INTENSIVE GROUNDWATER USE: A SILENT REVOLUTION THAT CANNOT BE IGNORED[1]

M.R. Llamas - Royal Academy of Sciences. Valverde 22, 28004. Madrid. Spain. mrllamas@geo.ucm.es
P. Martínez-Santos. Department of. Geodynamics. Complutense University. 28040. Madrid. Spain. pemartin@geo.ucm.es

ABSTRACT

Over the last decades, agriculture in arid and semi-arid countries has experienced a true "silent revolution" of intensive groundwater use. Millions of independent farmers worldwide have chosen to become increasingly dependent on the reliability of groundwater resources, and as a result their countries have reaped abundant social and economic benefits. Data from several countries shows that groundwater irrigation presents a much greater efficiency, than surface water irrigation systems, thus contributing to fulfil the motto of "more crops and jobs per drop". If this situation is confirmed globally, the usual world water visions have to be reviewed. However, the "silent revolution" has been carried out with scarce control on the part of governmental water agencies, and thus a series of unwanted effects have developed in certain places. While these by no means justify the pervasive "hydromyths" and obsolete paradigms that voice the frailty of groundwater, appropriate management of groundwater resources remains a worldwide challenge. This paper provides an overview of these issues, and concludes with the necessity there is to educate all levels of society on the importance of groundwater and to create bottom-up user associations to manage aquifers as common pool resources.

Keywords: groundwater use, silent revolution, irrigation efficiency, world water visions, UN Millennium Goals, hydromyths, groundwater user associations.

1. INTRODUCTION

It is well known that water is an essential element for the existence of any form of life. Water is also an essential element for many economical undertakings such as irrigated agriculture. The relevance of water extends well beyond utilitarian examples of that kind, often times in a manner which, although difficult to quantify, is by no means of a lesser importance. These non-quantifiable values include the importance to the environment, as well as the symbolic perceptions to which water gives rise in most cultures and religions.

Over the last few decades, numerous people have voiced the existence of world wide water crisis. As a result, a conscience exists today of the necessity to attain sustainable development in water resource management. While water problems do exist, they are seldom related to physical scarcity; rather, it can be shown that they are nearly always a consequence of human mismanagement or poor governance.

Furthermore, the United Nations Millennium Declaration (2000) stated as two of its main goals to halve by 2015 the number of people world-wide who suffer from malnutrition or do not have affordable access to drinking water. It is the belief of these authors that fostering groundwater development is the only realistic approach to achieve those two objectives.

Thus, the aim of this paper is three-fold. First, to show the multiple benefits the "silent revolution" of intensive groundwater use has yielded and second, to outline the potential shortcomings that may arise from this silent revolution; and third, to show that this greater efficiency of groundwater irrigation has several

[1] This invited paper was presented on Wednesday, August 18, 2004 in the 2004 World Water Week (Stockholm 16-20 August, 2004). It has been apublished in the WATER SCIENCE AND TECHNOLOGY SERIES, 2005, Vol. 51, No. 8, pp: 167-174. International Water Association. ISBN 1 84339 494 4

implications, not only from the point of view of water demand management, but also from the generally accepted world water visions.
To this effect, it must be noted that irrigation nowadays amounts to about 70% of the total world water use (a figure which increases to about 80-95% in arid and semi-arid countries) and produces almost half the food and fibres required by the human being (United Nations, 2003). Therefore, this paper deals in particular with groundwater and agriculture.

2. BENEFITS OF INTENSIVE GROUNDWATER USE

2.1 The silent revolution of intensive groundwater use

Groundwater development has yielded great economic and social benefits in many respects during the latter half of the last century. For example, the intensive use of groundwater for irrigation has contributed significantly to alleviate the problem of hunger or famines and of drinking water supply to cities and rural areas.
At the same time, the last few decades have witnessed an increase in the availability of new technologies such as the submersible pump. Thus, in arid and semi-arid countries, groundwater irrigation has usually become much more profitable *de-facto* than surface water irrigation. As a consequence, a real *Silent Revolution* has taken place: during this period millions of independent farmers in these countries have of their own accord implemented the necessary means to irrigate their land with groundwater. The participation of government agencies in the planning and control of these groundwater developments has usually been scarce.

2.2 Social and economic benefits of intensive groundwater use

Burke (2003), based on data from FAO, states that the total irrigated area across the world is about 390 million hectares. While specific data for Europe and the Pacific is not available, FAO estimates that for the rest of the world, about 152 million are under surface water control and some 89 million under groundwater control. If these figures are extrapolated to Europe and the Pacific, about 250 million hectares (2/3 total) are irrigated with surface water, and about 130 are groundwater irrigated (1/3). At the same time, the estimated total volume of water consumed for irrigation purposes in the world is 2000-2500 km^3/year. It is estimated that around 20% of that total demand is met by groundwater (United Nations, 2003). In other words, the consumptive water use is 1600-2000 km^3/year of surface water and between 400-500 km^3/year of groundwater.
On average, according to these data, the surface water irrigation dose is between 0.6 and 0.8 m/year (equal to 6000-8000 m^3/ha year). In contrast, this ratio is between 0.3 and 0.4 m/year for groundwater (equal to 3000-4000 m^3/ha year). This estimate is based on rough global data, and only allows for the comparison of technical efficiency (water used per hectare). However, it does not provide any information on the economic ($\$/m^3$) or social (jobs/$m^3$) efficiency of groundwater over surface water irrigation. Analyses on this topic are scarce, nonetheless data in countries such as India and Spain confirm the greater socio-economic efficiency of groundwater irrigation in comparison with that of surface water schemes. Thus, according to Dhawan (1995), research in India indicates that yields in areas irrigated with groundwater are one third to one half higher than those in areas irrigated with surface resources. In a previous report Dains and Pawar (1987) estimated that as much as 70–80% of India's agricultural output might be groundwater dependent. More recently, the Indian Water Resources Society (1999) published, among others, the following significant data:
(1) Groundwater is contributing at present 50% of irrigation surface, 80% of water for domestic use in rural areas, and 50% of water in urban and industrial areas. (2) Groundwater abstraction structures had increased from 4 million in 1951 to nearly 17 million in 1997. (3) In the same period the groundwater irrigated area had increased from 6 to 26 million ha. (4) It was estimated that this rapid pace of development is likely to continue and will reach 64 million ha in the year 2007.
By indirect calculation it may be estimated that in India the average amount of water applied in surface water irrigation is around 16,000 m^3/ha/yr; in groundwater irrigation this ratio is only 4,000 m^3/ha/yr. In other words, it seems that in India and on average, the economic yield in irrigation and by m^3 is from 5 or 10 times higher when groundwater is used than when irrigation is made with surface water. Most of these

data are ten or more years old. The spectacular increase of groundwater use has continued during the last two decades. A good number of papers have been published in the last years. Among them Deb Roy and Shah (2003); Moench(2003); Mukherji(2003). The current groundwater irrigated surface in India is larger than 35 million ha.

Similar conclusions can be drawn from the current situation in Spain. Thus, Llamas (2000) analysed the relevance of groundwater to mitigate drought effects in Spain. Hernández-Mora *et al*. (2001) published a well-documented irrigation assessment in Andalusia (Spain). The results of this comparison are outlined in Table 1 below:

Table 1: Socio-economic comparison of surface water and groundwater irrigated areas in Andalusia (Spain).

INDICATOR	SURFACE WATER	GROUNDWATER	TOTAL
Irrigated surface (10^3 ha)	600	210	810
Total production (10^6 €)	1950	1800	3750
Average consumption at origin (m^2/ha/year)	7400	4000	6500
Water productivity (€/m^3)	0.42	2.16	0.72
Employment generated (EAJ*/10^6 m^3)	17	58	25

* EAJ = Equivalent Annual Jobs.

Some significant data from this study are: (1) Average water applied is 4,000 m^3/ha/yr. in groundwater irrigation and 7,500 m^3/ha/yr in surface water (including the losses in surface water transport from the dam or river to the field). (2) The average economic yield per hectare is more than three times greater in groundwater irrigated areas than in surface water irrigated areas. The economic yield by m^3 used is five times higher in groundwater than in surface water.

This analysis has been extended to other regions of Spain (Hernández-Mora and Llamas, 2001) with different climatic and social conditions, and the results are also similar.

Table 2. Rough estimates of direct cost of groundwater irrigation in relation to crop value.

Type of aquifer (cost of water)	GA: Good aquifer (US$ 0.01/m^3) PA: Poor or deep aquifer (US$ 0.10/m^3)	GA	GA	PA	PA	GA	GA	PA	PA
Type of crops (water consumption)	LW: Low water-consuming (1,500 m^3/ha/yr.) HW: High water-consuming (15,000 m^3/ha/yr.)	LW	HW	LW	HW	LW	HW	LW	HW
Typical cost of irrigation water (US$/ha/yr.)	Combining type of aquifer and type of crops	15	150	150	1500	15	150	150	1500
Crop value	HV: High-value crops (US$ 50,000/ha/yr.) LV: Low-value crops (US$ 500/ha/yr.)	HV	HV	HV	HV	LV	LV	LV	LV

Cost of water/ Crop value	**Combining type of aquifer, type of crops and crop value**	**0.03%**	**0.3%**	**0.3%**	**3%**	**3%**	**30%**	**30%**	**300%**

While it would be highly desirable to carry out similar studies in other arid and semi-arid countries, it would be appropriate to include this type of analysis in the framework suggested in the report of the World Commission on Dams (WCD, 2000) in order to study the economic and social feasibility of new dams. A recent report by the European Environmental Agency (2003) notes that the increase of groundwater use is not restricted to the Mediterranean Member States (France, Spain, Portugal, Italy and Greece), but it also extends to other European arid and semi-arid countries (Romania and Turkey) and parts of Central Asia.

The most relevant socio-economic fact in relation to groundwater development in arid and semiarid countries is that the full direct cost (not including externalities) of abstracting groundwater for irrigation is only a small fraction of the value of the crops obtained. This fact has been the driving force of the aforementioned and practically universal *Silent Revolution* caused by the intensive use of groundwater. Table 2 (from Llamas and Martinez-Santos, 2004) shows a rough estimate of these values in most countries. The values in the table would be lower in poorer countries. For instance, in India, Pakistan and Nepal, the average cost of groundwater is between 0.02 and 0.04 US$/m^3 (Muhkerji, personal communication) in California this cost is 0.04-0.08 US$/m^3 (Hamer, 2002) and in Jordan 0.09 US$/m^3 (Chebaane et al, 2004).

Some conclusions from this table are: (1) In good aquifers all types of crops are usually economically feasible, except those that have low value and are high water consuming. (2) In low permeability aquifers or in aquifers where the pumping depth is significant, only crops that are low water consuming and/or have high value are economically feasible. This situation can be changed if energy is heavily subsidised like in some Indian states. (3) In summary, the economic feasibility of groundwater irrigation is mainly conditioned by the crop value. High value crops can usually be developed even using low permeability or deep aquifers. In most normal aquifers the cost of abstracting groundwater is usually affordable to grow any type of crops. These data explain why, in the last decades, the farmers in most arid and semiarid countries have intensively developed groundwater irrigation. A more detailed explanation of this table can be found in Llamas and Martínez-Santos, 2004.

It is only natural that social benefits should arise from the economic facts mentioned above. In fact, it can be argued that groundwater irrigation has the potential to rapidly (within a single generation), catalyse the transition from a rural and often illiterate society to an educated middle class with a strong secondary and/or tertiary sector (Moench, 2003).

3. SUSTAINABILITY OF INTENSIVE GROUNDWATER USE

3.1 Hydromyths and/or false paradigms

Given the above, why are groundwater resources so often neglected? The answer to this question is two-fold. On the one hand, pervasive *"hydromyths"* and obsolete paradigms state that groundwater is fragile and irrelevant as a resource. On the other hand, a series of unethical attitudes which have become widespread among the water policy decision-makers of many countries.

Groundwater development is a recent phenomenon (about 50 years old). This has been mainly undertaken by a large number of small (private or public) developers and often planning and control of this development by the responsible Water Administration has been scarce. In contrast, for a long time surface water projects have usually been of larger dimension and have been designed, financed and constructed by Government Agencies. This historical situation has often produced two effects: first, most Water Administrations have limited understanding and poor data on the groundwater situation and value; and second, in some cases the lack of control on groundwater development has caused some problems.

These problems have been sometimes exaggerated by groups with lack of hydrogeological know-how, professional bias or vested interests. Because of this, in recent decades groundwater fragility or overexploitation has become a kind of *hydromyth* that has pervaded water resources literature. A usual axiom derived from this pervasive *hydromyth* is that groundwater is an unreliable and fragile resource that should only be developed if it is not possible to implement the conventional large surface water projects.

All these have often led people to consider groundwater development as a “pillar of sand”, a fragile resource prone to collapse (Postel, 1999).
As a matter of fact, these authors do not know of any examples of medium or large size aquifers (over 500 km^2) where intensive groundwater development has caused social or economic havoc. This may be due to the huge amount of water usually stored in aquifers, usually taking one or two generations of “heavy pumpers” before noticeable adverse effects are perceived. In the meantime, however, the following process has taken place: (1) the illiterate farmers have learned better irrigation technologies, and to grow low water consumption cash-crops; (2) their children have had a chance to be educated, and many of them have moved on to the industrial or services sector. Nevertheless, it is clear that the corresponding governments should soon begin to assess their groundwater irrigation structures in order to avoid serious problems in the mid/long-term.

3.2 Potential shortcomings and real problems associated with the intensive use of groundwater

Groundwater is not a kind of *panacea*, and an uncontrolled intensive use can lead to a series of unwanted consequences. These, often a consequence of human mismanagement rather that a necessary occurrence, include groundwater-level depletion, degradation of groundwater quality, susceptibility to subsidence, interference with surface water and other ecological impacts. Note that, while there is not enough space to deal with these in depth in this paper, a more detailed description can be found in Llamas and Custodio (2003).

4. THE CONTROVERSY OF GROUNDWATER MINING

Certain authors consider that *groundwater mining* is clearly against sustainable development and that this kind of *ecological sin* should be socially rejected and/or legally prohibited. Nevertheless, a good number of authors (among them Freeze and Cherry, 1979; Llamas, 2001; Collin and Margat, 1993; Price, 2002; Abderrahman, 2003) indicate that, this is often a simplistic and misleading view of the issue, and that under certain circumstances, groundwater mining may be a reasonable option. As a matter of fact, groundwater mining is today practised in a good number of regions of developed and developing countries.
Fossil groundwater has no intrinsic value if left in the ground except as a potential resource for future generations, but are such future generations going to need it more than present ones? It is hoped that the recent activities in order to bring more data and transparency on this issue (Llamas and Custodio, 2003) will mean a clear step forward for a more equitable water policy.
Perhaps the main moral of this is that a *stressed aquifer system* can become an *eu-stressed aquifer system* if appropriately managed. In other words, groundwater mining can often be beneficial for society if such development is well designed and controlled (Llamas and Martínez-Santos, 2004).

5. ATTAINING AN ADEQUATE GROUNDWATER GOVERNANCE

As stated above, groundwater use has augmented dramatically in most arid and semi-arid countries, as well as in small islands and in the proximity of important urban nuclei. Nevertheless, groundwater resources remain heavily underused in poorer countries, even when these resources hold the key for development. The following paragraphs provide a succinct explanation of the main obstacles in the way to an adequate, neither excessive nor scarce, use of groundwater resources in both rich and poor countries.

5.1 Scientific and technological deficit

Those responsible for water management policies are, in most countries, people formed under the paradigm of the necessity and excellence of major surface hydraulic infrastructures. Besides, these people often present a serious lack of hydrogeological knowledge, which leads them to an attitude of “disregarding what they ignore”.

5.2 Lack of solidarity (mainly due to the lack of information)

Groundwater as a resource has been, and it still is, taken advantage of mostly by individuals. Each well functions whenever the owner chooses, without taking into account the potential influence it might have on the neighbouring beneficiaries of surface or ground water.

While surface water irrigation is usually regulated by local governing bodies, aquifer exploitation is often carried out by thousands of individual users, which act in a completely independent manner from each other. The latter attitude is probably a consequence of a generalised lack of knowledge of how aquifer systems work. Therefore, long and exhaustive education campaigns about groundwater resources are needed.

5.3 Newness of collective aquifer management institutions

Institutions for collective management of “common pool resources” are not rare. A close analysis of how these groups work openly challenges the commonly held perception of “the tragedy of commons”. These refer to different types of natural resources such as communal forest, hunting or fishing and there are also some well-known examples in the field of surface waters, like the Water Tribunal of Valencia, which has worked well over the last eight centuries. Nevertheless, as it has been stated repeatedly before, intensive groundwater use only dates from one or two generations ago, and thus the majority of groundwater management institutions are still in the early stages of development in most countries (Hernández-Mora & Llamas, 2001; Hernández-Mora et al., 2003; Van Steenbergen and Shah, 2003).

This is a crucial field, which will probably experience a great deal of activity over the next few decades. The basic idea is that a rational aquifer management can neither be based exclusively upon a series of laws nor on the establishment of government semi-policial bodies entrusted with the control of aquifer abstractions. It seems important to implement these organisations in a bottom-up manner, ensuring the pertinent help of the corresponding government organs.

5.4 Institutional inertia

Once again, it seems important to note that the relative novelty (less that fifty years) of groundwater as a resource, results in most of the public opinion, as well as most politicians, acting in agreement with the paradigms existing one or two generations ago. In fact, government water authorities in most countries work under the influence of the obsolete paradigms according to which their officers were trained. In order to accelerate the necessary change, an impulse is needed to launch groundwater education campaigns.

5.5 Vested interests

Last, but not least, there is the existence of certain historical attitudes which imply that water should be heavily subsidised, and that major hydraulic structures should be built with public funds (but by private companies). These constitute obvious nuclei of resistance against change.

Corruption is another unfortunate circumstance with affects most countries, albeit in varying proportions, and which indirectly opposes a turn towards taking advantage of groundwater resources. Thus, part of the public funds intended for hydraulic infrastructures sometimes ends up in illegal payments to certain politicians or public servants (Delli Priscoli & Llamas, 2001). Fortunately, the OCDE recently began a campaign against corruption, a topic which will be debated by a high-level panel during the 14th Stockholm Water Week.

6. CONCLUSIONS

The intensive groundwater exploitation carried out in arid and semi-arid countries in the last few decades has yielded abundant benefits to the human race. Thus, groundwater use is a key element to eradicate poverty and to dramatically reduce the proportion of the world’s inhabitants that still today do not have affordable access to water and suffer from famines.

As a general rule, intensive groundwater use has been carried out and funded by individuals with no or very little planning on the part of the competent hydrologic authorities of each country. As a consequence, a series of problems have arisen. These can and must be solved in order to achieve a sustainable development of this important natural resource. The launching of education campaigns, as well as the creation of bottom-up groundwater user associations constitutes a crucial step in this regard.

The usual greater socio-economic efficiency of groundwater irrigation in comparison with surface water demands a new approach in the World Water Assessment Project, since most of the figures on current and future water demands need to be reviewed.

REFERENCES

Abderrahman, W.A. (2003). Should intensive use of non-renewable groundwater resources always be rejected? In: M.R. Llamas and E. Custodio (eds.), *Intensive Use of Groundwater. Challenges and opportunities.* Balkema Publishers. Lisse, the Netherlands: 191–206.

Burke, J.J. (2003). *Groundwater for irrigation: productivity gains and the need to manage hydro-environmental risk.* In: M.R. Llamas and E. Custodio (eds.), *Intensive Use of Groundwater. Challenges and opportunities.* Balkema Publishers. Lisse, the Netherlands: 59-92.

Collin, J.J. and Margat, J. (1993). Overexploitation of water resources: overreaction or an economic reality? *Hydroplus*, 36: 26–37.

Chebaane, M.; El-Naser, H.; Filch, J.; Hijazi, A.; Jabbarin, A. (2004). *Participatory groundwater management in Jordan: development and analysis of options.* Hidrogeology Journal, vol. 12, no. 1, pp. 14-33.

Custodio, E. (2002). Aquifer overexploitation: what does it mean? *Hydrogeology Journal*, 10: 254–277.

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

Deb Roy, A. and Shah, T. (2003). Socio-ecology of groundwater irrigation in India. In: M.R. Llamas and E. Custodio (eds.), *Intensive Use of Groundwater. Challenges and opportunities.* Balkema Publishers. Lisse, the Netherlands: 307–336.

Delli Priscoli, J. and Llamas, M.R. (2001). International perspective in ethical dilemmas in the water industry. In: C.K. Davis and R.E. McGinn (eds.), *Navigating in Rough Waters*. American Water Works Association. Denver, Colorado, USA: 41–64.

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

European Environmental Agency (EEA) (2003). *Europe's Water: an indicator-based assessment*. http://themes.eea.eu.int//specific_media/water/date/reports.

Hernández-Mora, N. and Llamas, M.R. (eds.) (2001). *La Economía del Agua Subterránea y su Gestion Colectiva*. Fundación Marcelino Botín and Ediciones Mundi-Prensa. Madrid, Spain. 549 pp.

Hamer, G. (2002). *The cost of water in Southern California.* In: California Groundwatr Resources Association Annual Conference (September, 2002). Newport Beach. PowerPoint Presentation, 32 slides.

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

Hernández-Mora, N.; Martínez Cortina, L. and Fornés, J. (2003). Intensive Groundwater Use in Spain. In: M.R. Llamas and E. Custodio (eds.), *Intensive Use of Groundwater. Challenges and opportunities.* Balkema Publishers. Lisse, the Netherlands: 387–414.

Indian Water Resources Society (1999). *Water: Vision 2050*. New Delhi, India. 74 pp.

Llamas, M.R. (2000). *Some lessons learnt during the drought of 1991–1995 in Spain*. In: Vogt and Somma (eds.), *Drought and drought mitigation in Europe.* Kluwer Academic Publisher: 253–264.

Llamas, M.R. (2001). Considerations on Ethical issues in relation to groundwater development and/or mining. UNESCO Conference on international aquifers systems in arid zones; managing non-renewable resources. Tripoli, Lybia, 20–24 November 1999. *Technical Documents in Hydrology*, V IHP, No. 42. UNESCO. París, France: 467–480.

Llamas, M.R. and Custodio, E. (eds.) (2003). *Intensive Use of Groundwater. Challenges and Opportunities*. Balkema Publishers. The Netherlands. 478 pp.

Llamas, M.R. and Martínez-Santos, P. (2004). *Ethical issues in relation to intensive groundwater use*. Selected Papers of the Symposium on Intensive Groundwater Use (SINEX). Balkema Publishers. The Netherlands. 17-36pp.

Moench, M. (1999). Addressing constraints in complex systems. Meeting the water management needs of South Asia in the 21st Century. In: M. Moench *et al*. (eds.), *Rethinking the Mosaic*. Institute for Social and Environmental Transition. Boulder, Colorado, USA: 1–56.

Moench, M. (2003). Groundwater and Poverty: exploring the connections. In: M.R. Llamas and E. Custodio (eds.), *Intensive Use of Groundwater. Challenges and Opportunities.* Balkema Publishers. The Netherlands: 441–456.
Mukherji, A. (2003). *Groundwater development and agrarian change in Eastern India*. Comment No. 9 in IWMI-TATA Water Policy Program. (www.iwmi.org/iwmi-tata). 11 pp.
Postel, S. (1999). *The Pillar of Sand*. W.W. Norton and Co. New York, USA. 313 pp.
Price, M. (2002). Who needs sustainability? In: K.M. Hiscock, M.O. Rivett and R.M. Davison (eds.), *Sustainable Groundwater Development*. Balkema Publishers. Lisse, the Netherlands: 191–207.
United Nations (2000). *United Nations Millennium Declaration*. A/RES/55/2.
United Nations (2003). *Water for People, Water for Life*. UNESCO-WWAP. Paris, France.
Van Steenbergen, F. and Shah, T. (2003). *Rules rather than rights: self-regulation in intensively used groundwater systems*. In: M.R. Llamas and E. Custodio (eds.), *Intensive Use of Groundwater. Challenges and Opportunities.* Balkema Publishers. The Netherlands: 241-256.