Intensive Groundwater Use: Silent Revolution and Potential Source of Social Conflicts

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Many papers, including a recent editorial of this journal (Stakhiv 2003), have advocated the need for a paradigm shift toward adaptive, integrated water resources management as a means to attain a rationalization in water use. There is, however, one significant element of water policy that has received less attention by most experts and water decision-makers: intensive groundwater use for irrigation in arid and semiarid regions (more significantly in developing countries). This editorial provides an overview of this phenomenon and its main pros and cons, aiming to contribute to the current debate over adaptive integrated water resources management. Assessing the implications might not only shed some new light upon some pervasive world water visions, but also help to avoid or mitigate potential social conflicts.

Groundwater development has for a long time provided drinking water to urban and rural populations of developed and developing countries. Currently, groundwater is estimated to provide about 50% of the world's drinking-water supplies (United Nations 2003 p. 78). Moreover, groundwater is arguably the cheapest and fastest way to achieve the United Nations Millennium Declaration goal of halving the number of people worldwide without affordable drinking water and/or malnourished by 2015 (Llamas and Martinez Cortina 2002). In addition, groundwater abstraction by simplified mechanisms, such as the treadle pump, together with cheap drip irrigation systems, also constitutes a plausible alternative for developing countries to overcome the poverty threshold (one dollar/person and day per capita income) (Polak 2004).

While the human and political relevance of these figures is obvious, it cannot be overlooked that urban and rural domestic supply for human consumption amounts to less than 15% of global water use. Thus, this editorial is concerned solely with irrigation, which is generally acknowledged to be about 70% of the world's freshwater withdrawal (United Nations 2003). Note that this percentage might increase to about 90% if consumptive uses were considered.

The Silent Revolution of Intensive Groundwater Irrigation

A spectacular increase in groundwater development for irrigation has taken place during the last half-century in most arid and semiarid countries: a kind of "silent revolution," 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 been frequently incentivized by 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, and frequently have paid very little attention to groundwater development. This attitude, termed "hydroschizophrenia" by American hydrologist Raymond Nace (Llamas 1975), has been commonplace in India, Mexico, Spain, and many other arid and semiarid regions worldwide. As a consequence, certain adverse effects have ensued in places like South Asia, where the current situation concerning groundwater development has been described as a "colossal anarchy" (Shah 2004).

Fig. 1 presents a qualitative overview of the different water policy stages brought on by intensive groundwater use in arid and semiarid countries. Each of the five stages is roughly equivalent to one generation (about 25–30 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. In fact, the Western Water Policy Review Advisory Commission (1998) reminded that state laws should recognize and take into account the substantial interrelations of surface and groundwater, and that these resources should be administered and managed conjunctively. It seems that this has not yet been achieved in the two main groundwater user states, California and Texas. The legal situation is similar in many arid and semiarid regions worldwide. Two recent books, (Llamas and Custodio 2003; Sahuquillo et al. 2004) present about 40 worldwide case histories on intensive groundwater use. However, due to length restrictions, even some of the most significant ones will not be mentioned in this editorial.

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.

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 suboptimal choice: one is that groundwater can be obtained individually, thus bypassing 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.

Another important and seldom-mentioned benefit of the Silent

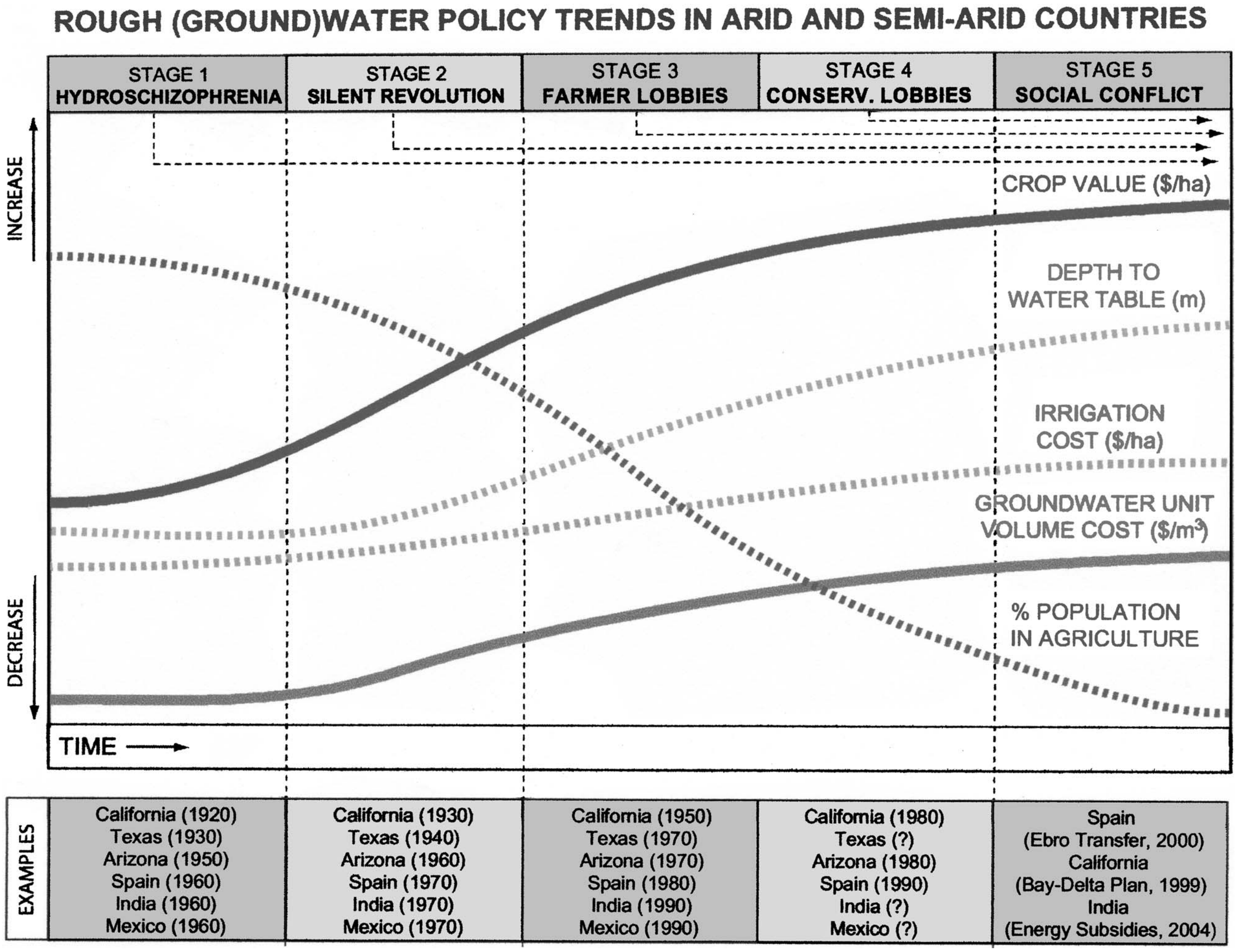


Fig. 1. Rough (ground)water policy trends in arid and semi-arid countries

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 in almost every country significant changes in the labor 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 labor 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 due mainly 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, and 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 Tamil Nadu, India (Palanisami et al. 2004).

Despite the illusory accuracy of global irrigation data and the variability of the existing estimates (Burke 2003; United Nations 2003; Shah 2004), 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 times 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 socioeconomic efficiency of surface and groundwater irrigation at a world scale. This may establish the need to change several pervasive paradigms and figures about the current and future water needs for irrigation (Llamas and Martinez-Santos 2004).

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 is 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 a motto is often achieved by groundwater irrigation.

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 time frame required for the implementation of equivalent 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 2004).

Potential Shortcomings and Solutions

Intensive groundwater use is not a panacea, and it will not necessarily solve the world's water problems. 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 0.5 m/year are frequent, although rates up to 5 m/year have been reported (Llamas and Custodio 2003; Sahuquillo et al. 2004). 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 overirrigation) is also a problem, for example, in Punjab, India, and Pakistan or in the San Joaquin Valley, in California. Rising of the water table often results in social and economic troubles due to soil water-logging and/or salination.

Groundwater unit volume cost (see Fig. 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$0.01 and US$0.20/m^3, depending on the country and the aquifer (Llamas and Martinez-Santos 2004). 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.

Groundwater quality degradation and/or pollution poses an important threat everywhere, but chiefly in humid developed regions. These are more prone to experience troubles due to intensive agrochemical use in rainfed agriculture and industrial (or urban) pollution point sources. However, groundwater quality degradation is not so significant in developing arid and semiarid regions since the effects are felt in the long-term. In fact, the inhabitants of these regions are usually much more concerned with alleviating poverty and improving their health and nourishment. Yet, the danger exists for experts from industrialized countries to adopt a kind of "colonial outlook" approach: those real issues in relation to groundwater pollution may be overemphasized in conference proceedings, declarations, and similar documents. There is no denying that developing countries must become aware of the potential effects of intensive groundwater use. However, Kutznet's curve suggests that environmental concern will only come after more immediate needs have been satisfied. In other words, the main step toward achieving a sustainable groundwater development in developing countries is the eradication of poverty.

Pumping-induced seawater intrusion in coastal aquifers is an important source of groundwater quality degradation. Nevertheless, this is usually an issue to do with poor management, rather than with intensive pumping *per se*. It is well known that seawater intrusion phenomena have successfully been stopped in the last 50 years (the case of Israel's coastal plains or California's Orange County), often by means of artificial recharge or pumping barriers.

A different and commonly raised issue in relation to groundwater quality is that of arsenic, a natural and highly toxic groundwater contaminant. Examples of places where high arsenic concentrations may be found would be aquifers in Mexico, Chile, China, some European countries, and, more importantly, Bangladesh. While arsenic contamination constitutes an undeniable health concern in those countries, the relative magnitude of the problem is perhaps exaggerated. Alaerts and Khoury (2004), for instance, point out that groundwater arsenic affects approximately 50 million people worldwide, in contrast with the 1.5 billion affected by waterborne disease (usually a consequence of pathogens carried by surface water). In addition, the same authors suggest that it has not yet been established whether groundwater pumping has a direct impact upon arsenic concentration or if this is predominantly a natural phenomenon. Thus, as long as arsenic removal techniques are not available at a large scale, the affected aquifers must not be considered within the available groundwater resources.

The authors are not aware of any documented cases where intensive groundwater use in a medium-sized or large "real" aquifer (those with medium-to-high transmisivity and storage capacity values) has already caused social or economic disturbances, at least not of 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. It is expected that the debate on this editorial may show if such documented cases exist.

Most aquifers present a large storage volume in relation to their renewable resources (often one or two orders of magnitude). A practical consequence is that the potential problems mentioned above do not usually become serious in the short-term (within one generation). 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. However, adequate groundwater management and governance remains an important challenge to ensure long-term sustainability. To this effect, adaptive integrated water resources management programs at graduate level are highly desirable (Kirshen et al.

2004). In addition, 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 that country, groundwater-irrigated surface has increased by more than 40 million hectares during the last decades (Shah 2004). As a consequence, India has not only achieved food security in practice, but has also become an important grain exporter (despite its population having nearly doubled in the last 50 years).

Groundwater Governance and Social Conflicts

A final consideration is the need for proactive governmental action in order to avoid water conflicts in the near future. Although such conflicts may be of a different nature in each country, they all seem to share a common trait: the benefits of groundwater irrigation have empowered farmers. As a result, farmer lobbies have been constituted in arid and semiarid regions worldwide as a means to protect their collective interests. While these have become increasingly vocal on the political front, opposing lobbies have arisen, often driven by environmental, economic, and political agendas. The latter are not generally concerned with groundwater issues, the focus of their militancy often being the opposition to large surface-water infrastructures such as dams and canals. As a consequence, they pose an indirect, but significant opposition to farmers' interests.

Take, for instance, the Californian and Spanish experiences. Once farmers considered the problems due to intensive pumping to be serious enough, they lobbied for heavily subsidized surface-water transfers from other basins. In doing so, they came into open confrontation with conservationist groups. The outcome of such conflicts varied widely. Californian farmers were successful in the 1950s through to the 1970s. Thus, they obtained large transfers (subsidized with federal funds), while conservation lobbies were still weak. However, as the latter became more powerful, they managed not only to stop and/or reduce new dams and water transfers, but also to divert a share of the transferred flows for environmental conservation purposes.

Similarly, the Spanish Parliament enacted the National Water Plan Law in 2001 in order to approve the Ebre River Transfer. However, environmental lobbies heavily influenced the newly elected government in rejecting the transfer in 2004. An example of the power attained by both factions are the huge demonstrations (over 300,000 people strong) that took place in cities like Madrid, Valencia, and Zaragoza in favor of and against the transfer.

Another interesting example is the recent electoral upset in India. According to Mukherji (2004), millions of modest groundwater farmers voted out a government that was doing apparently well in the macroeconomic front (high growth in GDP, historically high levels of foreign exchange reserve, high foreign institutional investment), but which had failed to take into account their demands. An analysis of states where the existing government was overturned apparently denotes a high correlation with groundwater use. The issue of electricity reforms (mostly financed by either World Bank or Asian Development Bank, and which entailed removal of electricity subsidy for agriculture) had been at the forefront of farmer's unrest in these states during the months prior to the election. Indeed, the new Chief Minister of Andhra Pradesh state promised free electricity to the farmers on the very day he took the oath of office, and the Chief Minister of neighboring Tamil Nadu followed suit in the ensuing hours.

Conclusions

A spectacular increase in groundwater use for irrigation has taken place in arid and semiarid countries over the last few decades. This development can be described as a "Silent Revolution," carried out by millions of independent farmers, often with no planning or control on the part of governmental authorities.

The popularization of the submersible pump, together with the wide availability of cheap well-drilling techniques and the advances in hydrogeology, has made this possible. However, the Silent Revolution is largely a market-driven phenomenon, since groundwater-irrigation costs represent only a small fraction of the *guaranteed* crop value. This has been an important source of benefits, including the socioeconomic transition of many modest farmers in developed and developing countries alike.

However, intensive groundwater use cannot be advocated as a panacea to solve the world's water problems: tailor-made solutions are required to suit the needs particular to each place. The frequently chaotic nature of groundwater development, coupled with the attitude of many water policymakers toward groundwater, have sometimes resulted in a series of unwanted environmental effects (water table depletion, groundwater quality degradation, land subsidence, or ecological impacts on aquatic ecosystems). Although sometimes exaggerated, these adverse effects pose relatively small threats in most places (given the large storage volume of most aquifers and the mentioned social transition). However, assertive action on the part of governments and thorough stakeholder education is required in order to ensure a mid- or long-term sustainable management of the resource.

A world-scale assessment of the relative social and economic value of surface and groundwater irrigation would probably change some pervasive (and obsolete) paradigms in integrated water resources management. In addition, it might constitute a significant step in avoiding potential sources of social conflict, and thus also in the path from confrontation to cooperation in adaptive integrated water resources management.

References

Alaerts, G., and Khoury, N. (2004). "Arsenic contamination of groundwater: Mitigation strategies and policies." *Hydrogeol. J.*, 12(1), 103–115.

Burke, J. J. (2003). "Groundwater for irrigation: Productivity gains and the need to manage hydro-environmental risk." *Intensive use of groundwater. Challenges and opportunities*, M. R. Llamas and E. Custodio, eds., Balkema, Lisse, The Netherlands, 59–92.

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

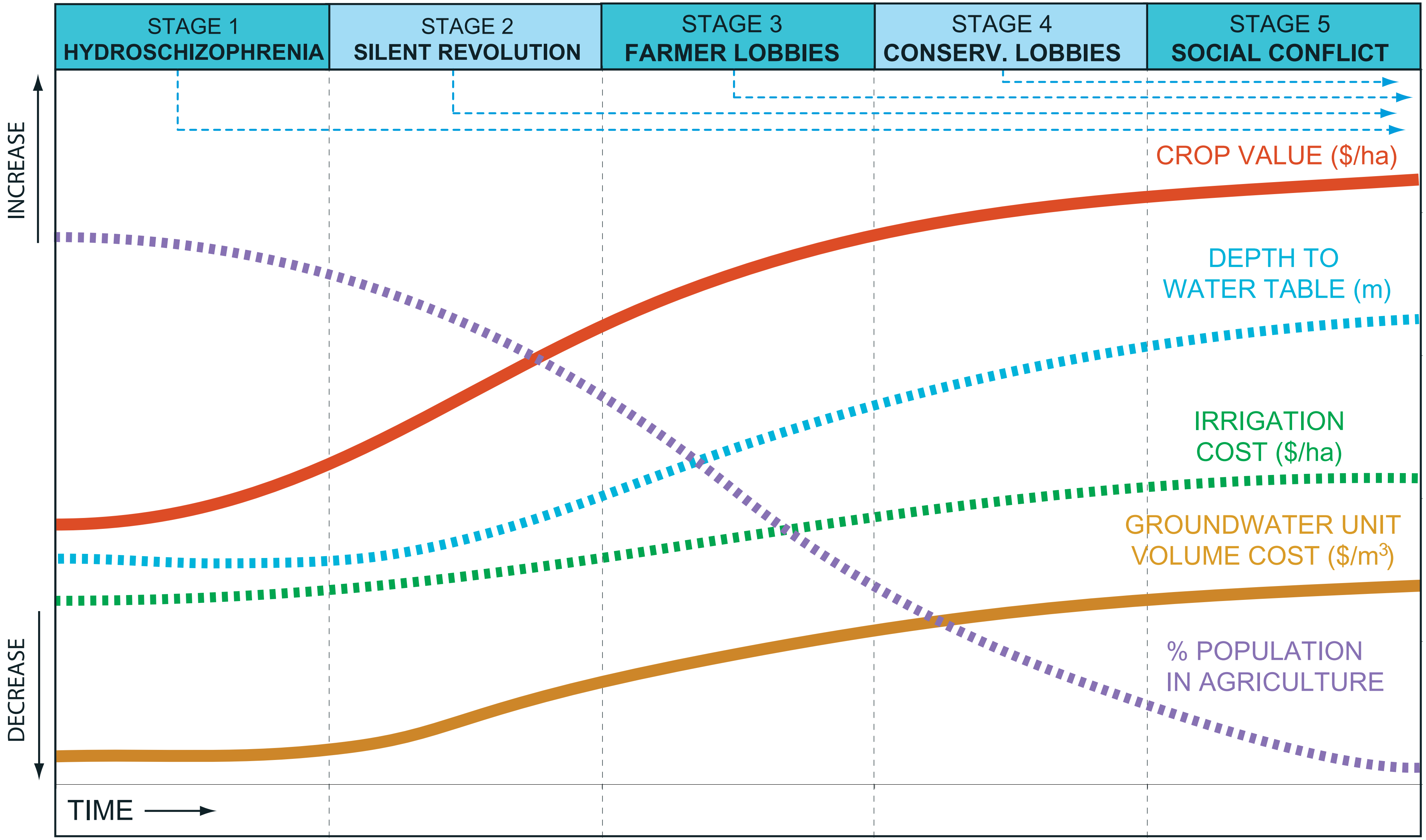
Hernández-Mora, N., Llamas, M. R., and Martinez Cortina, L. (2001). "Misconceptions in aquifer over-exploitation. Implications for water policy in Southern Europe." *Agricultural Use of Groundwater. Towards Integration between Agricultural Policy and Water Resources Management*, C. Dosi, ed., Kluwer Academic, San Diego, 107–125.

Kirshen, P., Vogel, R., and Rogers, B. (2004). "Challenges in graduate education in integrated water resources management." *J. Water Resour. Plan. Manage.*, 130(3), 185–186.

Llamas, M. R. (1975). "Non-economic motivations in ground water use:

Hydroschizophrenia." *Ground Water*, 13(3), 296–300.
Llamas, M. R., and Martinez-Santos, P. (2004). "Coping with the Silent Revolution of intensive groundwater use." *Proc. Int. Water Demand Conf. (CD-Rom)*, Dead Sea, Jordan, May 30–June 3.
Llamas, M. R., and Custodio, E., eds. (2003). *Intensive use of groundwater. Challenges and opportunities*, Balkema, Rotterdam, The Netherlands.
Llamas, M. R., and Martinez Cortina, L. (2002). "Groundwater irrigation and poverty alleviation." *Proc. IWRA Regional Symposium: Water for Human Survival*, 27–30 November, New Delhi, Central Board for Irrigation and Power, Vol. 2, 134–143.
Moench, M. (2003). "Groundwater and poverty: Exploring the connections," *Intensive use of groundwater: Challenges and opportunities*, M. R. Llamas and E. Custodio, eds., Balkema, Rotterdam, The Netherlands, 441–456.
Mukherji, A. (2004). "Is intensive groundwater use a solution to world water crises?" *Water crisis: Myth or reality? Proc. Santander Workshop*, P. Rogers and M. R. Llamas, eds., Organized by Harvard University, Complutense Univ. of Madrid, Marcelino and Botín Foundation, Balkema, Rotterdam, The Netherlands.
Palanisami, K., Vidhyavathi, A., and Ranganathan, C. R. (2004). "Wells: Welfare or illfare? Cost of groundwater overdraft in Tamil Nadu." Communication to the World Water Week, Stockholm 15–20 August, Preprint, Stockholm International Water Institute, Stockholm.
Polak, P. (2004). "Water and the other three revolutions needed to end rural poverty." Invited paper in the World Water Week, Stockholm 15–20 August, Preprint, Stockholm International Water Institute, Stockholm.
Sahuquillo, A., Capilla, J., Martinez-Cortina, L., and Sanchez-Vila, X., eds. (2004). *Selected papers of the Intenational Symposium on Intensive Use of Groundwater: Challenges and Opportunities*, Valencia, Spain, 10–14 December, Balkema, Dordrecht, The Netherlands.
Shah, T. (2004). "Groundwater and human development: Challenges and opportunities in livelihoods and environment." Invited paper in the World Water Week, Stockholm 15–20 August, Preprint, Stockholm International Water Institute, Stockholm.
Stakhiv, E. Z. (2003). "Disintegrated water resources management in the U.S.: Union of Sisyphus and Pandora." *J. Water Resour. Plan. Manage.*, 129(3), 151–154.
United Nations. (2003). "Water for people, water for life." UNESCO-WWAP, Paris.
Valencia Statement. (2004). *Selected papers of the International Symposium on Intensive Use of Groundwater: Challenges and Opportunities*, Sahuquillo et al., eds., Balkema, Dordrecht, The Netherlands, 399–400.
Vives, R. (2003). "Economic and social profitability of water use for irrigation in Andalusia, Spain." *Water Int.*, 28(3), 313–321.
Western Water Policy Review Advisory Commission. (1998). "Water in the West: Challenge for the next century." National Technical Information Service, Springfield, Va.

ROUGH (GROUND)WATER POLICY TRENDS IN ARID AND SEMI-ARID COUNTRIES



EXAMPLES	California (1920)	California (1930)	California (1950)	California (1980)	Spain
	Texas (1930)	Texas (1940)	Texas (1970)	Texas (?)	(Ebro Transfer, 2000)
	Arizona (1950)	Arizona (1960)	Arizona (1970)	Arizona (1980)	California
	Spain (1960)	Spain (1970)	Spain (1980)	Spain (1990)	(Bay-Delta Plan, 1999)
	India (1960)	India (1970)	India (1990)	India (?)	India
	Mexico (1960)	Mexico (1970)	Mexico (1990)	Mexico (?)	(Energy Subsidies, 2004)