Groundwater irrigation and its implications for water policy in semiarid countries: the Spanish experience

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Abstract Over the last decades, groundwater irrigation has become commonplace in many arid and semiarid regions worldwide, including Spain. This is largely a consequence of the advances in drilling and pumping technologies, and of the development of Hydrogeology. Compared with traditional surface water irrigation systems, groundwater irrigation offers more reliable supplies, lesser vulnerability to droughts, and ready accessibility for individual users. Economic forces influence the groundwater irrigation sector and its development. In Spain's Mediterranean regions, abstraction costs often amount to a very small fraction of the value of crops. In the inner areas, groundwater irrigation supports a more stable flow of farm income than rainfed agriculture. The social (jobs/m^3) and economic (€/m^3) value of groundwater irrigation generally exceeds that of surface water irrigation systems. However, poor groundwater management and legal controversies are currently at the base of Spain's social disputes over water. A thorough and transparent assessment of the relative socio-economic value of groundwater in relation to surface water irrigation might contribute to mitigate or avoid potential future conflicts. Enforcement of the European Union's Water Framework Directive may deliver better groundwater governance and a more sustainable use.

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Résumé Depuis les dernières décennies, l'irrigation avec l'eau souterraine est devenue commune dans plusieurs régions arides et semi-arides, incluant l'Espagne. Ceci est largement une conséquence due à l'avancement aux technologies de forages et des pompages, et au développement de l'Hydrogéologie. Comparé avec des systèmes traditionnels d'irrigation utilisant l'eau de surface, l'irrigation avec l'eau souterraine offre une technique d'alimentation plus fiable, une vulnérabilité à la sécheresse moins grande, et une accessibilité plus aisée pour chaque utilisateur. Les forces économiques influencent le secteur de l'irrigation par l'eau souterraine et son développement. Dans les régions de l'Espagne Méditerranéenne, les coûts d'exploitation représentent toujours une petite fraction de la valeur des cultures. Dans les régions intérieures, l'irrigation par l'eau souterraine supporte une agriculture plus stable et continue qu'une agriculture reposant sur l'eau de pluie. La valeur sociale (emploi/m^3) et économique (€/m^3) de l'irrigation avec l'eau souterraine, excède généralement celle des systèmes d'irrigation avec l'eau de surface. Néanmoins, des gestions pauvres de l'eau souterraine et des controverses légales sont couramment à la base de disputes sociales sur l'eau. Un bilan transparent et minutieux des valeurs relatives socio-économiques de l'eau souterraine en relation avec l'eau de surface d'irrigation, devrait contribuer à éviter de potentiels et futurs conflits. Un renforcement de la Directive Cadre de l'Union Européenne devrait apporter une meilleure gouvernance et un usage plus durable.

Resumen Durante las últimas décadas, la irrigación con agua subterránea se ha vuelto común en muchas regiones áridas y semiáridas alrededor del mundo, incluyendo a España. Ésta es en gran medida una consecuencia de los adelantos en las tecnologías de perforación y bombeo, y del desarrollo de la Hidrogeología. Comparada con los sistemas tradicionales de irrigación con agua superficial, la irrigación con agua subterránea ofrece suministros más fiables, la vulnerabilidad es menor a las sequías, y posee accesibilidad inmediata para los usuarios individuales. Las fuerzas económicas influyen el sector de irrigación con agua subterránea y su desarrollo. En las regiones mediterráneas de España, los costos de extracción suman a menudo una parte muy pequeña del valor de las cosechas. En las áreas internas, la irrigación con agua subterránea constituye un flujo más estable de ingresos para la

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granja, que la agricultura dependiente del agua lluvia. El valor social (empleos/m^3) y económico (€/m^3) de la irrigación con agua subterránea, generalmente excede a aquél con sistemas de irrigación de agua superficial. Sin embargo, la gestión pobre del agua subterránea y las controversias legales están actualmente en la base de las disputas sociales en España acerca del agua. Una evaluación completa y transparente del valor socio-económico relativo de agua subterránea respecto a la irrigación con agua superficial, podría contribuir mitigar o evitar los conflictos potenciales del futuro. La entrada en vigor del Marco Reglamentario de Agua de la Unión Europea, puede conllevar a una administración mejor del agua subterránea y a un uso más sostenible.

Keywords Irrigation · Groundwater management · Groundwater economics · Water policy · Spain

Introduction

Intensive groundwater use for irrigation in most arid and semiarid regions has experienced a spectacular increase over the last four decades. This development, considered by some a "Silent Revolution," has been carried out mainly by modest individual farmers, often with little planning and control on the part of governmental water authorities (Llamas and Martinez-Santos, in press).

Intensive groundwater irrigation has given rise to abundant social and economic benefits in Spain. However, poor management has all too often been the cause of certain unwanted effects, including groundwater quality degradation and other ecological impacts. Usually overlooked by water decision-makers and the general public, these matters are at the very heart of Spain's current debate over water resources.

The aim of this paper is two-fold. First, to analyse the economic significance of groundwater irrigation in Spain and to review the factors that explain its relative strengths; and second, to provide an overview of the role played by groundwater in Spain's water policy. Note that a distinction has been made throughout this paper between surface and groundwater irrigation. Wherever this difference is not specified, the authors refer to irrigation in general.

Groundwater irrigation in Spain: an economic analysis

Save for a few exceptions, groundwater irrigation in Spain and around the world is driven by market forces and the private economy. Small or large entrepreneurs take the risk to invest in a drilled well, a pumping set and irrigation equipment. Contrary to the process followed in large surface irrigation schemes, driven by intense supply policies, groundwater irrigators respond individually or collectively to opportunities identified in the food markets. It is the demand of consumer goods that drives the decision of thousands of farmers to become groundwater irrigators. Little wonder, then, that groundwater use is overall more efficient than surface water irrigation. The aim of this section is to provide an overview of the Spanish groundwater irrigation sector, discuss its key economic elements and offer an economic interpretation about the future challenges for sustainable management.

Spain's groundwater irrigation sector (SGIS, hereafter) represents 27% of the 3.3 M ha (M=million) of total irrigated acreage. About two-thirds of the SGIS are located in the Mediterranean or southwest regions, and one third in the Castillian plateau (central Spain). With rough measures, one can think of two types of agricultural regions within SGIS: one endowed with a mild Mediterranean climate, and another located in regions about 500 m above sea level and subject to a much shorter window of adequate physiological temperatures for crop production, which can be referred to as Continental Spain, as opposed to the Mediterranean and Coastal regions.

The economic processes governing these two types of SGIS are entirely different. On all social and economic calculations, agricultural productivity differs by at least one order of magnitude.

With comparatively much better climate than most other European countries, the Mediterranean SGIS behaves as dynamically as any other industrial sector. As an example, consider the Atlantic coastal areas of Huelva (Fig. 1). This region is one of the largest world producers of strawberries, second only to California, USA. Just when the sector became mature and stable, growers began to grow raspberries in response to increasing strawberries supplies in Poland and southern Italy. By the time the value of crops is close to 40,000 €/ha, strawberries are considered too risky and growers start moving to a new crop. The citrus industry follows a similar, albeit less evident trend. If a variety of oranges does not get good response in France, UK or Germany, then growers graft an entirely new variety. For the first time in history, Spain is exporting 100,000 tonnes of mandarins to the US, overcoming US trade barriers based on claims of found traces of larvae insects found in 2001 shipments. Groundwater-irrigated productivity ranges from 4 €/m^3 with pepper and tomato to less than 0.2 €/m^3 with field crops like corn, sunflower or cereals. Labour demand may range from 300 man-days per ha for peppers and tomatoes to 10 man-days in field-extensive crops. Full groundwater irrigation costs represent between 2 and 15% of direct costs of crop production. The price signal needed to deter irrigators' water consumption is nearing the cost of desalinised brackish waters, at 0.25–0.30 €/m^3.

Citrus and strawberries are just two examples of the factors driving groundwater demand in the Mediterranean region. Questions have been raised as to the social and environmental sustainability of this intensive mode of crop production (Arrojo 2001). While labour markets are tight in the regions, growers have organised their own contractual arrangements to hire workers from Poland, Morocco, or Latin American countries. Past social tensions resulting from poor immigrants' integration or inadequate living conditions are now milder. Environmental constraints are

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Fig. 1 Geographical setting of peninsular Spain's administrative basins

also beginning to be taken into consideration, as a result of the awareness of European consumers and the large food retail European companies. More than half of the fruits and vegetables export from Spain to the European Union (EU) take place through contractual agreements with the retail companies. These in turn request products for which a complete traceability record can be provided, with information regarding all cropping and environmental management practices. Tesco, a giant British food retailer, inspects the farms from which products are shipped.

In short, the economic forces of the Mediterranean SGIS can only be stopped if, and only if, more competitive water users eventually displace irrigators by means of financial agreements. This has occurred in the Canary Islands, where the tourist sector has purchased from growers a significant part of their water rights. Yet in mainland Spain, Mediterranean SGIS keeps its momentum, despite the appearance of significant water table drops, lowered extracted water quality and the pressing demands of the tourist and urban sectors. Nothing seems to deter irrigators from keeping their productive activity. As long as urban needs are fully met and the tourist industry can be supplied with desalinised water, it is safe to assume that groundwater-irrigated agriculture will maintain its prominence.

Consider now SGIS located in the Continental or interior regions of Spain, encompassing an area of 360,000 ha. In most of them, the window free of days of temperatures below freezing lasts only 4 months (from June to September). Crops are harvested when all other European growers harvest their crops as well. There is little comparative advantage in irrigating all crops, and for many of them there are comparative disadvantages. Yet, about half of Spanish total irrigated acreage shares these features.

In the Continental areas surface water is supplied for irrigation at a very low price (between 0.01 and 0.02 €/m^3).

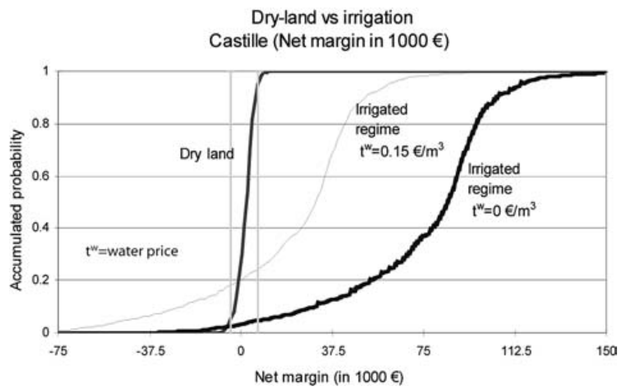

Fig. 2 Net margin measures of dry-land and groundwater-irrigated Castillian farms (cumulative distribution functions). Modelling assumptions given in Appendix 1

This partly explains why surface irrigation dominates in the interior regions of Spain. The other explanation is that the farm support granted by the EU Common Agricultural Policy (CAP) represents about 50% of the total farmers' revenue. Cheap surface water, cost recovery rates of 10–20% and lavish farm subsidies explain why 2 M ha of irrigated land has a market value that doubles or triples that of dry-land in Spain.

Yet, there are additional economic factors that explain the demand for irrigation in Continental Spain. One is that irrigation is an effective risk-reducing instrument to manage crop-yield risks. Risk reduction effects are shown in Fig. 2, which provides stochastic simulation results for two Castillian farms, representative of Continental Spain, under various hypotheses (Garrido 2004). Random variables include crop yields and price, with probability density functions estimated from real observed data (Appendix 1 provides details of the modelling assumptions). Figure 2 represents the cumulative distribution of farmers' net margins. It shows

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Table 1 Land values of dry-land and groundwater-irrigated vineyards and olive trees

Source: MAPA (2004)

[a]Compared with dry-land values. Assuming annual applications of 3,000 m^3/ha in vineyards and 4,000 m^3/ha in olive trees

	Land prices (€/ha)				Water implicit value (€/m^3)[a]	
	Dry-land		Groundwater irrigated			
	2001	2002	2001	2002	2001	2002
Vineyards	11,677	12,559	17,483	18,760	1.94	2.07
Olive trees for olive fruits	11,274	11,328	23,458	23,198	3.05	2.97
Olive trees for olive oil	16,099	16,162	31,759	32,343	3.92	4.05

that irrigation farming at a water price (t=0.15 €/m^3) is still more preferred than farming under a dry-land regime (rainfed), even if water prices are raised to meet full cost recovery criteria. Even if subsidised water prices were priced at full, or nearly full, cost recovery rates, farmers would prefer to keep their irrigation operations than to convert their farms and run them under dry-land regimes. As groundwater costs are significantly lower than 0.15 €/m^3, the low and unstable productivity of rainfed agriculture makes irrigation water a valuable resource as a risk reduction mechanism.

However, the importance of SGIS in continental Spain cannot be fully grasped from Fig. 2, which does apply only to a generic irrigation farm. There are two crops that are the champions in groundwater-irrigated acreage growth within Continental Spain: olive trees and vineyards. As shown in Table 1, a simple inspection of the land values of these two crops, both rainfed and irrigated conveys a clear idea of the strength of the SGIS, as these crops are primarily irrigated from groundwater sources.

Land market prices show that having rights to water multiplies the value of land by a factor of 1.5 in vineyards and 2 in olive trees. These values are capitalised in an implicit water value that is well above 2 €/m^3, and can go up to 4 €/m^3.

Many authors have established a connection with farm subsidies and irrigation water demand (see among them, Iglesias and Blanco 2004; Iglesias et al. 2004; Arriaza et al. 2003). Figure 3 shows another set of simulation results that combine the effects of the farm subsidies and two water price levels. The utility measures shown are based on following standard formulation of agent's risk preferences U(NM), according to the exponential function:

$$U(\mathrm{NM}) = \frac{\mathrm{NM}^{(1-rr)}}{1-rr}$$

where NM is the farmers' total (stochastic) net margin, including market and policy receipts, and rr is the relative risk aversion coefficient. Further, $rr=2$ is assumed since the literature suggests this value falls within a plausible range of coefficients of relative risk aversion between 0 and 4 (Appendix 1 provides more details).

The results show that, indeed, the elimination of farm subsidies has a larger impact on the farmer's utility than the rise of water prices. Since EU farm subsidies have become completely decoupled from (or 'not related to') crop-productivity in 2005 (European Commission 2003), the economics of SGIS will be more guided by the relative productivity of crops and water accessibility than by the relative farm subsidies granted to the crops themselves. Farm subsidies will deliver a less distorting form of support. As Fig. 3 shows, the elimination of coupled payments will exacerbate the marginal impact of water prices and marginal productivity of water (two left lines are more separate than the right lines). Resource price signals will

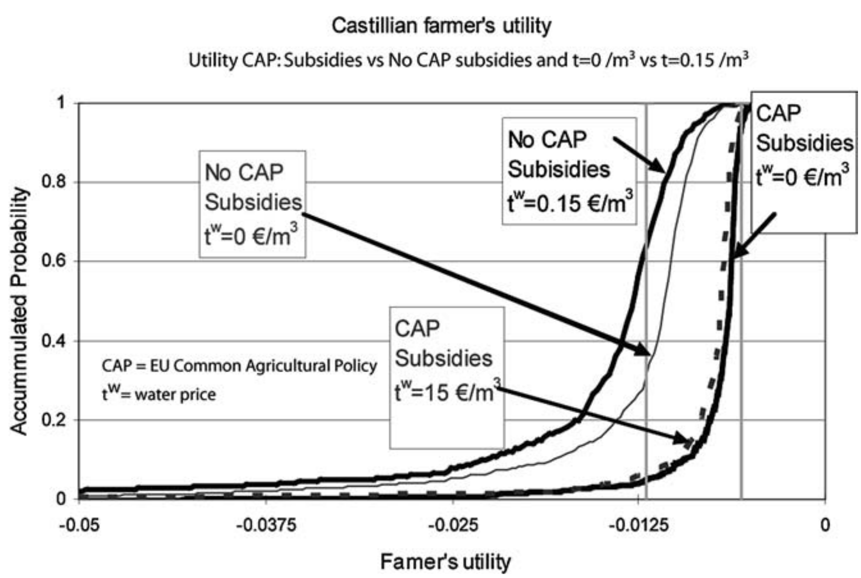

Fig. 3 Utility measures of dryland and irrigated Castillian farms with farm subsidies and water price variations (cumulative distribution functions)

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Table 2 Comparison of irrigation using surface and groundwater in Andalucía

Indicator	Origin of irrigation water			
	Groundwater	Surface water	Total	Ratio groundwater to surface water
Irrigated surface (10^3 ha)	210	600	810	0.35
Average use at origin (m^3/ha/year)	4,000	7,400	6,500	0.54
Water productivity (€/m^3)[a]	2.16	0.42	0.72	5.1
Employment generated (EAJ/10^6 m^3)[b]	58	17	25	3.4

[a] 1 € ≅ US$1.3

[b] Equivalent annual job (EAJ): full time work for one person during one year

be clearer and water saving technology adoptions, coupled with more environmentally friendly production techniques, will be encouraged. Once again, this will reinforce the role of groundwater as a key resource for precision farming and for ensuring more control over all crop growth factors.

Two other ways highlight the importance of the SGIS: the value of the crops and labour demand. Few studies compare the social and economic efficiency of surface and groundwater irrigation. However, those that do, point to a higher socio-economic productivity of groundwater-irrigated agriculture. Table 2 shows the results of a study carried out in Andalusia, southern Spain (Hernández-Mora et al. 2001). The table shows the average economical productivity of groundwater irrigation is five times greater than surface water's. In addition, groundwater irrigation was observed to generate three times as many jobs.

Generally, groundwater farmers usually present a more entrepreneurial mindset, as bearing the full direct cost of well-drilling, pumping and maintenance often requires a considerable investment. This is a significant incentive to minimize water use and maximise production, something that is achieved by switching to high-value water-efficient crops. In contrast, surface water farmers usually receive highly subsidized water at a much lower cost, so their incentive to invest in more efficient irrigation technologies is not as significant. This may explain why water productivity is higher for groundwater irrigation.

In relation to the number of jobs per cubic meter, it is perhaps the high degree of mechanization of modern extensive agriculture in comparison with intensive cropping that explains the difference. A study by Corominas (2004), states that about 50,000 m^3/year are required in order to generate one job in surface water irrigated extensive cropping (rice or cotton). In contrast, only 5,000 m^3/year are required for groundwater-based intensive greenhouse agriculture.

The figures in Table 2 were confirmed by an analysis carried out by Andalusia's regional government in 2002 (Vives 2003). Such analysis was based on average water volumes applied in each irrigated unit or land plot, while water losses due to transportation from the source (generally from a reservoir) and excess irrigation return flows (only significant in the case of surface water) were not estimated. Other studies had calculated the volume used in surface water irrigation as the water actually withdrawn from reservoirs. The White Book of Water in Spain (MIMAM 2000) estimated an average consumption of 6,700 m^3/ha/year and 6,500 m^3/ha/year for the two catchments of the Andalusia study, without differentiating between surface and groundwater irrigation. With these new figures and the volumes given for groundwater irrigation, the more realistic average of 7,400 m^3/ha/year can be estimated for surface water irrigation.

It could be argued that a certain part of the surplus surface water applied for irrigation is not lost, since it recharges the aquifer or ends up joining downstream surface water courses. This is only partially true. There are evaporation losses that cannot be recovered. In addition, the quality of that water, which recharges the aquifer, is worse than that of the surface water applied in irrigation. Take for instance the Segura basin, Spain, where headwaters present salinity levels of 0.5 g/l. Recycling results in a ten-fold increase of this salinity by the time the river gets to the sea.

Therefore, it is the view of the authors that the economics of SGIS evolve over strong economic foundations. So, as it will be seen, it is difficult to stop the growing irrigation demand for groundwater. The challenges ahead of SGIS are primarily connected to the implementation of the EU Water Framework Directive (WFD: European Union 2000) and to reversing the deterioration of the resource base. As the Directive only establishes the deadlines and goals, each EU Member State will have to pursue its own policies towards those ends. Livingston and Garrido (2004) argue that "Finely tuned policy reforms that succeed are those that manage to redefine the rights structure accordingly to the following criteria. First, current users are given more security over fewer rights in return for surrendering some use rights that are threatened by resource deterioration; second, established users are given a larger proportion of secured rights than more recent users; third, the transition spans a sufficiently long time path; and fourth, society as a whole is persuaded of the need for the existing rights structure to change. Variations in this scheme of redefinition are common in the most successful reforms, perhaps because they integrate aspects related to intra-generation equity based on users' seniority, and inter-generational equity in the form of an extraction path that leads to more sustainable use patterns" (p. 4).

Role of groundwater irrigation in Spain's water policy

It has been shown that groundwater irrigation is a key parameter in the economy of thousands of Spain's farmers.

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In contrast, traditional bias in Spain's water authorities towards large infrastructures is probably the main reason why groundwater issues remain unknown to the general public. As a result, groundwater irrigation currently acts as an "invisible" (although significant) driving force in Spain's water policy. Llamas and Martínez-Santos (2005) showed this to follow a five-stage pattern, seemingly common to most arid and semiarid regions worldwide:

Stage 1. Hydroschizophrenia This term, coined by American hydrologist R. Nace (Llamas 1975), refers to a widespread attitude among water decision-makers, who usually due to the lack of an appropriate mindset, play down the role of groundwater in relation to traditional surface water infrastructures (Llamas and Custodio 2003, Sahuquillo et al. 2004). In Spain, this phenomenon is deeply rooted in the nineteenth century, and in strong connection with Spain's centralized water governance system (Llamas 1985).

Stage 2. Silent Revolution Aquifer resilience against drought and the ready availability of water on demand are perceived by farmers as important advantages in relation to water supply, as these remove the otherwise significant economic uncertainties (as shown in the previous section). Thus, independent farmers usually drill their own wells, sometimes stimulated by soft loans from the government, but often with no planning or control on the part of water authorities. Encouraged by the prospect of enhanced revenues, farmers soon begin to switch to high value crops and more efficient irrigation technologies. The role of government in this stage is very limited, although recognition of the threats of uncontrolled water use rates eventually gives rise to legal initiatives.

Stage 3. Farmer lobbies As farmers become wealthier and better educated, they form strong lobbies to protect their own interests. As water table depletion or particularly groundwater quality degradation becomes an economic issue (i.e. leads to a decrease in crop value), farmer lobbies press the government for surface water transfers from other basins. The number of jobs at stake, directly and indirectly connected to agriculture, is often placed as the primary project benefit (MIMAM 2000). Lobbies' efforts are also meant to preserve farmers' wealth, in the form of their land values. Water transfers are usually to be built with public funds, prior to clearly identifying the beneficiaries, and large infrastructures are usually planned under grossed assumptions about their water demands, farmers' ability (or willingness) to pay, and unsound project finance (Arrojo 2001).

Stage 4. Conservation lobbies Conservation groups and farmers from potential water exporting basins form their own counter-lobbies. These are driven by environmental, political and/or economic agendas, and clash with those advocating large infrastructures. Very often these lobbies point to the disarray of groundwater governance in the transfers' recipient areas. As a result of stages 3 and 4, a vast array of studies, analyses and projects is given a significant push from all opposing camps.

Stage 5. Social conflict In order to gain support, opposing factions usually take advantage of emotional terms such as "solidarity", "thirst" or "rightful ownership of water". As a result, citizens easily feel cheated of their rights, and social conflicts may arise. Paradoxically, groundwater is seldom mentioned in these disputes. Yet the debate is framed within sounder scientific evidence, with increasing participation of world experts that are given assignments on partial aspects. Thus, water policy is brought to stalemate. In addition to the WFD, that came into force despite Spanish opposition, no national policy initiative has been brought to any substantial achievement since the 1985 Water Act.

As the above stages take place, changes in a series of key variables can be observed (Fig. 4). Intensive groundwater

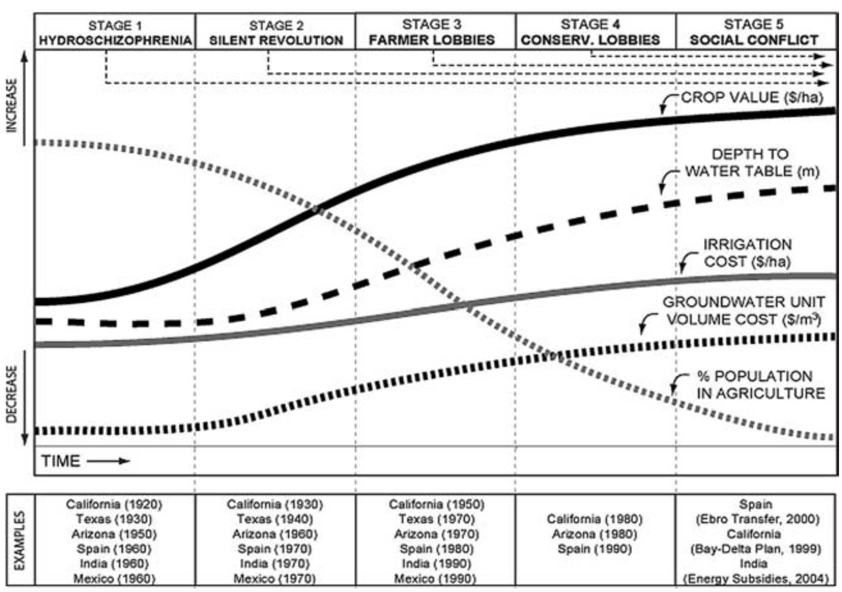

Fig. 4 Expected trends in socioeconomic aspects of groundwater use in arid and semiarid countries (source: modified from Llamas and Martinez-Santos 2005)

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use leads to an increase in depth of the water table. Abstraction costs increase with depth as more energy is required for pumping and drilling of deeper wells may be required. While irrigation cost also increases, it generally does so at a lower rate, since farmers tend to invest in better irrigation techniques. This is largely due to the resilience of aquifers against drought and the ready availability of groundwater (which remove uncertainties from farmer's perceptions), as well as to the dynamic nature of those farmers who seek their own sources of water and bear the full (direct) costs of drilling, pumping and distribution. Thus, as farmers become richer and more educated, they often switch to higher-value, lower water consuming crops (for instance, from corn or rice to grapes and olive trees). This process is likely to be reinforced when the EU farm support programmes are completely decoupled, and all present market distortions are removed beginning in year 2012.

This sequence is illustrated by two case studies in Spain: the Jucar and Segura river basins. However, similar examples may be found in places so diverse as California or India (Llamas and Martinez-Santos 2005; Mukherji, in press).

The Jucar River Basin and the Crevillente case

The Jucar River Basin (JRB) is Spain's main groundwater basin and "Pilot Catchment" for the implementation of the European Water Framework Directive (WFD) (Fig. 1). A large proportion of the basin's 43,000 km^2 is located within the Valencia Autonomous Community, a wealthy region renowned in Europe for the quality of its agricultural products. The JRB is home to almost 4.5 million people, peaking seasonally at nearly 6 million due to tourism.

Irrigation accounts for 80% of the JRB's water uses. An estimated 357,000 ha are currently under irrigation, out of which 200,000 ha rely exclusively and 26,000 ha partially on groundwater. A recent assesment of water economics in the Jucar basin, shows that below 10% of the economic costs of water services (abstraction, storage, regulation and conveyance) are managed by the Basin Authority, while over 90% are under private control (Estrela 2004). These figures show that, at times, the actual role of water authorities in Spain is limited. In contrast, farmers have a comparatively higher degree of control over water.

Many examples of intensive groundwater use may be found within the JRB, but the Crevillente case is particularly interesting. Crevillente is a small (100 km^2) karst aquifer located in the southern area of the JRB. Intensive groundwater agriculture, supplied exclusively through private wells, has taken place in Crevillente since the 1960s. Abstractions currently amount to 16–17 M m^3/year, very much in excess of the aquifer's estimated 0.5–2 Mm^3/year renewable resources (Bru 1993, and Corchón (Jucar River Basin Authority), written communication March 2004). Pumping is used to meet the needs of high-value exportable crops, i.e. table grapes. At an average irrigation dose of 3,500 m^3/ha/year, these crops used to yield an approximate

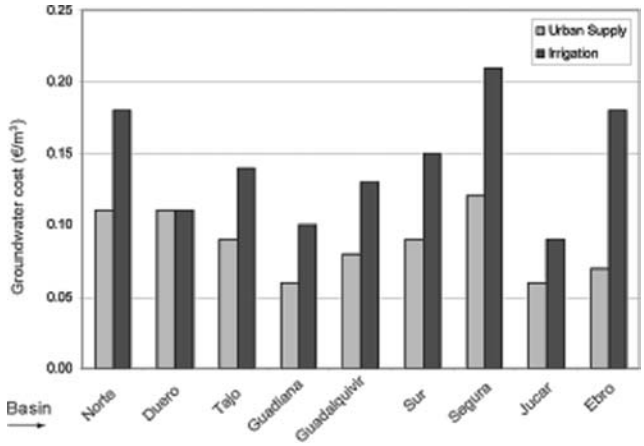

Fig. 5 Sectorial unit cost of groundwater in river basins controlled by Spain's Central Government (source: DGOH 2003)

value of 25,000 €/ha in the past, demanding more than 100 man-days/ha of labour.

Parallel to this, the water table was observed to drop at an average rate of 15 m/year in certain areas, at times plummeting 30–40 m within a single year (Pulido-Bosch et al. 1995). Unusually high rainfall led to a certain recovery in the late 1980s and early 1990s, but pumping depths currently seem to exceed 450–500 m in some sectors of the aquifer. In addition, intensive exploitation has shown that the aquifer is divided in five apparently independent units, some of which have experienced a degree of groundwater quality degradation (Andreu et al. 2002).

Such "environmental" effects in themselves would hardly be a matter of concern for farmers. However, there is also an economic reading. Pumping costs for irrigation in the Crevillente aquifer have increased to 0.29 €/m^3, way above Spain's 0.12 €/m^3 average (DGOH 2003, see Fig. 5). Besides, groundwater salinization has had a negative impact upon soil fertility. In consequence, crop value has gradually dropped from about 25,000 €/ha to 15,000 €/ha in the recent past. While the cost of water for irrigation has remained roughly constant (1,000 €/ha/year), it has increased proportionally from under 5% to almost 10% of crop value. Yet, as land without water is valueless, farmers will not be deterred by such productivity erosion.

Despite the spectacular nature of these figures, the social and economic system has not collapsed. However, economic and water quality issues have become increasingly pressing and pose a significant threat to the feasibility of crops. Crevillente farmers, together with farmers from small nearby aquifers and urban water supply companies, managed to obtain the approval of the Jucar-Vinalopo transfer (Jucar River Basin Authority 2004). The transfer's nominal conveyance capacity was 90 Mm^3/year, and the total investment approximately 230 M€ (two-thirds of the transfer was to be afforded by public funds from the European Union and Spain's Central Administration, while the beneficiaries would have to pay the rest). The feasibility of this transfer has been the source of bitter conflicts between scholars, environmental conservation lobbies, politicians

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and farmer associations in the recent past, to the point that its future is now uncertain.

The Segura River Basin

The Segura River Basin (Fig. 1), home to 1.5 million people, is one of the most interesting cases of water conflicts in Spain, and perhaps worldwide. Water scarcity has traditionally been perceived as one of the main drawbacks for the economic development of this region, known as "Europe's orchard". Two dozen reservoirs, with a total storage capacity of 1,000 Mm^3, have been built within this catchment since the Spanish Civil War (1936–1939). These have contributed to mitigate the catastrophic consequences of flash floods, but have not been able to meet irrigation demands. In fact, since the 1960s the Segura River Basin (SRB) has been one of Spain's most active catchments in terms of groundwater irrigation.

Until recently, agriculture and agro-industries have been the main revenue-generating activities in the SRB. Although tourism has now taken over, groundwater irrigation has been one main reasons behind the wealthy status the region currently enjoys. As a result, farmers maintain a strong political and social relevance.

In the 1970s, the 300 km Tajo-Segura transfer was built in order to meet SRB's increasing water demands. Since the transfer became operational, and despite its nominal conveyance capacity being 1,000 Mm^3/year, only an average 400 Mm^3/year has been transferred. This volume has been seemingly insufficient to meet the needs of SRB farmers. In 2001, strong social and political pressure led to the approval of the 1,000 km Ebro transfer to the Mediterranean region. About 45% of the transfer's 1,050 Mm^3/year was allocated to the SRB.

Ebro basin farmers, conservation lobbies and a number of scholars also played their role. Demonstrations against the Ebro transfer took place in Zaragoza and Brussels (Belgium). As a result, water allocation became an important issue in the months prior to Spain's 2004 general election. The Ebro transfer was finally overruled following democratic government overturn. In addition, the future of the operational Tajo-Segura transfer has become uncertain under the current political situation. These new events have led to widespread political controversy even within regional governments of the same political party, not to mention the social unrest between water-importing and water-exporting regions (Llamas and Pérez-Picazo 2002).

Governance issues arising from the legal ownership of groundwater

Although seldom mentioned in the public arena, poor groundwater management and the complex legal controversy over groundwater rights in Spain is at the very root of these conflicts. This is best summarised in the words of Sánchez (2003), Chief of the Groundwater Resources Area of the Directorate of Water Works and Quality of the Ministry of the Environment: "the economic growth of the country and outdated legislation (. . .) has raised important problems of unsustainable groundwater use which still remain unsolved. Eradication of groundwater overdraft will require an unusual endeavour on the part of water authorities".

Until 1985 groundwater rights were governed by the 1879 Water Act: whoever drilled a well *ipso-facto* obtained private property rights over the water. In contrast, the 1985 Water Act declared groundwater a public property. While this might appear an evident change in groundwater rights, it is in fact not so significant, as it only really applies to a minority of wells (those drilled after 1986). The rest could choose between keeping groundwater in private property (but without administrative protection under the 1985 Act) or surrendering their rights to the State (thus receiving administrative protection and the possibility to continue using their wells in similar conditions for a 50 year period). In order to do either, well owners had to apply to the "Catalogue of Private Waters" or the "Public Water Registry" respectively.

The application deadline of the Registry was set for 31 December 1988, while the 2001 National Water Plan Law closed the Catalogue. Moreu (2002) estimates that only 10–20% of the wells drilled prior to 1985 were inscribed in either. As a result, the legal situation of hundreds of thousands of wells in Spain is currently uncertain.

Spain's *White Book of Water* (MIMAM 2000), described the situation of groundwater rights as "very discouraging", stating that just below 250,000 wells had been declared while "The total number of wells could total over a million (. . .) giving an idea of the importance of groundwater resources". Llamas et al. (2001) estimated the total number of wells at 2 million, taking into account those drilled in areas of Spain where groundwater use had traditionally been considered irrelevant, like Galicia (Samper 2000) or the Greater Madrid.

Further to these issues, a new phenomenon has arisen since 1985: illegal wells. The President of the Guadiana Basin Authority acknowledged the existence of 25,000 illegal wells only within 16,000 km^2 of his jurisdiction (Rodríguez de Liébana 2002). Many (perhaps most) wells are drilled today without the preceptive authorisation from River Basin Authorities. Their officers in turn often lack the appropriate mindset, means and support to manage groundwater resources adequately.

Remedial actions, such as the ARYCA program (1995) and later the ALBERCA program (2002), have been launched by the government in the last decade. While an interesting step ahead, the former fell well short of the expectations. The later is probably insufficient in terms of scope, as it seems to ignore those wells that are still undeclared (Fornes et al. 2005).

An obvious first step towards solving the problem would be to compile a complete inventory of wells. Llamas et al. (2001), taking into account Spain's well density and aquifer features, and the legalization costs assumed by the ARYCA program, estimated this might cost 420 M€. This would exceed the joint budgeted amounts of the ARYCA (42 M€) and ALBERCA (155 M€) programs. However, this investment, would only represents the cost of 2–3 medium size

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dams out of the over one hundred foreseen by the 2001 National Water Plan Law to be built within the next eight years. Moreover, this investment appears a necessity, given that groundwater development is probably responsible for about half of Spain's irrigated production (Llamas 2004).

Conclusions

Like many other arid and semiarid regions worldwide, Spain has experienced a spectacular increase in groundwater use in irrigation over the last decades. Groundwater irrigation, mostly driven by market forces and the private economy, seems to present a much higher socio-economic efficiency (€/m^3 and jobs/m^3) than supply-based surface water irrigation. This is largely due to the lesser vulnerability of groundwater during drought periods and its ready availability on demand.

Despite the economic importance of groundwater-irrigated agriculture, farmer-scale development has not been coupled with an adequate management on the part of governmental water authorities. Groundwater development has therefore taken place in a chaotic manner, mostly through the initiative of individuals, with little or no planning and control on the part of water authorities. Complex legal and administrative controversies have arisen as a result, and remedial actions have failed to fulfil their objectives. As a result, the legal stand of hundreds of thousands of wells across the country is currently uncertain at best. Although seldom mentioned, these issues are at the very base of Spain's current conflicts over water transfers.

History in Spain shows that compensatory vehicles based on transferring water across basins to alleviate unsustainable groundwater use patterns are likely to fail. New supplies create their new own demand, and past groundwater users are reluctant to become contractors of new infrastructures in return for surrendering their groundwater rights, unless water access or water quality become seriously impaired. Making these rights clearer will have a two-sided effect. On the one hand, government agencies will be able to exert more control and reinforce their surveillance systems. On the other hand, groundwater rights, tradable since the 1999 Water Act reform, will become more solid assets. As water becomes more scarce and valuable, the market price of groundwater rights will tend to grow and fewer farmers will be inclined to surrender them in return for becoming beneficiary of a surface water project. These two effects provide a context that is vulnerable to a 'prisoners' dilemma' or 'tragedy of the commons' (Hardin 1968), by which farmers may not co-operate to achieve the most efficient outcome. If one farmer surrenders his groundwater rights, he makes a contribution to a more sustainable use pattern which is enjoyed by those that refuse to do so. So there is no incentive to switch to surface waters unless these are supplied at a very low cost. But this in turn creates a new demand, so reinforcing the problem.

Another factor of likely significance is the reforms of the European Union farm programmes starting in 2012. As income support will be fully decoupled from production and farmers' acreage decisions, the role of groundwater irrigation will probably become even more crucial to Spain's water policy than this paper has shown.

Compiling an inventory of wells would be an obvious (and affordable) first step towards addressing groundwater-related problems in Spain. Yet, even if all wells are recorded and eventually registered, there will be serious pending challenges to meet the obligations imposed by the European Union Water Framework Directive to Member States. Particular attention must be paid to those relative to participatory aquifer management and to the likely groundwater abstraction cuts required for environmental purposes. These issues, together with the significance of groundwater irrigation in Spain's water policy, call for a more proactive action on the part of governmental agencies.

Appendix 1. Modelling for the stochastic simulations

Let $f_i(q_i)$ and $g_i(p_i)$ be the probability density functions of crop i's yields and market price. These functions have been estimated using @Risk software from observed yields and recorded prices. Assume a representative farm of the area devotes h_i hectares to crop i. Stochastic net margin (NM) is defined by:

$$\mathrm{NM} = \sum_i h_i[(f_i(q_i)g_i(p_i)) - C_i - t^w W_i + EU_i]$$

Where C_i is the cost (per ha) for crop i; t^w is the water price in (€/m^3), W_i is the regular water consumption of crop i per ha (mm); $\mathrm{EU_i}$ represents subsidies (per ha) granted by the European Union's Common Agricultural Policy in 2002. The results plotted in Fig. 2 result from the simulation of the above model using the density functions $f_i(q_i)$ and $g_i(p_i)$, and other farm parameters obtained by the authors in field work.

Figure 3 reports the results of the simulations in the form of standard utility measures. Under stochastic economic returns, a utility function of the form shown in the text implies that individuals place relatively more importance on losses or adverse results than on favourable results, which is consistent with most people's preferences. The four plotted curves result from the combination of two scenarios (present EU Common Agricultural Policy subsidies vs. no subsidies) and (t^w=0 €/m^3 vs. t^w=0.15 €/m^3).

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