The Manifold Dimensions of Groundwater Sustainability: An Overview[1]

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Abstract

Sustainability is a manifold concept, approachable from many points of view (hydrological and ecological sciences, economics, social welfare, legal and institutional aspects, policy and inter and intra-generational solidarity). The following pages provide a succinct overview of what sustainability may entail when applied to intensive groundwater use, particularly in regard to irrigation in arid and semiarid regions. Environmental ethics play a significant role in identifying the driving motivations for human beings in relation to groundwater resources. These may at times relate to issues such as ignorance, arrogance, negligence and corruption. Four courses of action are suggested in order to ensure that future groundwater development may result 'sustainable' from most viewpoints.

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Introduction

This article summarises the inaugural lecture of the International Symposium on Groundwater Sustainability (ISGWAS) Symposium (Llamas et al. 2006a). Some modifications have been introduced in this version as a consequence of the debates during the Symposium and in the session FT5.33 of the Fourth World Water Forum (Mexico City, March 21st , 2006).

The origin of the ISGWAS Symposium was an invitation issued by Prof. Queré, co-President of the Interacademies Panel (IAP), to the President of Spain's Royal Academy of Sciences to lead one of the activities of the 2004-2006 IAP Water Programme. Prof. Sánchez del Río, former president of the Spanish Academy, accepted this offer in view of the institution's long-time involvement in water-related issues.

The National Ground Water Association (NGWA) and the National Academies of Brazil, Mexico and the United States supported the initiative from the outset. UNESCO also showed interest, proposing Paris as the venue for this meeting.

Prof. Ramon Llamas discussed this possibility with Spain's Secretary of State for Education, Prof. Salvador Ordóñez. The latter expressed his preference for the Symposium to be organized in Spain, and offered the economic, logistic and moral support of the Geological Survey of Spain (a Public Research Institute dependent on Spain's Secretariat for Education). The offer was gladly accepted by Spain's Royal Academy of Sciences, and thus the agreement was formalized to organize the meeting in Alicante.

Furthermore, UNESCO, IAP, Spain's Ministry of the Environment and certain regional institutions (particularly the University of Alicante), also contributed from the economic point of view. Last, but not least, this book relies on the support of the NGWA, the institution encompassing the largest number of groundwater experts worldwide, which has accepted to be in charge of publishing the final proceedings of the symposium.

This International Symposium was conceived from a holistic viewpoint. Therefore, a significant weight has been given to the social sciences, even if these are relatively underdeveloped in comparison with the "hard science" understanding natural groundwater phenomena (Llamas et al. 2006b).

Finally, it is only fair to mention a series of initiatives, which have already been put into practice in order to objectivize the costs and benefits of groundwater development. Take for instance Almería's National Symposium on Groundwater Overexploitation (Pulido et al. 1989) and Tenerife's International Congress on Aquifer Overexploitation (Simmers et al. 1992), or more recently the 2001 Workshop and 2002 Symposium on Intensive Groundwater Use (Llamas and Custodio 2003, Sahuquillo et al. 2005). All these have contributed to establish a solid ground for debate in Alicante.

Scope and objective

The objective of this Symposium was to contribute to clarify the role of groundwater resources on world water policy, and to perform a critical analysis on the advantages and disadvantages of groundwater intensive development. The main conclusions of the event were summarised in the "Alicante Declaration", submitted for possible endorsement to a wide range of individuals and institutions.

When approaching groundwater-related issues, the onlooker usually finds himself confronted with scarce data, often laden with uncertainty. This is largely a consequence of the relative novelty of intensive groundwater development, a phenomenon that has only become commonplace in the last four or five decades.

Intensive groundwater use has been often carried out with little or no planning or control on the part of public water agencies, leading to chaotic development in most cases. Causes should probably be found in the historical past: for thousands of years (although more particularly in the 20th Century), water managers and decision makers have generally been trained to build and operate surface water infrastructures, while paying less attention to 'invisible' groundwater resources.

Thus, the private initiative has traditionally been the main driving force behind intensive groundwater development, particularly in arid and semiarid regions, where irrigation is necessary for agriculture. Millions of farmers, modest for the most part, today drill their wells and pump groundwater at their own expense.

As a result, anarchy features high in groundwater development. Uncontrolled drilling and pumping has led to problems in some places. Some of these constitute an undeniable matter of concern, although the vast majority have been magnified due to unethical attitudes that may include ignorance, institutional inertia, vested interests and corruption (Delli Priscoli and Llamas 2001).

Finally, from the point of view of discussion, groundwater supply for urban and industrial purposes has been subordinated to irrigation uses. This is because intensive groundwater development is largely restricted to arid and semiarid regions, where irrigation often accounts for 80-90 percent of the total consumptive water uses.

The Manifold Concept of Sustainability

Since sustainability is at the heart of this symposium, it is probably appropriate to devote some space to elaborate somewhat on its conceptual implications.

The concept 'sustainable development' was first coined in the 1980s, and has been expressed in a variety of ways over the years. Rogers (2006), for instance, quotes the existence of fifty widely used definitions. Perhaps the better-known (and widely contested) meaning of sustainability was given by the United Nation's Commission on Sustainable Development in 1987: *'to satisfy current needs without compromising the needs of future generations'*.

Thus, it seems clear that sustainability means different things to different people. A reason for this is the multi-dimensional nature of the concept. There may be as many as ten different aspects to be considered in assessing whether a given development can be labelled sustainable (Shamir 2000). However, even if all these are taken into account, it may not be so easy to reach a univocal conclusion, that is, the different dimensions of sustainable development may at times clash.

Let us take a look at an example. At a given aquifer, pumping rates for irrigation may prove 'sustainable' from the hydrological viewpoint (provided that storage and/or average recharge are large enough). However, water table drawdowns may induce degradation of valuable groundwater-dependent ecosystems such as wetlands, which may be considered unsustainable from the ecological point of view. Would a restrain from pumping be the most 'sustainable' course of action? The answer to this question is difficult. If farmer livelihoods rely heavily on groundwater resources, a ruthless push for wetland restoration may not be the most sensible solution to the problem. In that case, like in many real life situations, the social and economic aspects of sustainability come into play, and may eventually offset environmental consciousness.

The following pages provide a succinct overview of nine different aspects of groundwater sustainability: hydrological, ecological, economic, social, legal, institutional, inter and intra-generational and political. Throughout the text, a distinction is often made between developed and developing regions. This is because perceptions as to what is sustainable vary across geographical boundaries, and are often rooted on cultural aspects and socio-economic situations.

Intensive Groundwater Use and Hydrological Sustainability

Intensive groundwater use is that which induces significant changes on natural aquifer dynamics (Custodio and Llamas 2003, Custodio et al. 2005). In contrast with 'aquifer overexploitation', 'intensive groundwater use' does not convey a positive or negative connotation. It merely refers to a change in flow patterns, groundwater quality or interrelations with surface water bodies.

Such changes may be perceived as beneficial or detrimental, and this perception may also vary with time. For instance, until the mid 20th Century, wetlands were considered barren land and a potential source of disease. Many a decision was made to desiccate groundwater-dependent wetlands by depleting the water table for, back then, that was perceived as a service to society. With the advent of the environmental movement and the advances in medical sciences, wetlands ceased to be wastelands to become ecological sanctuaries, to the point that nowadays advocates of wetland desiccation are generally frowned upon.

Pumping in excess of aquifer recharge is often dismissed as an unsustainable practice. Since it is not the aim of this paper to contest this claim, it should suffice to quote the work of several authors, who show this attitude to be conceptually simplistic, and potentially misleading (Selborne 2001, Custodio 2002, Abdehrraman 2004).

Groundwater Development and Ecological Aspects of Sustainability

This is perhaps one of the most frequently voiced aspects of sustainable development. However, scientific literature (general declarations aside) is not particularly abundant (Sophocleous 2003). Some authors, like Llamas (1988) and more recently Feitelson (2005), have considered the limitations imposed by environmental restrictions on groundwater development.

Conflicts have arisen wherever there has been a synchronism between groundwater-based irrigation and the increasing influence of environmental conservation lobbies. In Spain, this debate began two decades ago, due to the impacts of groundwater pumping on two National Parks in the Upper Guadiana basin (Llamas 1988 and 1992, Bromley et al. 2000, Coleto *et al*. 2003). This controversy, characteristic of developed countries, is still open (Varela et al. 2003).

However, perceptions as to the relative importance of environmental conservation vary across regions, particularly depending on wealth and cultural traditions. Since the 2002 Johannesburg meeting of the United Nations, there seems to be a general consensus that poverty is the greatest threat for environmental conservation.

Generally speaking, concern for the environment increases with social development. Some authors have tried to apply this principle, often referred to as Kutznets curve, to regional settings. This is the case of Mukherji's work in India, whose results point at a strong relation between gross domestic product and environmental awareness (Mukherji 2006).

Finally, climate change has lately become ever-present within the environmental dimension of sustainable development. In the view of the authors, Rogers (2006) provides a sensible approach to this issue:

> *'By the end of the 20th Century hydrologists were searching for evidence of long-term anthropogenic change caused by greenhouse gases. Many conflicting data sets and theories have been reviewed with contradictory results, and while at present there is no general agreement as to the change in variability of precipitation over the next five decades, there seems to be a growing consensus that precipitation will increase over large areas of the globe and that sea level may rise between 0.1-0.3m'.*

It is the view of these authors that climate change may prove influential in the long run. However, economic, social and political changes mentioned hereafter are more likely to affect groundwater sustainability in the near future.

Economic Sustainability of Groundwater Use

Groundwater development is often a market-driven reality, more akin to the private initiative. There are two main reasons for this. First, groundwater can be obtained individually, thus by-passing the often arduous negotiations with other farmers and government officers. A second and more important reason is the resilience of aquifers to dry spells. This removes a significant uncertainty from farmers' minds, thus encouraging them to invest in better irrigation technologies and higher value crops.

Again, a distinction must be made between developed and developing regions. Today, about one thousand million people live under the poverty threshold (i.e. those people who make a living with less than one dollar per day; whereas another two and a half thousand million make less than two dollars per day).

While access to drinking water is often said to be related to poverty, very few studies show the potential importance of groundwater resources in reaching another of the United Nations Millennium goals: halving the number of people who suffer from malnourishment by 2015 (Llamas 2005).

However, groundwater is already playing a key role on that front. Take for instance India, where groundwater irrigated surface has increased by over forty million hectares during the last decades (Deb Roy and Shah 2003). Largely as a consequence, India has not only achieved food security in practice, but has also become an important grain exporter. All this despite doubling its population in the last half century.

This is an example of the 'more crops and jobs per drop' motto, which groundwater is generally more likely to achieve than surface water irrigation (Hernandez-Mora et al. 2001). However, this is not necessarily applicable in developed countries, where 'more cash and environment per drop' is probably more in touch with reality.

Spain is probably a good example. Take for instance the Upper Guadiana basin, where water-intensive low-value crops such as maize or cereals are slowly disappearing in favour of water-efficient cash crops such as vineyards or olive trees. In some areas, like western Andalusia or the Mediterranean coast, revenues in the vicinity of US $60,000/ha for tomatoes, strawberries, cucumber and other greenhouse crops are not unheard of. In addition, environmental conservation groups exert their share of pressure on water-intensive crops, particularly in intensively used aquifers.

Therefore, any study on economic sustainability of groundwater use should take into account the specific regional settings. The following circumstances may serve as a first attempt to establish a classification:

- **Developing countries where easily-accessible unconfined shallow aquifers exist:** Devices such as the treadle pump to access shallow water tables may constitute a catalyst for irrigation development (Polak 2005), while environmental concerns are generally subordinated to human development. This is the case of many small African villages.
- **Developing (or semi-developing) arid and semiarid regions, like India or regions of East Asia:** Groundwater irrigation has experienced a spectacular development in recent years (Deb Roy and Shah 2003, Mukherji and Shah 2006). Such large regions may present a wide variety of conditions: from subsistence livelihoods to market economies, and from large alluvial aquifer systems (which may sustain long-term development) to hard-rock aquifers (where small communities may rely on scarce resources and pumping may result too expensive).
- **Developed arid regions endowed with good aquifers:** This may correspond to countries like Saudi Arabia or Libya, where groundwater mining is commonplace. Reliance on non-renewable resources, however, does not seem to render these economies unsustainable (Abdehrraman 2004, Khater 2003). Contrary to the perception of some environmental organizations, a good number of authors and the UNESCO World Commission on the Ethics of Science and Technology consider this practice to be acceptable under certain circumstances (Selborne 2001, Delli Priscolli et al. 2004).
- **Arid and semiarid regions of industrialized countries (California, Texas, Spain and others):** Intensive groundwater withdrawals for irrigation are a well established practice in these areas. Development is essentially market-driven, as the cost of obtaining groundwater generally amounts to a very small fraction of crop value. Some authors argue that depletion groundwater levels result in an increase of pumping costs, and may ultimately yield these developments economically unsustainable. However, empirical evidence in some areas seems to show the opposite. Farmers are undeterred from pumping despite depths in excess of 400m (Garrido et al. 2006). This is because switching to higher value water-efficient crops may offset the increase of pumping costs, provided that groundwater quality does not worsen (Llamas and Martinez-Santos 2005, Fornés et al. 2005, Vrba 2003). Particularly in Spain, economic studies show groundwater irrigation to be more profitable (US$/m^3) than surface water irrigation (Hernandez-Mora et al. 2001, 2003; Vives 2003). It would be desirable to carry out similar studies in other regions of the world in order to assess the general value of these results.

Groundwater Use and Social Sustainability

Groundwater irrigation has proven an excellent catalyst for the positive social transition of farmers in arid and semiarid regions worldwide (Moench 2003, Steenberger and Shah 2003). As mentioned before, this is largely a consequence of groundwater's resilience against drought. Secured access to water during dry periods removes a sense of risk from farmers' minds. Thus, they are more willing to invest in new technologies, both from the agricultural (selective seeds, agrochemicals) and the technical point of view (drip irrigation). Increased revenues result, and allow for a greater degree of social welfare. In addition, farmers become able to provide a better education for their children, who may either move on to other economic sectors or return to agriculture with a more productive outlook. Issues of social justice may arise in some situations, particularly in developing countries. For example, in some areas of India, deep boreholes drilled by wealthier farmers have caused the water table to drop below the reach of shallow wells, which are generally owned by the less resourceful (Moench 2003). However, this seems to be a transitory state. In fact, rich farmers end up selling excess water to shallow-well owners. Since supply is seemingly large enough to ensure a competitive market, the less resourceful have access to water at reasonable prices. This allows them to continue making a living out of irrigation, while getting wealthier in the process. After a few years, poor farmers have been able to drill their own deep wells (Mukherji 2006, Mukherji and Shah 2006).

Legal Aspects of Groundwater Sustainability

From the legal viewpoint, it could be said that there are three main issues of debate: whether groundwater resources should be public or private property, how groundwater rights should be inventoried and how these may be subsequently traded. The third aspect, usually equated to "water markets", is subordinated to the first and second in terms of importance, even if significant informal markets already play a relevant role in India (Mukherji 2006) and in other countries.

In relation to property rights, groundwater is usually public and can be accessed by means of governmental permits (sometimes called 'concessions'). This is the case in Israel, a number of states of the United States (US), Mexico and many other countries (Burchi and Nanni 2003). In other places, like California or Texas in the USA, Chile or India, groundwater is under private ownership.

Spain is perhaps a noteworthy exception, since it presents a mixed system. Due to the 1985 reforms of the Water Act, wells drilled after 1986 require governmental permission, while those operational before 1986 remain private. Private groundwater may remain so for fifty years (provided that the well-owner reaches an agreement with the government in exchange for 'administrative protection') or perpetually (if the owner wishes to preserve his/her rights under the 1879 Water Act) (Embid 2005).

However, the Spanish situation is far more complex due to the lack of a reliable registry of groundwater rights. While some remedial initiatives are currently underway, these are insufficient in the eyes of some authors. Fornes et al. 2005 for instance point out that these ignore a significant share of the existing wells (those which do not currently have any kind of permit), and that therefore the inventory is significantly incomplete.

The lack of a reliable inventory of wells is not restricted to the Spanish experience, but rather widespread in arid and semiarid regions of the world. This situation may at times be interpreted as unsustainable in the long run, particularly if a strong political willingness to apply the laws is lacking. Nevertheless, voices within the scientific community suggest this may not necessarily be the case. Take for instance California, where groundwater is private. Despite the fact that no reliable estimates of groundwater pumping exist to this date (Kretsinger and Narasimhan 2006). Blomquist (1992) argues that such a ‘polycentric’ (and largely uncontrolled) groundwater allocation system may have ultimately proven more adequate than a top-down allocation. The California case is again considered later.

Despite these claims, it seems clear that a reliable inventory of groundwater rights is desirable in order to ensure adequate management.

Institutional Sustainability

Any water management system requires the support of an appropriate governance framework.

A bottom-up approach seems the best way to achieve participatory management. Surface water irrigation communities constitute a good example. Seven thousand of such communities (some of them centuries old) currently exist in Spain (Murcia, Valencia and Alicante being the better known ones) (Mass and Andersen 1978).

However, there is an essential difference between surface and groundwater. A gatekeeper may ultimately control surface water, while groundwater is usually subject to the individual decisions of hundreds (perhaps thousands) of independent users with direct access to the resource. Thus, top-down control has proven insufficient in most places due to this intrinsic complexity of groundwater governance. This is the reason why user communities are often advocated as the most plausible solution to ensure adequate groundwater resources management.

Groundwater user associations are still fairly scarce. Under Spain’s 1985 Water Act, an attempt was made to impose these communities in ‘overexploited’ aquifers, although this initiative has been far from successful in most places (Hernandez-Mora and Llamas 2000, Lopez-Gunn 2003; Hernandez-Mora et al. 2003). Water agencies in Texas and California are currently trying to organize these communities, albeit by means of economic incentives rather than by compulsion.

In any case, since groundwater user associations are a relatively new feature, their ultimate implications on groundwater sustainability are yet to be seen (Schlager and Lopez-Gunn 2006, Lopez-Gunn and Martinez-Cortina 2006).

Intragenerational Equity and Groundwater Sustainability

Aquifers constitute an example of ‘common pool resources’, as in the majority of cases all actors have direct access (legal or illegal) to groundwater. Therefore, aquifers should typically follow the widely voiced ‘tragedy of the commons’ pattern (Hardin 1968). Nevertheless, after half a century of intensive groundwater use, these authors do not know any cases of medium-sized or large aquifers where the tragic outcomes outlined by Hardin may have taken place.

Due to the great volume of groundwater stored in aquifers, the potential adverse effects of intensive groundwater use generally take one or two generations to become apparent. By that time, farmers may have experienced a positive social transition. This facilitates the existence of ‘farmer lobbies’ that, instead of advocating a responsible use of groundwater resources, tend to demand costly water transfers from other basins to be funded by the general public (Llamas and Martínez-Santos 2005). At times, these may lead to social conflicts between water-importing and water-exporting basins, like the cases of the Tajo-Segura transfer or the recently overruled Ebro transfer, both in Spain.

The situation may be different in small or poor aquifers, where storage is not large enough to sustain development for over two or three generations. Though still uncommon, cases of small communities that have ‘run out of groundwater’ have been reported. Take for instance the example in Yemen outlined by Moench (2003).

Intergenerational Equity and Groundwater Sustainability

A frequently quoted aspect of ‘sustainability’ is that the potential future needs should be born in mind before launching into any development. In other words, the current generation should strive to preserve the world’s natural resources so that coming generations may be able to take advantage of them.

This argument has led people with little experience in the area of groundwater resources to dismiss groundwater mining as an always unethical practice. In recent years, this claim has been contested by some voices within the scientific community (Abdehrraman 2004, Khater 2003). This view is supported by the UNESCO World Commission on the Ethics of Science and Technology, which considers this practice to be acceptable under certain circumstances (Selborne 2001, Delli Priscolli and Llamas 2001).

It might be appropriate to point out the situation of some large aquifers that have undergone “overdrafting” or groundwater mining for many decades. In many of such areas, pumping data is hardly reliable. Take for instance California’s aquifers, where overdraft estimates range nothing less that between 1200 and 2400 Million m^3 per year. Kretsinger and Narasimhan (2006) inform that the overdraft in California aquifers has not been adequately analysed since the 1980s. It is perhaps the lack of willingness to monitor, rather than overdraft per se, that may constitute the greatest intergenerational threat for groundwater resources.

The Complex, Albeit Significant, Political Dimension of Sustainability

Politics has at times been defined as ‘the art of that which is possible’ (rather than ‘that which is reasonable’). Although in modern democratic societies decision-making is ultimately restricted to politicians, these are often influenced by more or less powerful lobbies. These usually defend the interests of large corporations or different sectors of the population (unions, NGOs and others). Rogers (2006) provides an excellent summary of those political motivations which usually influence water-related decision making.

The motivations behind political decisions are so difficult to take into account that they are generally overlooked. In addition, they depend very heavily on social and cultural constrains. Therefore this section is restricted to three brief examples as to how politics may come into play in regard to groundwater sustainability.

The first example refers to the 2005 events of the Upper Guadiana basin. The Guadiana water authority (dependent on Spain’s central administration) issued an order to shut down a series of wells that did not have the legal right to be operated. While law-in-hand this seemed an appropriate course of action, a social uproar ensued, fuelled mostly by farmer unions. This led the regional government to oppose Madrid’s orders. To this day (June 2006) the water authority has been unable to shut down these wells.

A second case is described by Mukherji (2006). In 2004, the ruling political party of Andra Pradesh (Central India) stated that they would gradually stop electricity subsidies for pumping. This led to a significant resistance on the part of farmers.

Seemingly as a result, the opposition won the 2004 ellection largely on the strength of opposing this measure. Electricity remains mostly free to this day.

Finally, the third example refers to California. In 2002, and after a long and arduous work, Prof. Sacks (Berkeley) developed a law to replace the old water act. This effort was motivated by the fact that the old law was conceptually obsolete since, among other erroneous assumptions, it ignored the unity of the hydrological cycle and equated groundwater to underground rivers. However, frontal opposition on the part of farmers and urban supply companies eventually caused the project to be rejected and the obsolete code to remain. The strategy to achieve a better groundwater governance by the California's government, as described in detail by Kretsinger and Narasimhan (2006), is a blend of economic incentives and promotion of the participation of local institutions.

These three examples show how political constrains (namely voters) may lead to potentially unsustainable situations. Education of the general public is perhaps the only means to avoid these kinds of occurrences in the future.

Peculiarities of Groundwater in Relation to Water Ethics

Ethical considerations in regard to human actions on the environment have become increasingly significant in the last decades. As stated by Pope John Paul II in his message for peace of 1990, environmental issues are essentially ethical problems.

There is currently a widespread consensus that the motivations or values behind human acts (ethics) cannot be ignored in relation to water management. In fact, water ethics has become the subject of the series of recent articles and monographs previously mentioned (Delli Priscoli and Llamas 2001, Selborne 2001, Delli Priscoli et al. 2004).

The general principles of environmental ethics (and hence water) stem from two main concepts. First, the intrinsic dignity of every human being; and second, the 'sociability' of the human being. A series of principles can be derived from these, like right to water, right to participation in management, and so forth.

Environmental ethics allow for a deeper assessment of wrong or perverse behaviours. These can often be classified in four groups: ignorance, institutional inertia (negligence), arrogance (or professional bias) and vested interests (which may result in corrupt practices).

All these aspects present practical implications in relation to the nine dimensions of sustainability described above. The following paragraphs outline some of the most common patterns in water policy of arid and semiarid regions.

First of all, it is necessary to take into account the relative 'youth' of intensive groundwater use (generally less than half a century) and of hydrogeology as a science, which is often the reason why obsolete paradigms are still present among high-level water decision-makers (Llamas 2005). In contrast, surface water development and infrastructures begun to be implemented about fifty centuries ago in Mesopotamia, Egypt and other valleys. Hydrogeological education appears a must, not only aiming at high-level water decision-makers, but also at the general public and more importantly to farmers (generally the main groundwater users and polluters).

Generally speaking, water managers and decision-makers have traditionally been trained to build and operate large surface water infrastructures. As a result, the importance of groundwater resources is often overlooked or even disregarded. This may provide an explanation for the generalized lack of accurate groundwater irrigation data in arid and semiarid regions. Besides, it appears to be the reason of the huge gap that currently separates water decision-makers from the main actors, particularly the millions of farmers who have drilled and equipped millions of water wells in the last half century.

Last, but not least, corruption is increasingly recognized as a potential ‘cancer’ for democratic systems (OECD 2000; United Nations, 2003). Water resources are not an exception. As stated by the Valencia Declaration (Sahuquillo et al. 2005), groundwater is less prone to corruption than large surface water infrastructures. This obeys to two main reasons. First, implementation of groundwater development presents a comparatively shorter timeframe (often weeks or months in comparison with several decades taken to implement a surface water system based on dams and canals). Second, investments in groundwater development are generally much smaller, and usually carried out by individuals with little or no public funding. In contrast, large surface water infrastructures frequently require significant public subsidies or donations from international organizations. This setting (long implementation time, significant funds) allows more room for unethical practices.

Suggested Actions to Achieve a Sustainable Groundwater Use

These suggestions, partly inspired in the Valencia Declaration (Sahuquillo et al. 2005, pp.385-386), were presented as a base for the more extense and complete Alicante Declaration (Ragone and Llamas 2006), and constitute a more comprehensive, if still general, call for action.

First: It is extremely difficult to provide a ‘general guide to groundwater sustainability’ as complying with the nine aforementioned dimensions may not be possible in most cases. Emphasis on one or another is likely to depend on economic, social, cultural and political constrains.

Second: Groundwater management requires a higher degree of user involvement than surface water developments. Experience shows that sustainable aquifer use cannot be solely achieved by means of top-down “control and command” measures.

Third: User participation requires a degree of hydrogeological education which is still absent in most places. Steps should be taken to make the peculiarities of groundwater resources known to all, from politicians and water decision makers to direct users and the general public. This should begin at the school level.

Fourth: Appropriate groundwater management requires a significant degree of trust among stakeholders. This implies that groundwater data should be transparent and widely available (via the internet, for instance). In addition, the system should be able to punish those who act against the general interest.

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