HYDROPOLITICS AND HYDROECONOMICS OF SHARED GROUNDWATER RESOURCES: EXPERIENCE IN ARID AND SEMIARID REGIONS[1]

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Abstract. Interest on shared or transboundary aquifers management is relatively recent, but has already been useful in order to increase the awareness about the role of groundwater among politicians and high-level water decision-makers. However, the process to achieve some kind of international convention or agreement on this issue will probably take a long time. Implementing international agreements on shared aquifers in arid and semiarid regions will be difficult if the current chaos in groundwater management is not previously

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[1] Paper presented in the Conference of the NATO ADVANCED STUDY INSTITUTE "OVEREXPLOITATION AND CONTAMINATION OF SHARED GROUNDWATER RESOURCES" Varna, Bulgaria October 1-12 2006 . To be published by Springer Verlag in 2007 in the NATO Security through Sciences Series-C Environmental Security

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corrected. In this regard, this paper analyses the causes of this situation, and the concerns these raise in regard to sustainability. Later the paper considers the political and economics factors that affect groundwater development, as well as the social and legal aspects involved. Finally the paper reproduces the call for actions included in the Alicante Declaration, approved in January 2006 on occasion of the International Symposium on Groundwater Sustainability.

Keywords: Groundwater overexploitation, groundwater sustainable development, groundwater intensive use silent revolution, groundwater economics, groundwater management institutions, groundwater conflicts.

1. Introduction

In recent years, transboundary aquifer management has begun to receive much deserved attention, partly thanks to initiatives such as UNESCO's, which have been successful in raising awareness among high-level water decision-makers.

However, transboundary water management is still under discussion for many surface water bodies, let alone aquifers, which, with few exceptions have traditionally been the 'cinderella' of water resources management. Thus, the process to achieve an international convention on groundwater management is likely to still take a number of years. Provided, that is, that the current usual administrative and legal chaos in groundwater management in most arid and semiarid regions can be corrected.

While inventories of transboundary aquifers already exist and thoughtful analyses of the implications of transboundary aquifer management have been carried out in the recent past (Puri and El Naser 2003), the practical difficulties of groundwater management have perhaps received less attention. Unesco expert A. Aureli who has been involved in this issue from its inception presents in this Symposium an updated outlook of the world situation on shared aquifers.

Groundwater is estimated to provide 50 percent of the world's drinking water supplies, and accounts for almost 100% in countries like Austria or Denmark. Nevertheless, it is in the field of irrigation where groundwater pumping has experienced a spectacular increase in the last decades. It cannot be forgotten that irrigation amounts to 70% of the world's water uses (reaching over 90% in many arid and semiarid regions). Today, the volume pumped from the world's aquifers for this purpose probably amounts to over one thousand cubic kilometres per year.

Particularly in the arid and semiarid regions of the world, groundwater management is far from adequate. Uncontrolled development is widespread, thus raising concerns as to the viability of the currently prevailing groundwater management paradigms. This is largely a consequence of the 'silent revolution' of intensive groundwater use (Llamas and Martínez-Santos 2005): the widespread availability of drilling and pumping techniques, together with the reliability of groundwater supplies during dry periods and their availability on demand, remove a significant uncertainty from farmers minds. Thus, despite the fact that groundwater is usually more expensive than subsidized surface water, pumping costs are generally a very small fraction of the guaranteed crop value.

Therefore, it can be said that the spectacular growth of intensive groundwater use for irrigation is mostly driven by economic reasons, and has provided great benefits to millions of mostly modest farmers, facilitating a relatively rapid social transition from illiterate farming communities to a middle class societies.

However, some adverse effects have also occurred, such as groundwater quality degradation or ecological impacts on aquatic ecosystems. While the significance of these effects varies depending on the outlook, these have frequently been exaggerated, thus giving rise to the hydromyth of the general fragility or unsustainability of groundwater resources development.

In any case, farmers usually pay little attention to such ideas and continue to drill and pump, often with scarce control on the part of water autorithies. These have traditionally suffered from what some authors term 'hydroschizophrenia', that is, placing the emphasis of water resources management on surface water infrastructures while largely neglecting the role of groundwater. This is the main cause behind the current disarray in groundwater resources management. As long as this situation continues, potential international regulations in regard to transboundary aquifer management are unlikely to be enforced.

2. Scope and aim

Given the above, hydropolitics and hydroeconomics of transboundary aquifers are heavily conditioned by the need for adequate management, which in turn tends to raise sustainability concerns. This paper focuses on analysing the relevance of the 'silent revolution' of intensive groundwater use, a relatively recent paradigm shift in groundwater resources development that cannot be ignored, discussing its sustainability in view of the current situation.

This paper refers almost exclusively to irrigation. As mentioned before, the reason is that despite the undeniable importance of urban supply, irrigation usually accounts for over 90 per cent of all the consumptive uses in arid and semiarid countries. As a consequence, potential conflicts about groundwater in shared -or not shared- aquifers are likely to be related to irrigation uses.

3. Hydroeconomics of groundwater resources in arid and semiarid regions: the 'silent revolution' of intensive groundwater use for irrigation

Perhaps the single most relevant factor in regard to transboundary groundwater management is the economic value generated by the 'silent revolution' of intensive groundwater use (Briscoe 2005; Fornés et al 2005; Llamas and Martinez-Santos 2005), which will be described in the following paragraphs. This new paradigm has given rise to management difficulties which need to be resolved in order to achieve adequate groundwater management.

Intensive groundwater use for irrigation has been carried out mostly by the personal initiative of millions of modest farmers in pursuit of the significant short-term benefits groundwater usually triggers. These farmers have frequently received incentives as soft loans or energy subsidies from governmental agriculture departments. In contrast, governmental water agencies have been mainly concerned with the planning, operation, maintenance and control of surface water irrigation systems, while frequently paying less attention to groundwater development. This attitude has been commonplace in India, Mexico, Spain, and many other arid and semiarid regions worldwide. As a consequence, the current situation concerning groundwater development has been described as a "colossal anarchy" not only in South Asia (Shah et al 2006, Deb Roy and Shah, 2003), but also in many other arid and semiarid regions worldwide.

Figure 1 presents a qualitative overview of the different water policy stages induced by intensive groundwater use in arid and semiarid countries. Each of the five stages is roughly equivalent to one generation (about 15-25 years). While the beginning of these can be traced back to the moment when intensive groundwater development begins, their end point might not be so easily identified. Thus, some overlapping between stages may occur: take for instance hydroschizophrenic attitudes, which may still persist in many countries.

Science and technology have played a key role in the *Silent Revolution*, since the advances in hydrogeology and well-drilling techniques, and the popularization of the submersible pump, have significantly reduced abstraction costs over time. The total direct cost of groundwater abstraction today -not taking into account externalities- is, in most cases, only a small fraction of the economic value of the guaranteed crop. Thus, the Silent Revolution is largely a market driven phenomenon, although in very poor rural areas it is mainly driven by a subsistence livelihood effort (Polak, 2005 a and b).

Surface water is heavily subsidized in most countries and therefore its price for irrigation is generally cheaper than groundwater's. Yet, many farmers prefer groundwater. Several motives exist for this seemingly sub-optimal choice: one is that groundwater can be obtained individually, thus by-passing negotiations with other farmers and government officers, often an arduous task. A second and more important motive is the resilience of aquifers to dry periods. In this regard, most farmers resort to conjunctive use when possible, using subsidized surface water whenever available and groundwater whenever surface supplies fail. Many irrigated cash crops, which usually require large investments from farmers, depend today on groundwater, either totally or on conjunctive use with surface water. Garrido et al. (2006) show how Spanish irrigation is a typical case of this situation.

Another important and seldom mentioned benefit of the Silent Revolution is its positive effect on the social and economic transition of many farmers. Relatively low pumping costs, and the protection groundwater provides against drought, have allowed poor farmers to gradually progress into a middle class status, enabling them to provide a better education for their children. After one or two generations, those children have been trained as teachers, technicians and so forth, thus contributing to the overall progress of society. At the same time, those who choose to continue as farmers are in a position to use better agricultural technologies to grow cash crops that demand less water (Moench, 2003). During the 20th century and almost in every country significant changes in the labour force have occurred. Generally the population share in the agrarian sector has decreased dramatically as a consequence of technological advances. For example, during the last half century the proportion of the Spanish labour force in the agrarian sector has decreased from about 50% to less than 6%. Groundwater irrigation has been an excellent catalyst for such social and economic transition.

Perhaps one of the most significant aspects of the Silent Revolution is the manner in which farmers, as they become richer and more educated, move from low value crops to cash crops. This is mainly due to the intrinsic reliability of groundwater: encouraged by the expectation of enhanced revenues, farmers invest in better irrigation technology and, in turn, shift to higher value crops. As crop value is related to crop type, climatic and other natural and social variables of each site, and subject to trade constraints, it ranges widely: in Europe for instance, between US$ 500 per hectare (e.g. cereals) and more than US$ 60,000 per hectare for tomatoes, cucumber and other greenhouse crops. Frequently the ratio between crop value and groundwater irrigation cost is greater than 20 (Llamas and Custodio, 2003). However, in aquifers with low permeability and storativity located in densely populated areas, this ratio can be substantially smaller (even if energy is heavily subsidized). This appears to be the case in some very poor regions of India, mainly located on hardrock (poor) aquifers.

Despite the illusory accuracy of global irrigation data and the variability of the existing estimates, rough calculations yield the following conclusion: groundwater-based irrigation seems to be twice as efficient as surface water irrigation in hydrological terms (m^3/ha), a ratio that increases to between three and ten from the social and economic points of view (US\$/m^3 and jobs/m^3). Regional scale analyses carried out in Spain seem to confirm these figures (Hernandez Mora et al. 2001; Vives, 2003). Thus, it appears relevant and urgent to assess the comparative hydrological and socio-economic efficiency of surface and groundwater irrigation at a world scale. Assessing the implications of this Silent Revolution should constitute a valuable contribution to the debate about global irrigation needs as perceived by many water experts. The “more crops and jobs per drop” motto has been considered crucial in order to avoid a “looming water crisis”. This is because of the large share of irrigation in global water use, and irrigation’s often low efficiency. However, few water experts or decision-makers are aware that the goal behind such motto is now often achieved by groundwater irrigation. Really in arid and semiarid regions in industrialized or rich countries the new motto is “more cash and nature per drop”.

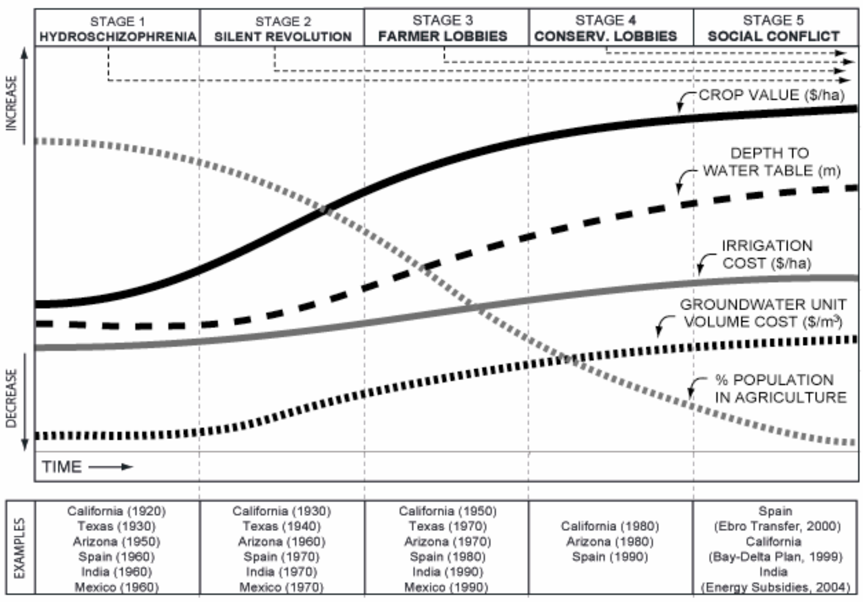

Figure 1. General groundwater-related trends in arid and semiarid regions (after Llamas and Martínez-Santos 2005).

The required investment to assess the value and efficiency of groundwater versus surface water irrigation can be afforded by most governments, and the same holds for the promotion of hydrogeological education campaigns. For many countries, the cost of such undertakings would probably be in most cases only a small fraction of the amount invested every year in the construction of conventional hydraulic infrastructures. In many cases, the issue might be more of an ethical nature, related to the lack of political willingness to fight ignorance, arrogance, institutional inertia or corruption (Delli Priscoli and Llamas, 2001). In this regard, it is pertinent to note that groundwater development is less prone to corruption that traditional surface water irrigation systems, due to the smaller investment and shorter timeframe required for the implementation of groundwater supplies. Perhaps in some regions, this lesser susceptibility to corruption, and not the lack of economic means, may explain the lack of political willingness to truly assess the value of groundwater development (Valencia Statement, 2005).

3.1. POTENTIAL PROBLEMS IN INTENSIVE GROUNDWATER USE

Intensive groundwater use is not a panacea that will necessarily solve the world’s water problems (Mukherji, 2006). In fact, should the prevailing anarchy continue, serious problems may appear in the mid or long-term (two to three generations). Some are already well documented, although at a lesser scale, and are usually related to water table depletion, groundwater quality degradation, land subsidence or ecological impacts on aquatic ecosystems.

Intensive groundwater use frequently depletes the water table. Drawdowns in the order of 0.5m/yr are frequent, although rates up to 5-10m/yr have been reported (Llamas and Custodio, 2003). Farmers are seldom concerned by this issue, except in the case of shallow aquifers: the increase in pumping costs is usually a small problem in comparison with potential groundwater-quality degradation or equity issues such as the drying up of shallow wells owned by the less resourceful farmers. The opposite phenomenon (rise of the water table due to surface water over-irrigation) is also a problem for example in Punjab, India and Pakistan or in San Joaquin Valley in California. Rising of the water table often results in significant social and economic troubles due to soil water logging and/or salination.

Groundwater unit volume cost (Figure 1) increases with depth to groundwater, as more energy is required for pumping and deeper wells might be needed. These costs usually range between US$0.02 and US$0.20/m^3 (Figure 2) depending on the country and the aquifer. Groundwater irrigation cost per hectare also increases with time, albeit at a lower rate. This is because farmers begin to use a more efficient technology and switch (if soil and climate allow) to less water consuming crops: from maize or rice to grapes or olive trees, for instance. It is estimated that groundwater irrigation cost generally ranges between US$20 and US$1,000 per hectare and year.

Documented cases where intensive groundwater use in a medium-sized or large "good " aquifers (those with a surface larger than 500 km^2 and medium to high transmisivity and storage capacity values) has already caused social or economic disturbances are practically unknown; at least not in the degree of magnitude of those caused by soil water-logging and salinization (India, Pakistan, or California) or the serious social conflicts in relation to people displaced or ousted by the construction of large dams (Briscoe, 2005; and Shah et al. 2006).

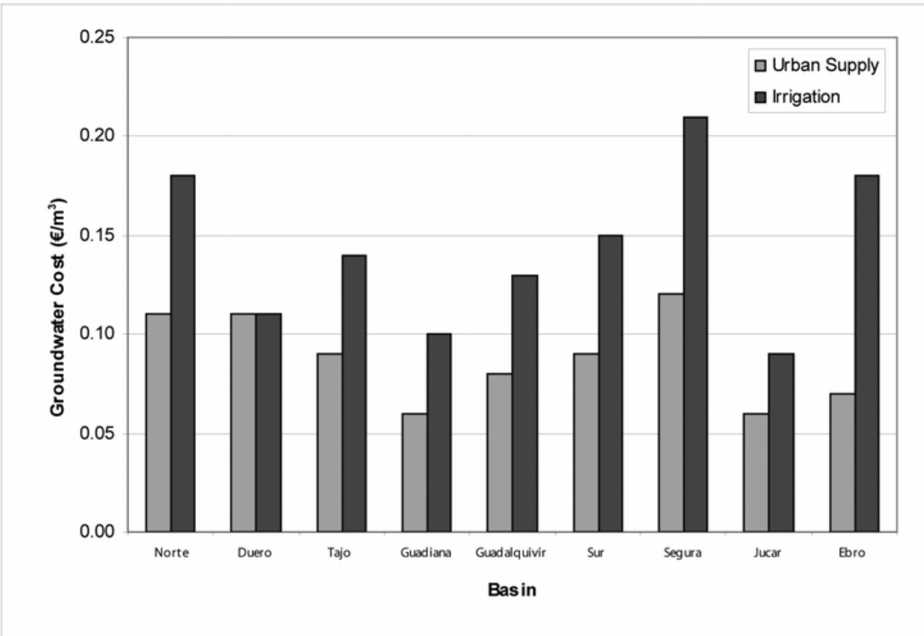

Figure 2. Unit volume cost of groundwater in Spain's administrative water basins (after Llamas and Martínez-Santos 2005).

Most aquifers present a large storage volume in relation to their renewable resources (often two or three orders of magnitude). A practical consequence is that the potential problems mentioned above do not usually become serious in the short term (within one or two generations). Besides, the social transition triggered by groundwater together with the implementation of more efficient irrigation technologies can often result in a sustainable use in the mid-term. The general reduction of global poverty and the transfer of population from agricultural sector to other more productive sectors (Sachs 2005, Sala-Martin, 2006) also are contribution to this transition. However, adequate groundwater management and governance remains an important challenge to ensure long-term sustainability. To this effect, the education of stakeholders and widespread presence of groundwater user associations is crucial for an adequate participatory bottom-up management approach.

The reality is that even some poor aquifers, such as the Indian "hard rock aquifers", have played a key role in increasing food production. In India groundwater irrigated surface has increased in more than forty million hectares during the last decades (Shah et al, 2006; Deb Roy and Shah, 2003). As a consequence, India, despite a 100% increase of its population in the last 50 years, has not only achieved food security in practice, but has also become an important grain exporter.

However, uncontrolled aquifer development in arid and semiarid regions worldwide raises sustainability concerns, particularly whenever the natural rate of recharge is low.

4. Groundwater sustainability vs aquifer overexploitation

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'*. In a more recent book (400 pages in 13 chapters) Rogers et al (2006) present a thorough study on the general concepts of sustainable development.

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 towards 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 conscience.

Llamas et al (2006a) provide a succinct overview of nine different aspects of groundwater sustainability: hydrological, ecological, economic, social, legal, institutional, inter and intra-generational and political. Throughout that 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, political aspects and socio-economic situations. In this regard, the Hydrogeology Journal theme issue of March 2006 presents the socio-economic analyses of a dozen of case studies from all over the world (Llamas et al, 2006b).

Whenever adverse effects of groundwater development begin to be felt, it is common to hear about overexploitation, a term usually equated to pumping in excess of the recharge. While this practice is often dismissed as ‘unsustainable’, the concept of overexploitation is conceptually complex. This is the reason why a significant number of authors consider it simplistic and potentially misleading (Selborne 2001; Delli Priscoli and Llamas, 2001; Delli Priscoli et al 2004, Abdehrrahman 2003; Llamas 2004). Probably the most complete analysis is the one by Custodio (2002). As a consequence more and more authors are changing to the expression “intensive use of groundwater” instead of using “groundwater overexploitation”.

Intensive groundwater use is that which induces significant changes on natural aquifer dynamics (Llamas and Custodio 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.

As explained before, 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.

5. Social, legal and hydropolitical issues in intensively exploited aquifers

In the preface of the last Hydrogeology Journal Theme Issue Llamas et al (2006b) warn about the scarcity of analyses on the social sciences aspects about groundwater role in the general water resource policy. As a matter of fact that theme issue tries to set the pace to increase that type of studies.

The following sections are mainly taken from the paper by Llamas et al (2006a) presented in the recent International Symposium on Groundwater Sustainability (Alicante, Spain, 23-27 January, 2006).

5.1. SOCIAL SUSTAINABILITY

As mentioned before, 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). This is largely a consequence of groundwater's resilience against drought. Secured access to water during dry periods removes a significant perception from farmers' minds. These are thus encouraged 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.

5.2. LEGAL ISSUES

From the legal viewpoint, transboundary aquifers present two main issues of concern. The first one relates to whether groundwater resources should be public or private property. The second refers to the way groundwater rights should be inventoried and to whether the possibility should be allowed to trade with them. This second aspect, usually equated with 'water banks' is perhaps subordinated to the first in terms of importance, even if significant informal markets already exist in some places (Mukherji 2006).

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 US, Mexico and many other countries. In other places, like California, Chile, India or Texas, groundwater is under private ownership.

Spain presents a particularly interesting example of a mixed system. Wells drilled after January 1st, 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).

In any case, the Spanish situation is far more complex due to the lack of a reliable registry of groundwater rights. While the government is currently carrying out a series of remedial initiatives, these are insufficient in the eyes of some authors. Fornes *et al*. 2005 for instance point out that these ignore a significant share of existing wells, and that the registry or inventory is therefore incomplete.

While some voices seem to disagree (Blomqvist 1992) the current situation may be considered unsustainable in the long run, particularly if a strong political willingness to apply the laws is lacking. It seems clear that a reliable inventory of groundwater rights is desirable in order to ensure adequate management, whether it be transboundary or not.

Given the 'polycentric' nature of groundwater development, a bottom-up approach seems the best way to achieve adequate 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; Lopez-Gunn and Martinez-Cortina 2006). Water agencies in Texas and California are currently trying to organize these communities, albeit by means of economic incentives rather than by compulsion (Kretsinger and Narasimhan 2006).

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

5.3. HYDROPOLITICAL ISSUES

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). An excellent summary of the main factors in water governance can be read in Rogers (2006).

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, which are very different from country to country. 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. 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. Up to date, the central water authority has been unable to shut down the 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 practically 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. However, as Kretsinger and Narasimhan (2006) describe the Government of California has abandoned the “command and control” approach while implementing a policy of education and economic incentives whose results seem encouraging.

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. In the case of transboundary aquifers, this is may be a particularly relevant issue, since integrated political actions are required on both sides of the border.

6. Conclusions

Transboundary aquifer management initiatives are still recent, and likely to take a number of years before being fully operational. In arid and semiarid regions, the current situation of groundwater management is generally far from adequate, which raises concerns as to the viability of transboundary management schemes in the long run.

While political motivations are highly volatile, the economic importance of groundwater resources, particularly for irrigation, suggest the need for urgent action to ensure these are managed first within each country's borders. Though not exent of practical difficulties, a participative effort based around groundwater user associations appears the most plausible way of attaining adequate management in the future. The Alicante Declaration (Ragone and Llamas, 2006) is included as an annex to this paper, and constitutes call for action in regard to these practical issues.

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ANNEX. The Alicante Declaration: The Global Importance of Ground Water and a call for action for its responsible use, management and governance

Water is essential for life. Groundwater —that part of all water resources that lie underneath land surface— constitutes more than ninety five percent of the global, unfrozen freshwater reserves. Given its vast reserves and broad geographical distribution, its general good quality, and its resilience to seasonal fluctuations and contamination, groundwater holds the promise to ensure current and future world communities an affordable and safe water supply. Groundwater is predominantly a renewable resource which, when managed properly, ensures a long-term supply that can help meet the increasing demands and mitigate the impacts of anticipated climate change. Generally, groundwater development requires a smaller capital investment that surface water development and can be implemented in a shorter timeframe.

Groundwater has provided great benefits for many societies in recent decades through its direct use as a drinking water source, for irrigated agriculture and industrial development and, indirectly, through ecosystem and streamflow maintenance. The development of groundwater often provides an affordable and rapid way to alleviate poverty and ensure food security. Further, by understanding the complementary nature of ground and surface waters, thoroughly integrated water-resources management strategies can serve to foster their efficient use and enhance the longevity of supply.

Instances of poorly managed groundwater development and the inadvertent impact of inadequate land-use practices have produced adverse effects such as water-quality degradation, impairment of aquatic ecosystems, lowered groundwater levels and, consequently, land subsidence and the drying of wetlands. As it is less costly and more effective to protect groundwater resources from degradation than to restore them, improved water management will diminish such problems and save money.

CALL FOR ACTION

To make groundwater's promise a reality requires the responsible use, management and governance of groundwater. In particular, actions need to be taken by water users, who sustain their well-being through groundwater abstraction; decision makers, both elected and non elected; civil society groups and associations; and scientists who must advocate for the use of sound science in support of better management. To this end, the undersigners recommend the following actions:

<u>Develop more comprehensive water-management, land-use and energy-development strategies that fully recognize groundwater's important role in the</u>

hydrologic cycle. This requires better characterization of groundwater basins, their interconnection with surface water and ecosystems, and a better understanding of the response of the entire hydrologic system to natural and human-induced stresses. More attention should be given to non-renewable and saline groundwater resources when such waters are the only resource available for use.

Develop comprehensive understanding of groundwater rights, regulations, policy and uses. Such information, including social forces and incentives that drive present-day water management practices, will help in the formulation of policies and incentives to stimulate socially- and environmentally-sound groundwater management practices. This is particularly relevant in those situations where aquifers cross cultural, political or national boundaries.

Make the maintenance and restoration of hydrologic balance a long-term goal of regional water-management strategies. This requires that water managers identify options to: minimize net losses of water from the hydrologic system; encourage effective and efficient water use, and ensure the fair allocation of water for human use as well as ecological needs, taking into account long-term sustainability. Hydrological, ecological, economic and socioeconomic assessments should be an integral part of any water-management strategy.

Improve scientific, engineering and applied technological expertise in developing countries. This requires encouraging science-based decision-making as well as "north-south" and "south-south" cooperation. Further, it is important that funds be allocated for programs that encourage the design and mass-dissemination of affordable and low-energy consuming water harnessing devices for household and irrigation.

Establish ongoing coordinated surface water and groundwater monitoring programs. This requires that data collection become an integral part of water-management strategies so that such strategies can be adapted to address changing socio-economic, environmental, and climatic conditions. The corresponding data sets should be available to all the stakeholders in a transparent and easy way.

Develop local institutions to improve sustainable groundwater management. This requires that higher-level authorities become receptive to the needs of local groups and encourage the development and support of strong institutional networks with water users and civic society.

Ensure that citizens recognize groundwater's essential role in their community and the importance of its responsible use. This requires that science and applied technology serve to enhance education and outreach programs in order to broaden citizen understanding of the entire hydrologic system and its global importance to current and future generations.