, autonomous in theory, but in fact highly dependent on the Ministry of Public Works for economic resources, personnel and guidelines. In 1959 the Water Basin Authorities (Comisarias de Aguas) were created to deal specifically with water resources and water rights management, or water administration in national terms. However, in 1979 they were put again inside the Confederaciones Hidrográficas, losing the benefits of separating investment and project management from the administration (management) of public water. Groundwater was almost absent in the water management objectives of the Public Water Administration.

In 1985 a new Water Act was enacted, and shortly afterwards two Regulations to develop the Water Act were approved by the Government. It emphasizes the uniqueness of the water cycle and declares both surface and groundwater a public domain under the responsibility of the Ministry of Public Works, acting through the River Basin Water Agencies, the successors of the former Confederaciones Hidrográficas. The Water Act and its two Regulations refer to both quantity and quality issues. This Act was long pursued by many water managers to substitute the obsolete but effective old Water Act. However, it was prepared hectically and it was little discussed publicly. There is a series of advances and positive steps, but groundwater is treated erroneously in some aspects, overoptimistically in others, and is often considered as an extension of surface water. After a decade it is felt that many potential improvements of groundwater management have failed, due to poor knowledge, lack of trained personnel, foot dragging, preconceived ideas and insufficient involvement of groundwater users [8]. Consciously or unconsciously, groundwater has been considered of secondary importance, full of problems, difficult to manage, a competition to the use of existing river schemes and a risk to consolidated surface water rights. Also, the Water Act is in some aspects dominated by poorly understood groundwater problems in the Mediterranean and central peninsular areas and in the islands, which leads to a pessimistic — sometimes

Malthusian — view of groundwater resources. Overexploitation and the salinization risk of aquifers are now legal terms, although poorly defined and used in different ways by the different Water Agencies.

To avoid economic compensations to those who legally had groundwater ownership, acquired before the 1985 Water Act and consolidated in the Property Register, and who did not want to transform them into a concession of public water, two possible options were established in the transitory section of the Water Act: (1) to continue with the private ownership; (2) to yield the right to the Administration and transform it into a concession after fifty years of using the private rights, in exchange for a poorly defined 'legal protection'. Maintaining private rights implies that the conditions of the extraction work (well or gallery) cannot be changed without transforming the full right into a concession. However, it is unclear what a 'change' means, and this is variably interpreted by the different Water Agencies and experts. Many groundwater rights holders have decided, consciously or unconsciously, to maintain the old situation, and some lawyers even recommend well owners not to follow the Water Act, since they are already protected by rights derived from the registration in the Property Register. Thus groundwater is a public domain, but many present groundwater extracters continue to own the water they get. Only new extracters are obliged to get a concession if the quantity to be extracted exceeds 7000 m^3/year in common cases. All this is a serious hindrance for applying the Water Act as it has been conceived. This is not necessarily detrimental for a reasonable groundwater management, provided it is participatory. However, real participation of water rights holders in management is still in its infancy and poorly understood by some top men of governmental agencies, to which the Regulations give large autocratic power of decision.

The Water Act is closely linked to the Water Basin Plans and to the National Water Plan defined in it, and so its application depends largely on them. These plans have proved to be difficult to draft and not one has been definitively approved yet. There is a growing feeling that they have little chances to be definitively approved if their orientation and concept are not changed. What concerns groundwater, existing drafts are poorly conceived and unsupported from a technical, economic, and managerial point of view. Often groundwater exploitation is veiledly seen as something reducing the efficiency of existing or future surface water works [9,10]. Conjunctive use of surface and groundwater is advocated in theory but not in practice.

Spain is politically divided into seventeen Autonomous Regions, each with its own elected regional government. When the river basin is not wholly inside a Region, the River Basin Water Agencies hold the water administration. However, some regional governments have also competencies on groundwater resources management inside their territory, even if they are in interregional basins. This is a source for litigation between the central and the regional governments, but things are being solved as experience is gained and agreements are set.

The new legal situation has not provided a separation of public water works financing and control from public water administration, neither at the State nor at the Autonomous Government level. Water quality and quantity affairs are split by convenience into separate administrative bodies both in Central Government and in some Regional Governments, but not in the Water Agencies, which depend on two separate Central bodies. This is a detrimental situation, which needs improved coordination or a new structure of water administration.

In Spain agriculture uses about 80% of total water resources for the irrigation of about 3.5 million ha. This demand is the cause of most water quantity problems and of many water quality problems. When strictly defined, agriculture contributes only 6% to the national income and employs 8% of the active population. However, if agriculture and animal raising related activities and factories are included, according to the draft of the National Plan for Irrigation the contribution to the national income is 15%, employing 8.5% of the active population and representing 17% of export. About 13% of the total agricultural surface area is under irrigation and contributes about 60% of the agricultural national income, or irrigated lands produce economically seven times the output of dry farming areas. The difference is much higher in the Mediterranean and island areas.

About 18% of the total used water resources is pumped groundwater in Spain [11], but in large areas the share is much higher, close to 100%. About 15% of the 5.6 km^3/a of groundwater extracted, according to official figures, goes to public and industrial water supply for about 30% of the population, and 85% is used to irrigate about 700,000 ha of cropland, plus incidentally another 300,000 ha.

Official data show that about 700 hm^3/a (about 15% of total groundwater extraction) is aquifer overexploitation [11], although this figure is controversial and possibly largely overstated. Seawater intrusion in coastal aquifers is also considered a major and widespread problem, although many areas lack detailed studies and often the quoted problems are the result of poor exploitation strategies and some misinterpretation of the origin and causes of salinity. Official data show that about 28% of the territory has a high risk of aquifer contamination, but data on the real situation are scarce and patchy.

There are serious groundwater contamination problems, many of them related to agrochemical use, but problems of oil, organic solvents, and heavy metals are appearing and growing in importance. However, the situation is still bearable [12,13]. Groundwater (well head) protection areas are still to be realized, although they are considered in the Water Act. About a hundred significant groundwater related wetlands are considered for protection.

There are some interesting, more than a century old, hydrogeological studies. The recommendations and management flaws detected by Vilanova y Piera at the end of the nineteenth century read like an assessment of the current situation. The first scientific studies using modern means are from the sixties of this century, and were started by the Geological Service of Public Works. Different Water Authorities and the Geological and Mining Institute became active in the late sixties and in the seventies. These activities covered most of Spain, with a varying degree of understanding. Some were in-depth and included some applied research. The main aquifers are coded and administrative limits have been provisionally established until being definitively defined in the respective Water Plans. Conversely, the hydrogeological tasks to prepare the Water Plans, which started late in the seventies, have produced relatively poor results, in spite of the large economic resources invested. Groundwater levels are patchily monitored and groundwater quality monitoring is still at its infancy.

Two groundwater-oriented associations are especially active, involving about five hundred professionals and specialists. Two international groundwater hydrology courses, one in Barcelona and another in Madrid, have provided qualified trained personnel. A major book on groundwater hydrology was published in 1976 and reprinted twice [14]. It is a main study source for Ibero (Latin) America. In spite of this, there is a conspicuous and unfortunate loss of scientific and technical capability in the Water Authorities and other official institutions by the substitution of experts for politically oriented persons, lacking a background in water science and management. This appears in the drafts of the Basin Water Plans, in which most references and supporting studies, if they exist, are often older than fifteen years, or do not contain new information.

Fortunately several University Departments are taking a leading role in training, studies and applied research on groundwater. Currently there are more than fifty full time professors and researchers interested in this field, but this is not a substitution for a degrading water management, although it keeps things working and creates pressure for changes. Funds for groundwater research and development are scarce, corresponding with the small percentage of public spending devoted by Spain to research goals. Recently a long expected water research plan has been introduced, but it is poorly funded. The financing through the Water Plans is doubtful since what is quoted as study, research and development seem to have other goals. Consulting firms and professionals suffer from the lack of continuity of public investments and studies, and the private sector does not produce a large enough and stable demand of studies. So these firms and professionals are underdeveloped and underqualified compared with the potential needs of the country. Something similar happens to other groundwater-related enterprises, such as well drilling companies, of which the average level is poor. Occasional improvements last shortly, due to lack of specifications to be respected, failure to produce sustained work and cutthroat competition. Also groundwater quality and contamination issues are at the starting point, with a hesitating water administration and courts, in spite of reasonable but incomplete regulations.

COMMON OBSTACLES AND DISEASES RELATED TO GROUNDWATER MANAGEMENT, WHICH ORIGINATE GROUNDWATER PROBLEMS

Groundwater development and management are plagued by management-related obstacles and diseases, shared by the exploitation and management of other water resources, although not with the same degree of intensity. The fact that groundwater resources are scarce, unevenly distributed and entangled in a network of old traditions and rights make these obstacles and diseases more acute. They are at the source of many so-called groundwater problems, and involve technical, knowledge, educational and ethical aspects, these last being some of the most serious [15]. They are reflected in groundwater myths that will be commented on later. They oppose the basic management rules of solidarity, subsidiarity, participation, education, information and foresight.

An obstacle is ignorance. Poor or deviated knowledge may hinder correct groundwater development and management and may produce damage even if the manager or water authority tries to act honestly. Other obstacles are ethical and comprise arrogance (which is often linked to ignorance), negligence and corruption. Corruption includes the efforts to maintain privileges of social, professional or public administration groups. It is not always only connected with money, but also with power, prestige and the wish to exclude other persons and groups.

Besides these obstacles or capital sins, there are diseases. A common disease is ‘hydroschizophrenia’ [16]. It is attributed to widespread ignorance about the origin, movement and methods to explore and develop groundwater. Llamas [17] considered it an endemic disease in Spain.

Another common disease concerns insufficient, poor, erroneous, biased and partial information, and also difficulties in getting information. This is especially acute for groundwater. The delay and difficulties (and perhaps foot dragging and red tape) in implementing the European Union Directive 90/313 on environmental data accessibility in Spanish legislation may be a symptomatic example of this disease.

Another group of diseases are the obstacles to public participation in groundwater affairs and the autocratic behaviour of top water managers, still common in Spain. These attitudes persist even if public participation is clearly the only practical solution in a democratic society to deal with the many actors involved in aquifer management, respecting individual freedom, land use rights and environmental values. These diseases are often accompanied by ignorance about the methods to deal with these aspects and by arrogance.

Another disease concerns the poor public education about groundwater principles, characteristics, use and environmental implications. This education is needed to direct policies and the preferences of politicians towards the right management of water resources. It is also needed to avoid the existing enthusiasm for large and costly public works, which are applauded by the mass media without considering their usefulness, how they condition and how they burden the local and national economy and the possible corruption involved. This large works are often presented as a means to create jobs when unemployment is high, without studying alternatives and better prospects for job upgrading.

A different kind of disease is the overoptimistic thinking that new, complex, undefined and poorly understood tasks, such as placing groundwater in the public domain, can be dealt with by the previous organisational, human and economic resources, mainly devised for surface water. This is often accompanied by regulations charging management agencies with tasks they are not prepared to do and that they cannot accomplish. A complementary disease is expecting that difficulties will be simply solved by just producing laws and decrees. This explains that the Spanish Water Administration is now in many aspects unable, understaffed and lacking the resources to deal with the new situations and the unforeseen deviations. Furthermore, the existing structure is mostly set up to deal with surface water related affairs, but not with the new technical, managerial, social and administrative issues of groundwater, and there is little incentive for this. Thus obstacles and diseases proved difficult to contend with, especially if the three-dimensional nature of groundwater and the existence of wells in private land, inside buildings, and even inside houses is not fully considered when providing means, and when users' participation in management is not increased.

To further complicate this panorama, the slow pace of groundwater movement and the delayed and dampened effects, even those resulting from well-identified causes, are poorly understood. There is no experience on how to deal with long delayed responses. Also prevention, as a necessary step, is unclear for many managers and often clashes with land use planning and management, which depend on other authorities. Putting water management and administration under the umbrella of a wider authority is not an easy task and sometimes mechanisms for coordination are not readily available.

Management and administrative failures in organizing, defining or simply surveying groundwater rights lead to situations in which regulations are poorly observed. A new disease is trying to solve this by amnesties. These amnesties may become an unfair punishment for those who have respected the regulations, supporting all the charges, troubles and loss of opportunities involved, and a reward to roguish behaviour.

Improvisation is a last kind of disease, leading to costly, little effective solutions, instead of better and less traumatic ones. To do this, often some regulations are short circuited, or urgent action, an emergency and the public interest are brought forward to justify what is done. The sequence of recent dry years affecting a large part of Spain has favoured short-term, improvised and politically rewarding solutions, which have temporarily solved problems in some but not in all areas. Many of them have been carried out under emergency decrees, often without evaluating alternatives and the future use, and even waiving legal public water concession procedures.

GROUNDWATER: REAL, PERCEIVED OR IMAGINED PROBLEMS

Aquifers are a reliable source of distributed water, but also a storage and a strategic, emergency and drought reserve. They also sustain river base flow and wetlands. Groundwater moves slowly. Transport of solutes and pollutants takes a long time. Hydraulic (pressure transmission) effects are faster and this is a source of misunderstanding for untrained persons. As for any other natural resource, groundwater exploitation presents a series of favourable aspects as well as a series of drawbacks. Some of the favourable aspects can be summarized as follows.

(a) Large associated water storage, which allows for slow response to recharge (rainfall) fluctuations, for reserve to deal with droughts and failures of other water supply sources, constant or slowly varying temperature and quality of water, relatively reliable forecasting of future water availability and cost.

(b) Aquifers extending below large surface areas, which allows for distributed exploitation using smaller, cheaper pumping centres, with fewer water transport structures.

(c) Extraction better adapted to changes in water demand and to the development of the area.

(d) Reliable estimates of aquifer characteristics, development results and management, even considering the risk of mixing with saline water.

(e) Relatively acceptable to good protection against short term pollution, accidents and catastrophes, which may affect water quality.

(f) Relatively simple study, exploitation and monitoring, using techniques most of them locally available or not too sophisticated.

(g) Small and progressive investments to develop the resource, affordable with local economic resources or small loans, easily repayable and without the large financial costs of large projects.

(h) Minimal interference with land use.

(i) Easy concealing of landscape degrading works.

(j) Possibility of combining aquifer use with other water sources, mainly surface water, both permanently and temporarily.

(k) Relatively easy correction of water quality for a given use.

(l) Low risk of containing disease producing organisms in correctly constructed wells.

(m) Water prices closer to real ones and less prone to economical distortion.

(n) A motor to local economic development.

However, groundwater development is not without drawbacks. This is the main objective of this paper. These drawbacks are often called 'problems'. They can be seen under different viewpoints: (i) problems affecting water resources that derive from physical principles; they can be easily understood and internalized; (ii) problems affecting land use and persons not directly related to groundwater extraction; their internalization is less obvious; (iii) real or imagined problems, consciously or unconsciously denounced and presented in order to belittle the benefits of groundwater use and to promote or protect the use or expansion of other water sources; education and ethics are needed.

When considering a given management alternative, problems are associated to costs and damages, and involve prevention and corrective measures. The selection of alternatives is technically and economically oriented, but sociopolitical conditions play also a decisive role since they are the way to get a compromise among the conflicting interests that often appear, after avoiding obstacles and curing the management diseases presented before. Different kinds of groundwater problems will now be discussed, grouped under the heads: technical, environmental, economic, managerial and sociocultural. This will be followed by comments on overexploitation and groundwater myths. Unless groundwater exploitation is limited to spring flow winning, some groundwater level drawdown (drop) is always needed to create a head gradient that directs groundwater to the extraction works (wells, water galleries, drains).

TECHNICAL PROBLEMS

Head-related problems

Problems related to groundwater extraction are the consequence of aquifer hydrodynamics. Consequently they can be known, quantified and predicted with reasonable accuracy if aquifer parameters and stresses, such as extraction and recharge, are well known. Water level drawdown is a problem since groundwater has to be pumped from deeper levels, wells may become short and their yield may decrease, drains may become dry, and parts of the aquifer may be dewatered. Furthermore, natural groundwater discharges reduce its flow or become dry, and saline or contaminated water may move to the wells. Existing groundwater rights are more or less affected. There is a transient period in which ground water level drawdown increases since part of the water extracted comes from aquifer storage. It ceases when captured recharge equals pumping, if pumping is less than the aquifer system recharge from rainfall, river infiltration, snow melt or any other source. The duration of this transient period is directly proportional to the square of aquifer size (lineal dimension) and inversely proportional to hydraulic diffusivity, or the aquifer transmissivity divided by the specific storage. Typically this duration may range from some weeks to many decades for regional systems comprising aquitards (low permeability, porous formations). This is well known to hydrogeologists and groundwater engineers, but less obvious to many water managers, who may easily be alarmed and suspect some kind of overexploitation, thus adducing groundwater problems. In mountainous areas, which are common in Spain, especially when aquifer transmissivity is small, total groundwater level drawdown of tens (sometimes hundreds) of metres may occur, and this happens even if extraction is less than recharge, as in the Gran Canaria and Tenerife islands [18]. Situations of intensive exploitation and overexploitation will be considered in the paragraph 'Intensive aquifer exploitation and overexploitation problems'.

The often slow response of the aquifer to extraction when there is a large water storage associated, allows to pump out large quantities of water during some time without important impact on natural discharges in the short term. This gives the aquifers an important role for dealing with seasonal peaks of demand, drought mitigation, emergency supply in case of a major breakdown or accidental quality impairment of existing supply systems, and also for conjunctive use by increasing available storage capacity. The system recovers in the out-of-season period if wells can be adequately placed and aquifer characteristics allow for it [19,20]. This is something not fully understood by many water managers and environmentalists, who mostly think in steady situations and consider extraction a problem to avoid since it changes exploitation conditions to existing groundwater rights holders and to wetlands.

In aquifers connected to surface freshwater bodies (rivers, natural or artificial lakes) the water level drawdown associated to groundwater extraction produces induced recharge from them. This recharge is larger the greater the groundwater extraction is and the closer the wells are to the water body, but there is an upper limit which is a function of the characteristics of the infiltration surface and the sediments on it. Actual recharge is very sensitive to surface water depth changes, flow velocity, water turbidity, characteristics of sediments, flow regime, effect of floods, river channelling, manmade changes in the channel, and so on. What may be an important recharge in some moment may largely decrease afterwards if adequate maintenance, prevention, restoration and substitution measures concerning recharge are not undertaken. Something similar happens for recharge in alluvial fans, which is very important in foothill areas in dry climates, as in eastern Spain. Poor land use management has spoiled much of the induced and alluvial fan recharge, thus arising consequences that are often and erroneously labelled aquifer use problems. The uncertainty of aquifer recharge is often considered a problem which is opposed to surface water calculations based on stream gauging and surface runoff calculation. Really, even with these uncertainties, often recharge can be known more accurately than surface water volumes at a given point in a river, and forecasting errors are less for aquifer recharge than for river flow with the same level of investment in studies. What is often mentioned as problems and failures in groundwater exploitation really are only the results of incorrectly interpreted observations, due to poor knowledge. Moreover, the consequences of errors are less serious and easier to correct without excessive traumatic measures due to the large water storage involved. Large and expensive surface water works may behave the other way. Often hidden economic data, unknown subsidies, concealing of results and undefined goals may apparently change assessments and rise nonexistent aquifer and groundwater use problems.

Related groundwater use problems are often adduced by people from some of Spain's governmental water management agencies. They argue that since a very large proportion of surface water is already used after important dams and canal systems have been constructed, and a large part of the water comes from aquifers upstream, especially in the carbonate rock areas of the east, aquifers are already fully used and no more development is advisable. This is called indirect use of groundwater. It is also said that aquifer exploitation will decrease the surface water availability thus impairing the use, management and cost recovery of the existing works. This is partly true when a large part of the water is used for irrigation, which consumes about 80% of it, and thus most of this water is not available again. However, some management errors are involved in this reasoning and at least they are a serious loss of opportunities for using the water where it is needed [9], in the most efficient way and adding to usable basin storage provided by the groundwater level drawdown (depletion).

Problems in coastal aquifers

Coastal aquifers are important water resources elements since they are often situated in densely populated areas, where other water resources are often scarce or of low quality. Coastal aquifers are not only a supply source but also a storage for seasonal peaks of demand and for emergencies. This role is increasingly important to guarantee water supply quantity and quality. However, they are vulnerable to salinization. This is often considered a major and unavoidable groundwater problem. Marine water is slightly more dense than freshwater. Thus near the coast saline water occupies the deeper part of the aquifer (salt water wedge), and freshwater slides on it when flowing to the coast or aquifer submarine outcrop [14,21]. Freshwater flow in coastal aquifers limits the inland penetration of the seawater wedge, and controls the thickness of the mixing zone between the fresh and the saline water. If wells are far enough from the shore or if their penetration into the coastal aquifer is small, it is possible to extract freshwater or water that at the most is only slightly affected by salinity, but in a part of the aquifer brackish and saltwater will substitute freshwater. To make the freshwater extraction in a coastal aquifer sustainable and to maintain the capacity to attend seasonal water demand peaks and emergencies, some freshwater discharge into the sea is needed. If the coastal aquifer is known with enough detail, its behaviour can be modelled, although heterogeneities are difficult to know and to take into account. Management failures may require changing well location and the exploitation pattern, as well as introducing some control measures, some of them administratively complex and difficult for untrained managers. In Spain this has created the erroneous but widely extended idea that coastal aquifers are sooner or later affected by saline water, but this has been the reaction of some water managers after observing some salinization problems, and extrapolating the unsatisfactory results of some wells to the whole aquifer system. Really, a large part of what are considered coastal aquifer problems is technically due to poor location, design and construction of the wells, inadequate exploitation, lack of reliable observations and poor knowledge of aquifer hydrodynamics. Often local saltwater upconing is taken as lateral salt water displacement.

However, salinization problems of coastal aquifers are not always due to modern seawater intrusion. Other circumstances leading to salinization are the deep infiltration of saline irrigation return flows, climatic aridity in a saline fallout environment, saline water from other aquifers or aquitards penetrating through misplaced well screens, corrosion, poorly welded casing joints, uncemented or poorly cemented annular spaces, infiltration of highly evaporated surface water and leaks from pipes, canals and reservoirs transporting through the territory or storing brackish or saline water. A careful study, supported by chemical and environmental isotope studies, is needed to identify the true cause of salinization, before decisions on aquifer management are made. Management failures due to poor identification of salinization sources and mechanisms add to the assumed coastal aquifer problems.

Salinity and quality related problems

In the past, groundwater has been considered to be of relative good quality and quite well protected against pollution. Experience shows that this was an overoptimistic point of view. In fact, many cases of serious aquifer water deterioration are known and their number is increasing. These problems stem from the following.

(1) Displacement of saline or degraded quality water in surface water or in the ground (in aquifers and in aquitards) towards the wells due to groundwater head changes. Sea water intrusion is a special situation commented before.

(2) Leaching of pollutants from the land surface, the soil or buried in the ground, by rainfall and surface water infiltration that was not formerly admitted into the exploited aquifer and now is able to penetrate due to water table drawdown.

(3) Accelerated downward movement of saline water existing in thick unsaturated zones. This saline water may be the result of a large concentration of salts in recharge water in a semi-arid environment due to very efficient use of rainfall by native vegetation. Deforestation for pastures or cropland may greatly increase recharge and thus the rate of transfer of this saline water to the allochthonously fed aquifer. This is currently a major issue in the Murray basin in Australia, but probably also happened in the past in some areas of Spain, as in the Monegros.

(4) Enhanced dissolution of solid matter due to chemical changes (pH, redox potential, buffering capacity, complexing by soluble organic matter etc.).

Generally the water quality changes appear long delayed (from months to years) with an advancing front or contaminant plume which is often quite dispersed. This is especially true for nonpoint pollution sources. Mixing of aquifer water by pumping wells increases the dispersion shown by samples.

What has been briefly described, appears quite complex for untrained water managers, still more if they receive pessimistic reports on groundwater quality deterioration, which often unconsciously extend local problems to the whole aquifer system, and do not differentiate between true aquifer contamination, local effects and effects produced by poorly constructed, operated and maintained wells.

Aquifer protection involves not only decisions on groundwater extraction and aquifer management, but many other decisions on land use too, which concern other agencies and administrations and which may involve regulations for the transport of dangerous substances, agrochemicals use, storage activities, type of acceptable industrial factories and so on. This may cause changes of property value and activities inside private land or buildings. These are also considered as major groundwater problems by managers trained to deal with the often more docile, less complex and easier to monitor surface water schemes.

The situation in Spain is rather confusing since information is still poor and fragmented, but some well studied cases exist. As in other European Union countries the most worrisome aspect is nitrate buildup, which may attain a concentration of hundreds of mg/l NO_3 in some aquifers. There is also serious pollution of aquifers by mining, industrial, domestic and oil activities [12,13]. Some managers of the Public Water Administration have a growing, although erring feeling that these are complex, expensive and difficult groundwater problems and that it is worthwhile to get rid of them in spite of the Water Act and the European Directives. Thus, recently it has been argued to soften aquifer protection measures since most of its water is for agricultural use, which is much less quality demanding. This assertion neglects the importance of groundwater for human water supply in Spain, especially at small town and rural levels, and the role of aquifers as security storage elements. This is to some measure a way to escape from unmastered groundwater problems and to promote more expensive, easily marketable and politically rewarding large investments in other sources, including desalination. Upstream water use for irrigation increase the river and aquifer water salinity downstream. The increase can be worrisome, especially if irrigation water dissolved solids content is rather high and if more efficient irrigation does not mean less water use but more surface for the same water. Storage in the unsaturated zone holds the effect temporarily, but this may lead to a long delayed problem, with possible serious future aquifer and river problems. Surprisingly, many agricultural water managers, even those who pay attention to soil salinization, rarely think of salinity storage in the basin and its delayed release. In some areas of Spain this may be aggravated by mobilization of existing soluble salts in the ground, such as evaporite rocks.

Problems related to land subsidence and collapse

Heavy groundwater extraction in thick unconsolidated formations may produce significant compaction due to an effective stress increase. It is partly elastic, but a large part may be irreversible compaction and thus regional land subsidence may happen. This is well documented for several areas in the world [22]. This subsidence may alter the surface drainage system and how it works, distort canal and sewage networks, produce more frequently flooded areas, affect transportation ways and modify the coastal line. This is a true groundwater problem that manifests itself only under certain circumstances. It is an externality of groundwater exploitation, although it is seldom taken into account when evaluating water supply alternatives.

In Spain there are no documented cases of land subsidence due to groundwater exploitation. This is in part because many heavily exploited, thick aquifers are consolidated ones, but in unconsolidated aquifers land subsidence due to groundwater extraction cannot be ruled out. There are simply no data and the possible effect may go unnoticed, or has been unconsciously corrected by other human land activities. This may be the case in the intensively exploited Llobregat delta aquifer system, at the southwest boundary of Barcelona. There is a clear coastal recession in some areas, which is attributed to enhanced coastal erosion, but land subsidence cannot be ruled out as a contributing factor. Land subsidence has also been mentioned in Murcia as due to increased groundwater extraction in the last dry years. In formations subjected to concentrated dissolution (karstification of carbonates and gypsum), relatively shallow cavities may collapse. The result is localized, sudden land sinking (collapse), leaving depressions up to several tens of metres deep and up to several hectares of surface area. This is well known in some parts of the eastern United States and southwest China. In Spain there are examples in several areas such along the Ebro river valley near Zaragoza, near the lake Banyoles, Girona, and around a well field in Torrelaguna (Madrid), which was practically abandoned because of water table depletion. Landforms clearly show that these collapses happened in the past. These areas are prone to new ones, which can be enhanced by groundwater exploitation. This is a local groundwater exploitation problem, very difficult to manage and forecast, but the involved costs are generally minor.

ENVIRONMENTAL PROBLEMS OF GROUNDWATER EXPLOITATION

Groundwater discharges sustain riparian forests along rivers, wetlands in flat areas and vegetation strips (ecotones) at the limit between formations of contrasting permeability. Vegetation in these areas and the associated fauna, which periodically or occasionally eat, drink and rest in them, depend on the sustained discharge of groundwater. Groundwater exploitation from the aquifer produces a progressive reduction of discharge, which may appear delayed and long lasting. The effect is greater and faster, the closer the wells are to the discharge areas, but aquitards may greatly smooth and delay the effect. This is an environmental problem that may adopt different forms according to circumstances. They may appear as a reduction of the length or the surface area of vegetation, or a habitat change due to a widespread reduction of groundwater availability to plants. This last circumstance may appear as more severe droughts last longer and become more frequent. However, wet periods do not disappear, although they occur less often and last shorter.

These modifications are due to groundwater head changes and may be compounded with chemical shifts due to modified evaporation areas, recharge of saline water or contamination. Main sources of contamination are nearby agricultural areas that modify salinity and introduce fertilizers and pesticides. The nitrate is free to move if the medium is electron donor free. The result is that the vegetation density and the number and distribution of plant species may change.

These groundwater exploitation problems can be known in advance and duly monitored, thus allowing for protection measures and restoration efforts to be applied. Even if such efforts are poorly efficient, the ecological impact uses to be less traumatic and more prone to correction than the sudden changes derived from river management.

The Tablas de Daimiel wetlands, in central Spain, have been desiccated in just a couple of decades by overpumping the carbonate aquifers feeding them [23,24]. Aquifer exploitation increased from 200 hm^3/a in 1974 to 600 hm^3/a in 1987 to irrigate 130,000 ha. Mean recharge is about 300 hm^3/a. The main springs (Ojos del Guadiana) disappeared in 1983, and now the wetlands have been changed into a kind of recharge pond [25,26]. This has been accompanied by the process of long lasting spontaneous combustion of dried out peat formations, something that before was very infrequent and short lasting. Besides the spectacularity of the process, this burning means land subsidence and makes restoration to initial conditions impossible. Also there is social unrest among the farmers around, due to official attempts to reduce groundwater extraction, something that would happen as a matter of course later, due to overdevelopment. The constitution of a general water users association coordinating thirty municipalities is going slowly, due to internal problems and disagreements with the Water Authority. Their constitution became compulsory in 1987, when the aquifer was declared overexploited under the Spanish Water Act. Simultaneously some governmental agencies, to save their environmental face concerning international nature preservation agreements, have launched some unfortunate attempts to restore the wetlands with expensive and inefficient water transfer and surface storage schemes, which are not able to adequately restore the ecological functioning and sometimes seriously damage other valuable wetlands along the tributary rivers.

In the Doñana area in southwest Spain, placed between the lower Guadalquivir river, the estuary of Huelva and the Rio Tinto, a large irrigated agricultural project extracting local groundwater very close to important groundwater fed wetlands has been carried out, starting in the seventies and developed mostly in the eighties [27,28]. About 7000 ha of intensively irrigated land exist near the most sensitive area, plus a population to be served of about 25,000 inhabitants, which may peak to 250,000 in summer. Current total extraction is 50 to 60 hm^3/a. Groundwater extraction concentrates in a deep aquifer layer, which drains a fine sand aquitard holding the water table [29]. Nature preservation organisations and experts have widely contested these agricultural — also some urban-developments, well before major vegetation and fauna changes have been fully noticeable, by using scientific assessment of future changes. There is hope for reaching an equilibrium between nature protection and development of the area. However, the fate of agrochemicals in the aquifer system is poorly known. Their impacts are delayed and more difficult to deal with.

In other areas of Spain, as in the Empordà (northern Catalonia) and the Llobregat delta (near Barcelona), changes due to groundwater exploitation have gone on almost unnoticed in spite of being serious. At the time they happened social conscience about the environment was less developed or even desiccation was a reasonable goal, protected by law. Continuous human changes in the system help in concealing some effects.

ECONOMIC GROUNDWATER PROBLEMS

Economic problems derived from groundwater exploitation depend on aquifer characteristics, on where the extraction works are and on the intensity of exploitation relative to recharge. Many of them derive from groundwater level drawdown and imply that the cost of extracting groundwater increases. This is due to greater energy consumption, which may be accompanied in some cases by the cost of substituting the wells for deeper ones, or deepening existing ones, the cost of new electric transport lines, transformers and pumps, and the extra energy losses due to the decreased efficiency of the pump. All these are foreseeable and internalizable consequences, which should be part of the economic study of a properly planned groundwater exploitation. Thus, what are sometimes considered groundwater problems are really mostly problems due to lack of prevision and a consequence of poor knowledge on how an aquifer behaves. It is a serious error to think that the economics of groundwater exploitation can be based on cost calculations based on starting conditions, without considering future changes, which may be quite important in large and thick aquifers. This error is not rare when managers think in surface water terms. Under correct economic planning, this increasing winning cost is really favourable since the water to be extracted is cheaper (less extraction) at the beginning, which favours economic development.

Other economic groundwater problems refer to quality deterioration and contamination prevention. Although prevention seems too expensive, in most cases it is worthwhile when the real aquifer opportunity cost is taken into account. This is not always easy since there is a series of externalities that are difficult to evaluate, but other alternatives also present externalities that are often unfairly waived to make them more attractive or concealed under subsidies or public deficit. Action for aquifer protection may change — often decrease — land and property value, and this may oblige to compensate for singular damages or losses, but not for general limitations or burdens. This includes reducing agrochemicals and manure use, compensating for the loss of agricultural production and in some cases of crop quality. However, in fair play possible benefits should be collected and redistributed. This is not an easy task, needing management skills. This is considered a new groundwater problem by untrained personnel or those who are resistant to change.

Some economic groundwater problems refer to management. They involve possible incentives and/or taxes to lower the aquifer system exploitation rate from the value that cancels the net benefit from individual users to that of maximum long-term social net benefit after internalizing the externalities [30,31]. This is also a complex task. Really these actions are more difficult to address than in surface water schemes, but generally this does not justify discarding an alternative since the cost of implementing the necessary organisational instruments is relatively low. Associations of groundwater users may greatly help in attaining these goals, as well as continuous education of water users to change their attitude and increase collective feelings.

Studying, monitoring, protecting and restoring an aquifer system needs economic resources. This is clearly so for dams, canals, and treatment and desalination plants, and should be equally clear for an aquifer system that produces benefits to its users. The difference is the result of the larger number of actors, the lack of collective conscience of groundwater exploiters and the inability of some managers to grasp it. However, this can be overcome. Taxation, direct or through other existing fiscal means, or shared expenses, plus economic responsibility for damage and irresponsible action, and security funds to deal with very delayed effects, are possible sources to cope with management expenses.

MANAGERIAL AND ADMINISTRATIVE PROBLEMS OF GROUNDWATER DEVELOPMENT

Many problems associated to groundwater development are not technical but managerial and administrative ones, including economical and legal ones, and knowledge-, ownership- and regulation-related problems. Some derive from technical circumstances, but others are unrelated and refer to economic, social and cultural circumstances. The management of an aquifer system implies that it is possible to carry out decisions by some kind of management agency. These decisions are directed to modify the extracted flows and volumes, the location of wells and other groundwater winning works, and how they are constructed and operated, considering economical, social, environmental and political goals. There is a wide range of possibilities, from full administrative regulation to doing nothing, to modify the trend.

This management not only refers to sustainable groundwater flow (quantity aspect), but to the preservation of water quality as well. This means decisions on groundwater exploitation and on land use, such as regulations and limitations to the use of agrochemicals, establishing well head protection areas or setting the limits of areas in which the aquifer is subjected to specific regulations to protect water quantity and quality. Specific situations appear in coastal aquifers, since the exploitation pattern is a key subject of management. Management objectives include analysing the positive and negative aspects of each alternative to adopt the right decisions, instead of trying to correct the negative effects — often labelled groundwater problems — once they have been produced. However, unfortunate decisions are often made under poorly informed public opinion pressure and when emotions dominate.

Since aquifer exploitation means groundwater head changes and fluid displacement, as explained before, management rules have to specify whether these changes affect existing groundwater rights and which modifications have to be supported to get full use of aquifer storage capacity after defining environmental goals to be respected. This is difficult to understand for untrained managers and may become a groundwater problem if regulations do not contain provisions or if there is not a general agreement on exploitation rules and cost sharing.

The main groundwater management problem stems from the very large number of actors involved and the very different interests they have. These actors are the persons, enterprises, societies, agencies and public organisations holding groundwater rights and wells, as well as those who are the users of groundwater, people living in the territory who are the possible subject of water taxes, restrictions and conditions of the activities, or who may suffer some water quantity and quality impairment, and the agencies in charge of land management, public works and transport. Complexity is generally much greater for groundwater than for surface water. The public or private character of water ownership has some influence on the way to cope with this complexity, but in real terms probably there is not much difference. This character affects the way how decisions are to be implemented, but not their foundations.

The problems caused by the large number of actors seem very difficult to solve when there is no experience, when there is no training for using available managerial instruments and when they are dealt with by unprepared personnel. The situation worsens when decisions are taken with arrogance or when they are the result of hectic moves yielding to pressure for solving as fast as possible situations that need a ripping time, training, public education, the rising of confidence between the actors, and the definition of widely consented goals. Often all this leads to consider groundwater as a too hot and unmanageable issue, a source of conflicts that result in personal loss of prestige, of jobs, or in political troubles. Thus a common reaction is to forget groundwater, leaving it to its own fate and applying only unavoidable policy regulations to apparently comply with what is mandated by law, and to cool down noisy or uncomfortable conflicts raised by the users or by pressure groups. The consequence is fostering large investments for surface water control and interbasin transfers, desalination or treated sewage water reuse, as now happens in Spain. This is currently promoted by new water managers, often taken from other jobs, who favour exotic and expensive solutions, which are easier to grasp by inexperienced persons lacking a prepared staff or good assessors. Besides, these solutions are politically well marketed and approved by mass media. They are less complex, more docile and more easily subjected to easy-to-enforce centralized decisions. However, often they are not the most appropriate ones from a technical, economic and social point of view, or they imply detracting economic resources from other more needed sectors, or heavy capital borrowing. Under these circumstances conjunctive use is out of consideration since groundwater is neglected or downvalued. This is a new loss of opportunities and of valuable alternatives. Water management decisions should derive from the study of all logical alternatives, weighed with technical, economical, social, environmental and legal considerations, used to support a political decision, but not by pondering on nonexistent or created problems, speculation and opportunism.

Some management agency is needed. It may act by itself, according to the Water Act and its Regulations, may be a consortium of agencies or may act under the agreement of the affected physical and juridical persons [30]. The country's political system and tradition play an important role in how the management agencies are shaped.

The different interests of the multiple actors can be put together through water districts or associations of water users, under a wide range of forms and control measures. There is a good experience in California, coming from the sixties [30]. In Spain these associations of water users (communities) are included in the Water Act of 1985 as public law entities entitled for water management inside the framework set by the River Basin Water Agency. These organisations are traditional and well established in Spain for surface water, some of them centuries ago, to manage communal and public water works and canals, and to arrange for irrigation shifts and the distribution of available water. For groundwater there are no evident communal water systems — the aquifer is rarely recognized as a common structure — nor the feeling of the need to share available resources, due to the large water storage involved, in spite of the multiple interference effects. To raise the feeling that there is a common aquifer system and recharge, a serious information effort is needed.

The convenience of forming an association of users is unclear at the first stages of exploitation, and when problems appear the actors are often unprepared to understand and recognize that there is a common interest and that yielding some rights and freedom to such an organisation produces benefits that exceed the inconveniences. This is a problem of groundwater exploitation, but can be solved through education [32], good data collection and easy accessibility to users, and the progressive involvement of users in decision-making. This can be anticipated by a responsible Public Water Administration or will come later, after some suffering and losses.

In Spain an association of groundwater users was created in the seventies under the Water Act of 1879. Then groundwater was still a private domain. This was the result of a commonly shared interest in preserving groundwater resources in aquifers dominantly exploited by municipalities and industrial factories. They are more receptive to technical reasoning about the common interest than farmers. The communication between farmers and managers greatly improves if social communicators and agrarian technicians are involved.

Creating new associations of groundwater users appears to be a difficult task in Spain, even if they are now defined in the Water Act of 1985 and administratively needed when an aquifer is declared overexploited or under risk of salinization. This is presented as a problem for using groundwater. The real problem is that people do not accept something coming from above as mandatory if they do not understand it clearly. Raising a collective conscience, education, trust, information and a share of power needs time and good social communicators. If negative reactions from groundwater users are compounded with the scarce enthusiasm towards these associations from many managers of the Water Authorities the problem becomes practically bogged down, even if groundwater is a public domain. Many managers resist sharing their decision power with outsiders. Things are worsened by the scarcity of studies, patchy monitoring and poor data diffusion means, and the lack of trained personnel to contact, convince, solve problems and educate the groundwater actors. The result is a failure to create associations of users. However, this is only circumstantial and can be solved. The Water Authorities, the universities and other organisations play an important role in advising and supporting, but not in trying to impose what is in the regulations. In fact there is hope for change. Recently a coordinating association has been created in Catalonia to reunite efforts, share experience and increase the real management capabilities of existing and future associations of groundwater users in the territory.

It has been said that creating these associations is equivalent to privatisation of groundwater management, which is a situation that is fully endorsed by some experts and plainly rejected by others. Really this is not true privatisation, but focussing on the problems and benefits of groundwater extracters may easily downgrade general objectives and social goals. Then some external control is always needed and essential, depending on national factors and the ability of the Public Water Administration to play a role that needs skills. Also, the control organisation has to be able to supply means for study and specialized monitoring, and to help solving the financial needs.

Other groundwater management problems refer to the availability of technical means for monitoring and studies. They include groundwater level, extraction, recharge and water quality observation, monitoring and control stations and devices, as well as tools to help decision-making, such as calculation methods, from the simple ones up to complex simulation models of the aquifers and the water resources system. If these elements are missing, do not work properly or are insufficient, management errors can be easily made, which add to the perceived aquifer problems.

SOCIAL AND CULTURAL PROBLEMS OF GROUNDWATER EXPLOITATION

Social problems related to groundwater exploitation are mild as compared to what currently happened in large surface water projects, especially at the early stages of construction and exploitation. Since groundwater development follows the pace of regional growth, there is often time to adapt to changes. However, there are cases in which violent reactions appear such as with large groundwater development plans with intensive land use changes from the beginning or when springs and rivers become rapidly dry, due to pumping in the surroundings. Often real or fictitious problems are attributed to the newcomers or to the largest groundwater exploiters. The resulting social unrest makes management more difficult and sometimes there are serious difficulties in coordinating efforts. In coastal aquifers well water salinization is a further aspect to be considered. This can cause complaints since it may be a relatively fast process, over a few months or years, even after a delay of decades with respect to the true cause, and if only part of the exploiters is affected.

Other problems such as groundwater-dependent wetland desiccation, loss of vegetation and shift of species are not often a serious source of complaints, since changes are slow and may go on unnoticed, especially when other human activities are intense. This does not mean that these are not serious effects or that environmental protection has to be downgraded. This only shows a fact which is progressively reversed as environmental concern, studies and data increase, and as the groundwater role is better understood and the Public Water Administration is responsible for the preservation. This is now included in the Spanish Water Act. Public awareness is important, but it is considered a groundwater problem by some irresponsible managers. When changes are fast or when local inhabitants and nature preservation organisations are aware of changes and have data to support their claims the reaction can be stiff.

Conflicts like the Tablas de Daimiel case are due to unbounded development without a reasonable water plan. In Doñana there is the possibility of accommodating urban and agricultural development with reasonable nature preservation, provided all actors agree to compromise, there is fair play and other disturbances are not introduced such as new large developments, with or without water importation from outside. This refers mainly to water quantity aspects. Water quality aspects are still poorly known and they are more difficult to accommodate, but may be dominant in the future.

New problems may appear when groundwater exploitation ceases in some areas. The water table drawdown extraction associated with an intensively exploited aquifer may drain the upper part of the land, in what were formerly shallow water table areas or even wetlands. If these areas have been later transformed from industrial or agricultural uses into urban sectors, it is not uncommon that basements, cellars, underground parking lots and underground transport ways become inundated or subjected to uplift when the water table goes up. This may produce local unrest, inconveniences and property loss.

Cultural problems are those derived from the traditional use of springs, water mines and wells. Often the water or the site are connected with emotions and tales concerning water quality, properties or benefits from its use. Something linked to local cultures is lost when they become dry due to aquifer exploitation, but it may be often corrected by veiledly introducing water from elsewhere, generally a nearby well. In Barcelona the city network now supplies some of these springs. It is more traumatic when people are not allowed to use the spring or well water because it is contaminated. They try to get the water they consider as having favourable properties, even if it is clearly shown that it is not drinkable.

More important are the problems related to real or assumed groundwater rights based on the continuous use, the fact of living in the territory or being partners of the water winning works. These are also considered groundwater problems. In general the solution is not difficult, but it takes time and some care is needed if lengthy court processes are to be avoided. In some cases quite strong reactions may occur. In the Canary Islands the Regional Government was obliged to call new elections when some right restrictions were introduced into to the Canarian Water Act, a complement of the Spanish one, which takes into account the islands' peculiarities.

INTENSIVE AQUIFER EXPLOITATION AND OVEREXPLOITATION PROBLEMS

It is difficult to define what is intensive exploitation and overexploitation of aquifers since there are many elements involved such as water balance, water quality, economic, environmental, managerial and social elements [18,33,34]. A first attempt is to compare extraction with recharge, considering the natural and artificial variability of these figures. When extraction is less than, but close to aquifer recharge, there is intensive exploitation. It can be sustainable if other issues do not ask to reduce the extraction difference, such as excessive cost of pumping or too much environmental damage. Overexploitation includes more negative results and often assumes that exploitation is close to or exceeds recharge, although this is not always the case. A large excess of extraction over recharge is also called water mining.

When groundwater extraction exceeds total recharge, it is not possible to attain a stable final situation if pumping is not reduced. In this case, after a period of a continuous level ofgroundwater extraction that causes the natural aquifer outflow to decrease and finally cease, a period follows in which all the water extracted in excess of the recharge comes from the storage (reserves). The physical limit is storage depletion in some areas of the aquifer, which means that pumping cannot take place, either by insufficient saturated thickness or by low yield of the wells. This implies a reduction of extraction and a trend towards stabilization. However, there are other limits that depend on impairment of extracted groundwater quality such as salinity increase or undesirable chemical changes. Also there is an economic limit when water costs become unaffordable. However, an increased water price may induce reductions of water use due to savings or process changes, making higher water costs affordable. The limit of exploitation may be the failure of the aquifer as a freshwater source, or more often a progressive reduction of extraction as technical and economic water use efficiency is increased [34,35] to accommodate to renewable aquifer resources, or because local welfare allows for developing other freshwater resources. This is the case in the area around Tarragona. The final sustainable flow is uninteresting only in arid climates, where recharge is very small, or when the initial pumping is much higher than the recharge, a rare situation, or when water quality is impaired beyond reasonable limits and there is no other water source for dilution. Even in this last situation brackish water desalination may allow the use of part of aquifer water once residual brine disposal problems are solved.

The sometimes long transient period of groundwater extraction in many practical situations, or the slow movement of poor quality water masses, blur the difference between intensive exploitation, in which there is a final equilibrium situation, and strict overexploitation of aquifers. Anyway there is a conspicuous use of groundwater reserves. A strict economic analysis shows that often the best water resources strategy to start the economic development of a region is aquifer exploitation, although other social and political considerations may discourage this. There are clear advantages in starting with limited aquifer overexploitation. This allows to construct other more expensive water works to attend the water demand generated by this economic development or allows to delay the construction of expensive works, thus improving economic efficiency. The ultra-conservationist attitude, often heard, of only extracting from the aquifer the return (recharge) without using the capital (storage), beside being physically unfeasible, involve two false propositions. One is that the return will not disappear with the use of reserves, but will probably increase due to the enlarged extraction area or induced recharge. The other is that using the term 'capital' for a natural resource is a semantic distortion: it is the use of the resource that allows to convert it into economic or financial capital [31].

These considerations explain that the public opinion and many water managers consider overexploitation (and often intensive exploitation since it shows similar trends during the transient period) an ethical sin and a problem to be eliminated. This is in some way reflected in the European Union attitudes and in the guidelines to prepare the drafts of the Spanish Water Plans, even if figures of overexploitation are probably overstated and are much less than in California or other western United States areas. There is a common feeling that overexploitation is intrinsically bad, and this is not true in correct economical terms and overexploitation may be socially and environmentally acceptable if some compensations are introduced. What is detrimental, is irresponsible overexploitation due to situations such as short-term speculation, ignorance, concealed facts or undue destruction of nature.

PROBLEMS RELATED TO GROUNDWATER MYTHS

Around water there is a series of myths that are of help for the right preservation and management, but also introduces deviated concepts. A water myth is an idea or concept more or less widespread and coming from the deformation of a real fact or a scientific concept as it is currently accepted by most hydrologists [37]. This deformation may have different origins. Sometimes it is the result of a dominantly political manipulation to justify restriction or deprivation of some freedoms, based on what is presented as out-of-discussion imperatives of modern science. In other cases they are simply the result of thinking inertia, of unfounded knowledge or of the intent to uphold rights, property or privileges [38].

Thus, a groundwater myth is: (a) a popular belief or tradition that has developed around something real; (b) a false or unsupported knowledge; (c) an almost sacred axiom or dogma. This refers to the population and to those who manage water.

These myths embrace a large field of topics. They are related with real or assumed groundwater problems and influence its management negatively. In the following a list of some important myths will be shortly presented. The reader may easily extend the list.

(1) The water cycle is unique. This truth is used to give preference to one aspect, neglecting or downgrading others, generally groundwater; opportunities for taking advantage of the very different basic characteristics are lost.

(2) Groundwater is full of serious and irreversible exploitation problems, and unforeseeable; conversely, groundwater is unlimited and well protected. Both are the result of ignorance.

(3) The cost of groundwater is only that of the extraction. This is economically wrong since externalities are forgotten, it leads to socially abusive exploitation and neglects the cost of monitoring, management, preservation and restoration.

(4) A contaminated aquifer cannot be restored. This is the result of a downgrading of the aquifer's economic opportunity value; often it is an irresponsible attitude.

(5) Groundwater behaves and can be treated in a similar way as surface water. This forgets the ground-

water's large turnover time and its slow response to external actions; this my lead to large errors in management and monitoring.

(6) Groundwater management is cost-free. This is a serious error that prevents management; part of the benefits of using groundwater must be used for management and preservation.

(7) Coastal aquifers cannot be exploited, due to sure salinization problems. This is the result of poor observation and ignorance; this may discard important aquifers for water resources management.

(8) Good management needs to declare groundwater a public domain; conversely, private management produces the best results. The legal character is not essential for good management, but the will to manage, the involvement of users and the provision of good technical and management tools.

(9) Groundwater quantity issues are different from quality issues and are better managed in separated specialized agencies. This goes against the hydrological cycle; it hampers management, as currently happens in Spain.

(10) Overexploitation is intrinsically evil and has to be avoided. This may be a loss of economic development opportunities. Often the assumed overexploitation is only a transient groundwater level drawdown.

(11) Groundwater solutions produce unemployment by reducing large structural investments. These economic resources can be placed in other, more effective investments, even if this means a loss of power of a given agency; it is better to promote training for more qualified jobs than those dominantly provided by public works or extensive agriculture.

(12) Groundwater management needs very sophisticated tools; conversely, simple methods are enough. Each case needs a different degree of accuracy, according to the scale, intensity of exploitation and seriousness of externalities.

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