

## Groundwater intensive use and mining in south-eastern peninsular Spain: Hydrogeological, economic and social aspects



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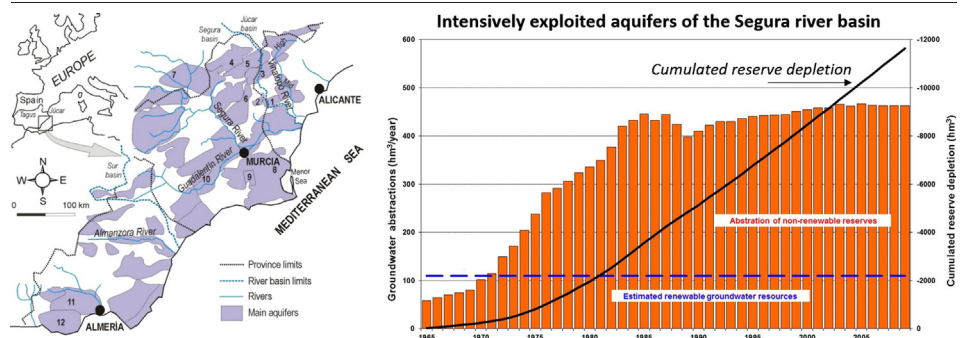
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### HIGHLIGHTS

- Intensive use and mining of groundwater allow social development.
- Groundwater mining is not sustainable, but is a valuable transient water resource.
- Groundwater mining in south-eastern Spain is estimated to be 15 km<sup>3</sup>.
- Groundwater mining is not compatible with the European Water Framework Directive.
- The intensive and mining uses of groundwater involve ethical and moral problems.

### GRAPHICAL ABSTRACT



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### ABSTRACT

Intensive groundwater development is a common circumstance in semiarid and arid areas. Often abstraction exceeds recharge, thus continuously depleting reserves. There is groundwater mining when the recovery of aquifer reserves needs more than 50 years. The MASE project has been carried out to compile what is known about Spain and specifically about the south-eastern Iberian Peninsula and the Canary Islands. The objective was the synthetic analysis of available data on the hydrological, economic, managerial, social, and ethical aspects of groundwater mining. Since the mid-20th century, intensive use of groundwater in south-eastern Spain allowed extending and securing the areas with traditional surface water irrigation of cash crops and their extension to former dry lands, taking advantage of good soils and climate. This fostered a huge economic and social development. Intensive agriculture is a main activity, although tourism plays currently an increasing economic role in the coasts. Many aquifers are relatively high yielding small carbonate units where the total groundwater level drawdown

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may currently exceed 300 m. Groundwater storage depletion is estimated about 15 km<sup>3</sup>. This volume is close to the total contribution of the Tagus-Segura water transfer, but without large investments paid for with public funds. Seawater desalination complements urban supply and part of cash crop cultivation. Reclaimed urban waste water is used for irrigation. Groundwater mining produces benefits but associated to sometimes serious economic, administrative, legal and environmental problems. The use of an exhaustible vital resource raises ethical concerns. It cannot continue under the current legal conditions. A progressive change of water use paradigm is the way out, but this is not in the mind of most water managers and politicians. The positive and negative results observed in south-eastern Spain may help to analyse other areas under similar hydrogeological conditions in a less advanced stage of water use evolution.

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## 1. Introduction

The continuous depletion of groundwater reserves – groundwater mining – is a real fact since decades ago in arid and semiarid areas, where water is mostly used for irrigated agriculture. Groundwater depletion reaches such an important volume that storage changes can be detected in the landmass of a wide number of water stressed countries by using time series of accurate gravity measurements with GRACE satellites (Rodell et al., 2009; Famiglietti et al., 2011; Famiglietti, 2014; Richey et al., 2015). According to Konikow (2011), global groundwater depletion during 1900–2008 is estimated on ~4500 km<sup>3</sup>, and may explain 12.6 mm of sea level rise. There is fairly literature on recent regional estimates of groundwater depletion from GRACE (started in 2002), but scarce long-term data series are available and a more local scale data are needed for model calibration (Konikow, 2015). Spain occupies 14th place among the countries with higher rates of groundwater depletion (Wada et al., 2012), and the third in Europe. Some of the Spanish aquifers are among the first ranking cases worldwide (Werner et al., 2013). Other world surveys can be found in Wada et al. (2012), and Margat and van der Gun (2013).

To compile what is known about groundwater mining in Spain, the MASE project has been carried out between 2013 and 2015. MASE is the Spanish acronym of *Minería del Agua Subterránea en España* (Groundwater Mining in Spain). It is not a research but a compilation of knowledge project. The main objective is to analyse and comment existing information on groundwater mining in Spain. Specific studies and surveys have not been carried out. The results are available in a detailed report (Custodio, 2015) containing the general and specific data and the references. Published, unpublished and difficult-to-access reports have been used as well as the results of personal talks with selected local persons and the answers to a detailed technical questionnaire sent to experts. Often, non-coincident data and evaluations were found in the sources of information. The MASE project has been carried in the Technical University of Catalonia, with the economic contribution of AQUALOGY and the control of CETaqua. It largely benefited from the voluntary contributions of many public and private organizations, universities and experts.

The main objective of the MASE project is the evaluation of intensive exploitation and mining of groundwater from the hydrological, hydrogeological, economic, administrative-legal, social, and ethical points of view, using the available sources of information. It does not intend to contribute solutions nor proposes action to be carried out, but tries to show the current situation, its consequences, and the importance of benefits and costs associated to groundwater mining.

The MASE project specifically concentrates in the intensively groundwater developed areas in Spain where groundwater mining is more important: the South-east (Levante) of the Iberian Peninsula and Gran Canaria and Tenerife Islands, in the Canary Islands archipelago. This paper refers only to south-eastern Spain. Other aspects that are often related to intensive groundwater exploitation and groundwater mining, as seawater intrusion and salinization, and nitrate pollution of groundwater, have not been specifically considered. Comments about application of the results to other areas are briefly discussed in the conclusions.

The evaluations take into account the relevance of local conditions and the spatial variability of the very diverse factors involved. Hydrogeology is a basic factor that has to be adequately known, but often it is not the main one on social grounds. One of the goals is to go beyond local descriptions and analyses to derive knowledge that can be used to understand and evaluate other similar areas worldwide subjected to this kind of development.

This paper is organized differently than a typical research one as it is a compilation of results and facts. The different aspects of groundwater intensive development and mining are presented successively, from the hydrogeological to the social ones, passing through those referring to the environment and the economy.

## 2. General concepts

The consumption of groundwater reserves has been often the trigger of local economic and social development and provides an important input to local economy. However, the relevance of the contribution decreases with time due to increasing water costs, limits to groundwater reserve depletion, and sometimes water quality impairment.

The following concepts are used hereinafter. Intensive aquifer exploitation is produced when the natural behavior of the groundwater component has been significantly modified, as well as the relationships with other water bodies. Intensive aquifer development is accompanied by a decrease of groundwater reserves (Konikow and Leake, 2014), the capture of springs and surface water, and the reduction of discharge into wetlands. The associated changes evolve slowly, depending on the hydraulic properties of the aquifer and the location where groundwater is exploited (Custodio, 2002, 2012). Recharge under exploitation conditions (actual recharge) includes inflow induced from other water bodies and a reduction of evaporation and evapotranspiration from the saturated zone. Provided abstraction does not exceed actual recharge under exploitation conditions, groundwater reserves decrease until average piezometric levels stabilize. The groundwater level drawdown, small or large depending on circumstances, is hydraulically needed to convey (capture) part of the recharge to the abstraction points. All this results in reserve depletion, on a large or small scale depending on local conditions.

There is strict groundwater mining when abstraction exceeds actual recharge or when fresh water reserves are progressively replaced by saline water. Only the first situation is considered hereinafter. When groundwater abstraction exceeds recharge produced under exploitation conditions, a final equilibrium cannot be attained and reserves are continuously depleted, until exhaustion or until exploitation cannot be continued due to a combination of physical, water quality, and economic or legal restrictions.

In practice, it will be considered that there is groundwater mining when, after a hypothetical end of the exploitation, the recovery produced by recharge, up to approach natural conditions, requires at least two human generations (about 50 years). Thus, groundwater mining can be produced even if abstraction is less than recharge. Groundwater evaluations are highly uncertain, as atmosphere, land, and ground properties are also highly variable and have a wide uncertainty range. This is

a common circumstance for natural resources. Recharge is one of the most difficult variables to be accurately evaluated. In arid or semiarid areas, evapotranspiration is the dominant soil water balance term, whose uncertainty combines with that of the other terms to sometimes yield a recharge error that may exceed the recharge value. Recharge and discharge to and from surface water are also difficult to assess, as well as diffuse outflows. So the evaluation of surface water and groundwater resources is quite uncertain, especially in arid and semiarid areas. This explains that results found in different well-done reports may vary, sometimes widely. Environmental, economic and social data and processes are also quite uncertain. They are often more important to water users and society than hydrological and hydrogeological ones. However, hydrological and hydrogeological knowledge are at the basis of any reliable evaluation.

### 3. The considered area: south-eastern Spain

A simplified general map of south-eastern Spain is shown in Fig. 1. The area has about 29,000 km<sup>2</sup>. There are important urban and tourist developments and about 150,000 ha of agricultural land irrigated with groundwater, besides the large areas traditionally irrigated with surface water in the Segura river basin. The area consists in three main parts, 1) the High and Mid Vinalopó river basin in the North-east (it is the southern part of the Júcar Water District), 2) the Segura river basin in the centre, and 3) the north-eastern part of the province of Almería in the South-west, which is part of the Mediterranean Water District of Andalucía.

South-eastern Spain is semiarid, trending to arid toward the south-western coastal sector. The average precipitation over the Segura river basin varies between less than 300 mm/year in the low parts of the SW up to 750 mm/year in the river's headwater highlands. Precipitation

varies conspicuously from one year to another. Drought periods lasting several years are frequent.

The Vinalopó river and the streams in the south-western part are currently almost dry ravines, although they were permanent before the intensive groundwater development of their basins. The Segura river upper basin and its tributary in the lower part, the Guadalentín river, contribute important flows to the surface reservoirs existing in them (Fig. 2).

To cope with the growing water demand in the area, seawater desalination was introduced in the 1980s to increase freshwater resources. It has greatly expanded recently up to an installed capacity of about 500 hm<sup>3</sup>/year (Custodio, 2015). Desalinated water is commonly used for the supply of urban and tourist areas, but also for irrigation of cash crops. In coastal areas, brackish groundwater, mostly originated by seawater intrusion but also by irrigation return flows, is also treated by means of many small and medium size privately owned desalination (de-brackishing) plants, mostly using reverse osmosis. Many of them are in Campo de Cartagena and in Campo de Níjar (see Fig. 1). Since the late 1980s, urban waste water is being reclaimed for agriculture and golf courses irrigation, gardening, and other uses. Urban water reclamation is almost total in the Segura basin.

Water is imported to the area from neighbouring river basins. The Tagus River-Segura River water transfer canal is operating since 1979. Water transfers need specific government approval, should water resources be available. In the SW of the area, some external water is also occasionally imported through the Negratín-Almanzora canal. A new and controverted Júcar-Vinalopó water transfer is just completed and intended to operate continuously, mostly to substitute the excess of groundwater abstraction for irrigation in the High and Mid Vinalopó basin. This water transfer may additionally incorporate desalinated water generated at the coast in a just completed large reverse osmosis plant (CHJ, 2015). The approximate relative contribution of each

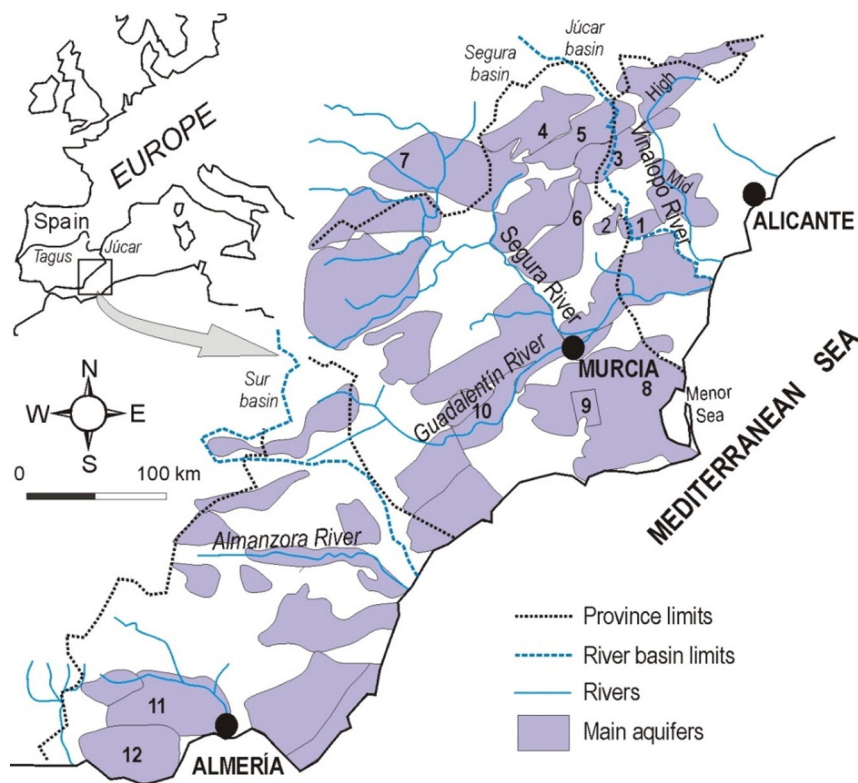
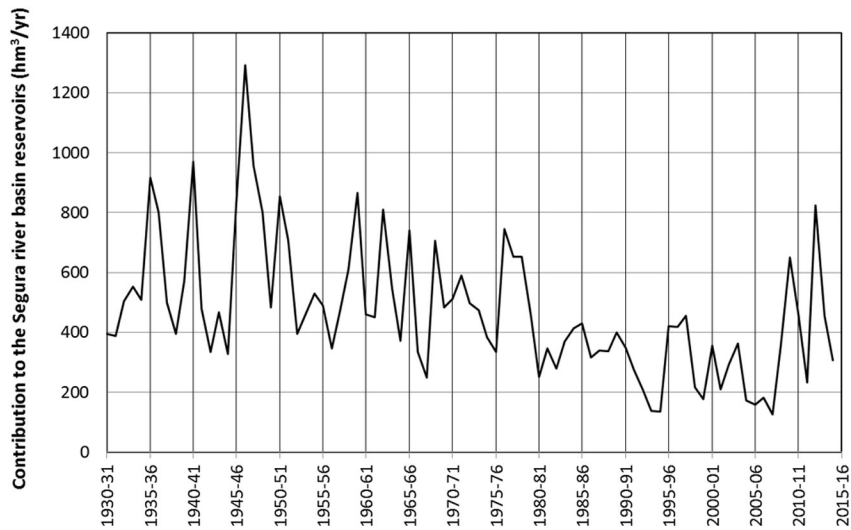


Fig. 1. Schematic map of what is considered here south-eastern Spain (*Levante*). The main rivers and streams are shown as well as the main aquifers: 1: Serra de Crevillent; 2: Quibas; 3: Serral-Salinas; 4: Cingla; 5: Jumilla-Villena; 6: Ascoy-Sopalmo; 7: Alto Río Mundo; 8: Campo de Cartagena; 9: Triásico de Los Victoria; 10: Guadalentín river basin aquifers; 11: Campo de Dalías; 12: Sierra de Gádor.



**Fig. 2.** Water contribution to the Segura river basin surface reservoirs between the hydrological years 1930–1931 and 2014–2015. The average values are 470  $\text{hm}^3/\text{yr}$  for the full period and 300  $\text{hm}^3/\text{yr}$  for the more recent years (rounded after data from the Segura River Water Plan). Hydrological years start in October and finish in September.

water source to water demand in the Segura river basin is shown in Fig. 3.

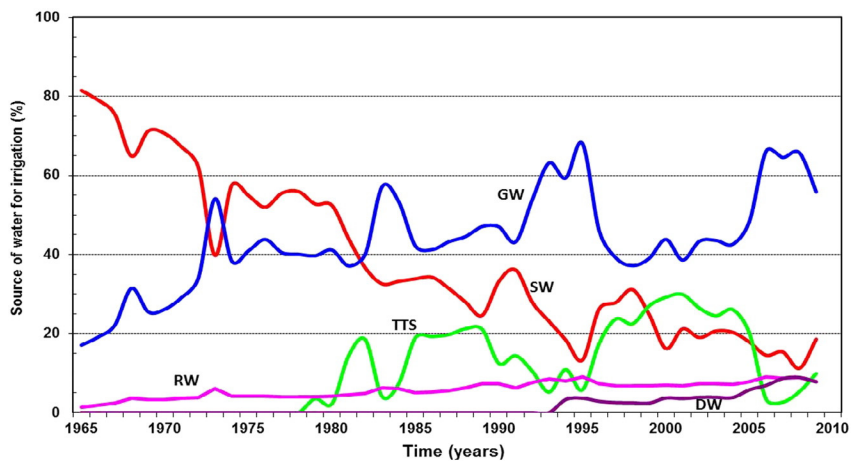
#### 4. Hydrogeological characteristics and intensive exploitation and mining of groundwater in south-eastern Spain

South-eastern Spain is geologically quite complex due to the intense tectonic events associated to the formation of the Betic range during the Alpine orogenesis. The result is the existence of numerous thick aquifers with sizes ranging from some few to some hundreds of  $\text{km}^2$ . Aquifers are mainly hosted in carbonates, a few medium-sized depressions filled with detrital materials, and some alluvial deposits. In spite of the compartmentalization and small drainable porosity of carbonate materials, groundwater reserves may be relatively important due to the great thickness and non-outcropping extent of some of the aquifers, as summarized in Custodio (2015). Groundwater in these carbonate formations is easy to abstract due to the often high hydraulic transmissivity, although this favors fast depletion of reserves. Figs. 4 and 5 show examples of the two main kinds of aquifers.

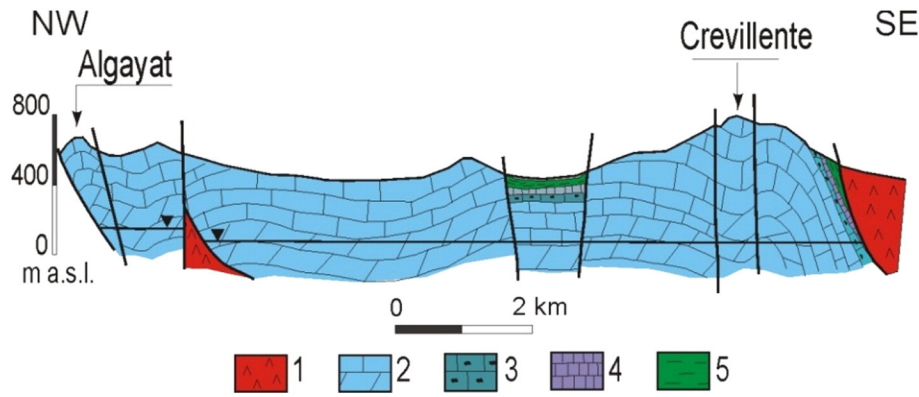
About 250 aquifers are identified in south-eastern Spain. They have a surface area of about 13,000  $\text{km}^2$ , almost half the total area. Some of the main carbonated aquifers are shared by the Júcar and the Segura Water

Districts. Intensive groundwater development occurs in about 9000  $\text{km}^2$ , many of them subjected to groundwater mining. However, the aquifers in the basins' headwaters are close to natural conditions and groundwater is taken there from springs and river base flow. The most detailed studies refer to the mid and low Segura, Guadalentín, and Vinalopó basins (García-Aróstegui et al., 2013; Rodríguez-Estrella, 2006, 2014; Sahuquillo, 2016). In the complex Campo de Dalías aquifer system, to the SW of the area, the large groundwater level drawdown is compounded with increasing salinization (Pulido-Bosch et al., 2000; Domínguez-Prats et al., 2013).

In the intensively exploited aquifers of the High and Mid Vinalopó river basin, the cumulated piezometric level drawdown between 1980 and 2013 varies between 65 and 350 m, with a median of 150 m. The total cumulated groundwater reserves depletion is about 3.3  $\text{km}^3$ . The recharge rate is about 50  $\text{hm}^3/\text{year}$  and the abstraction measured with flow meters is 115  $\text{hm}^3/\text{year}$ . The ratio of abstraction to recharge rates is from about 1 up to 10. Fig. 6 shows the piezometric level evolution in some of the most relevant aquifers in this area and in the adjacent areas of the Segura river basin. The drawdown rate varies between 0.2 and 10 m/year, with a median of about 2.5 m/year. The slower drawdown rate observed in recent years seems to be due to decreasing abstraction rates.



**Fig. 3.** Approximate percent contribution of each water source to water demand for irrigation in the Segura river basin. SW = surface water, GW = groundwater, TTS = imported water from the Tagus river basin, RW = reclaimed urban water, DW = desalinated seawater. Updated from García-Aróstegui et al. (2013).



**Fig. 4.** Example of a thick and complex carbonated aquifer system: NW–SE hydrogeological cross-section comprising Serra de Crevillent (Crevillente) and Algayat (Argallet) aquifers in the Mid Vinalopó and eastern Segura river basins. 1. Keuper deposits; 2. Lower Jurassic limestones and dolomites; 3. Middle Jurassic limestones; 4. Upper Jurassic limestones; 5. Cretaceous marls with a thin cover of Quaternary deposits.

In 8 of the most intensively exploited aquifers of the Segura river basin, the drawdown rate was between 2 and 15 m/year from the 1970s to the mid-2000s, with a median value between 4 and 6 m/year. In the period 2005–2013, a recovery between 0 and 10 m/year was observed in some of these aquifers, with a median value of 1 to 2 m/year. It seems to be the joint result of decreasing abstraction rate and the occurrence of recharge in a wet period. However, in other intensively exploited aquifers the decreasing water level trend is maintained, as shown in Fig. 7. The Jumilla-Villena and the Serral-Salinas aquifers, also shown in Fig. 6, are aquifers shared by the Júcar and the Segura Water Districts.

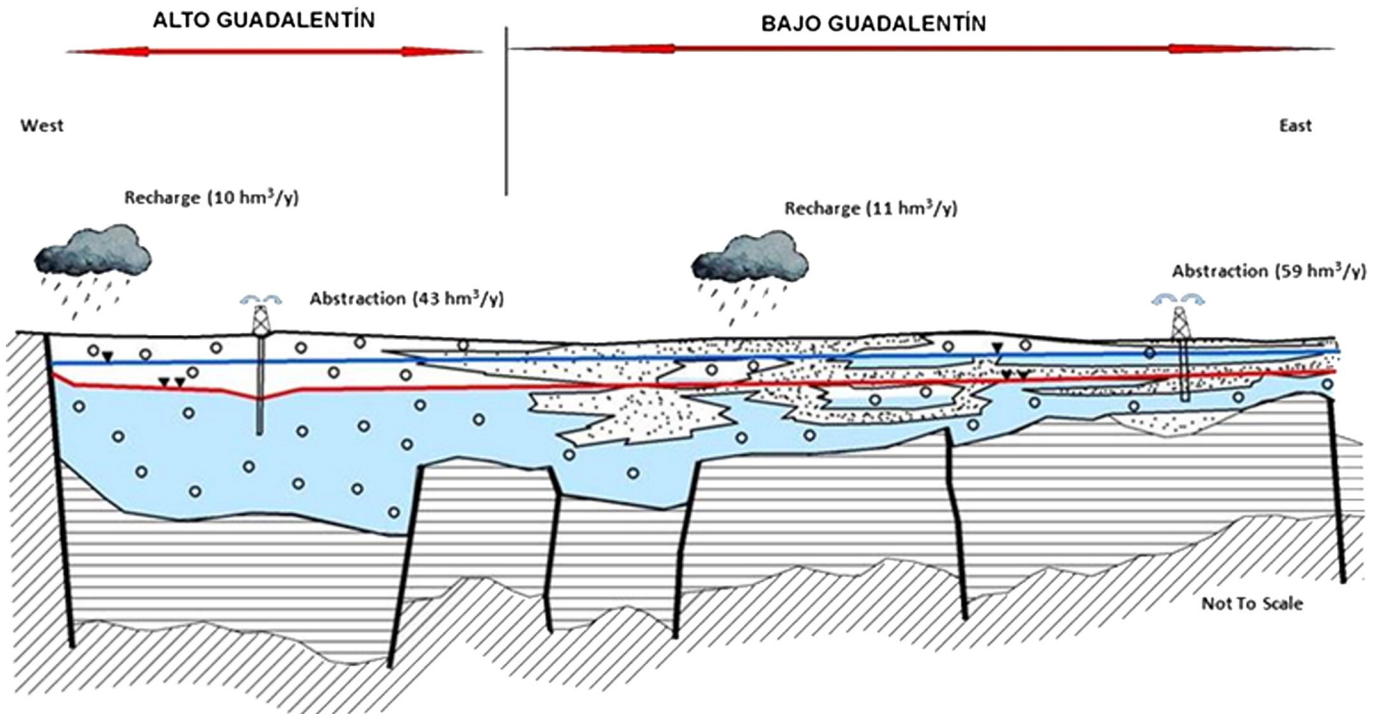
Fig. 8 shows the piezometric level evolution of the coastal Campo de Dalías aquifer, in the SW of south-eastern Spain, which receives groundwater transferred from the Sierra de Gádor aquifer.

The evolution of abstraction, as far as it is known, and the calculated groundwater reserve depletion in the most intensively exploited

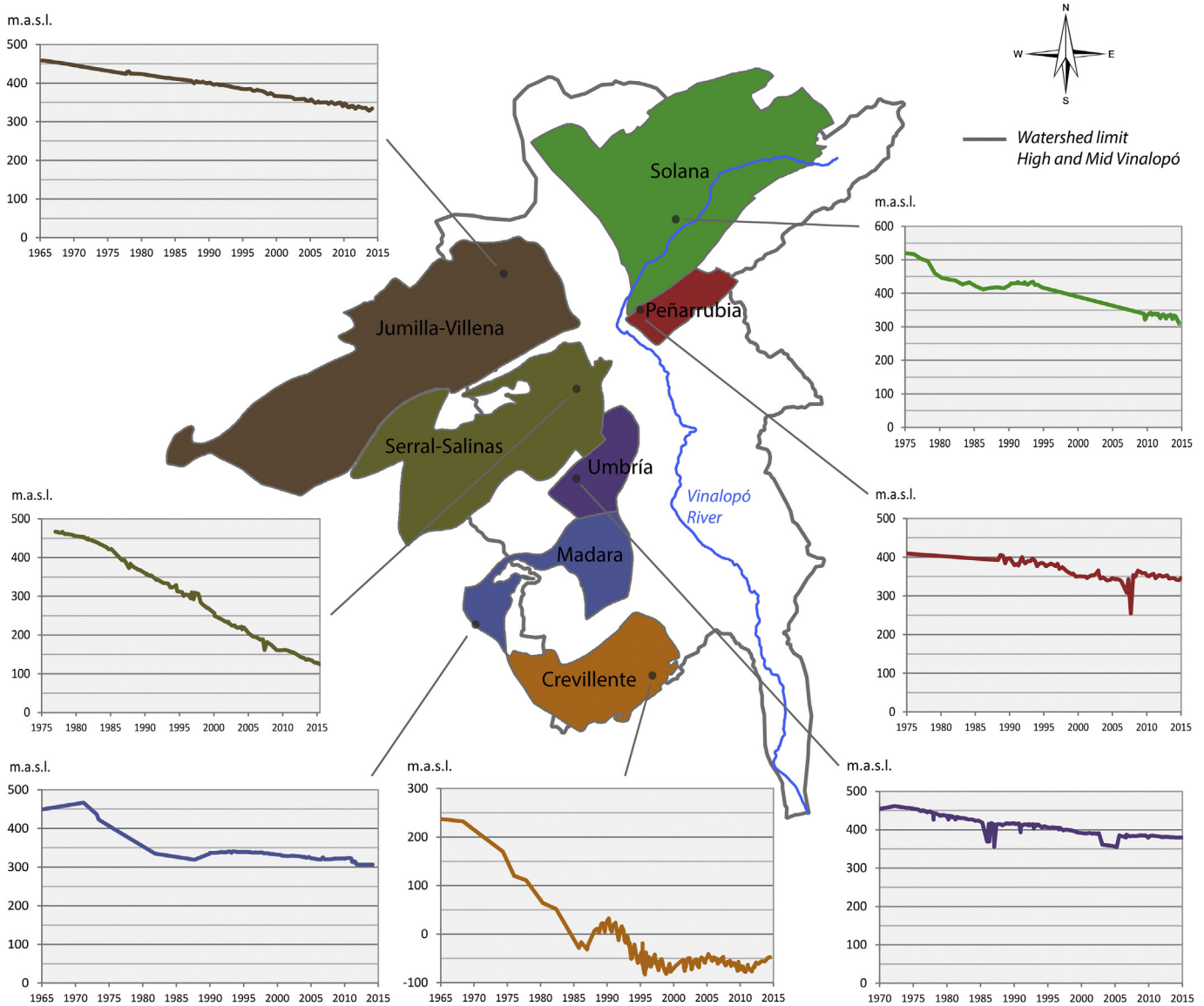
aquifers in the Segura river basin are shown in Fig. 9. The abstraction to recharge rate ratios are >20 in Ascoy-Sopalmo, 7 in Jumilla-Villena and Serra de Crevillent, about 4 to 5 in Alto and Bajo Guadalentín, Quibas, and Triásico de Los Victoria, and about 3 in Serral-Salinas and Cingla-Cuchillo aquifers. Total depleted groundwater reserves exceed 1 km<sup>3</sup> in each of the Ascoy-Sopalmo, Alto Guadalentín, Bajo Guadalentín, and Jumilla-Villena aquifers.

In the Segura river basin, after data from the Water Plan (PHS, 2013) and other sources, about 1430 hm<sup>3</sup>/year are used, of which at least 170 hm<sup>3</sup>/year are non-renewable (mined) groundwater resources. The discharge in the sea is non-significant. The non-renewable groundwater values are obtained as a difference between poorly known magnitudes. Consequently, they are quite uncertain.

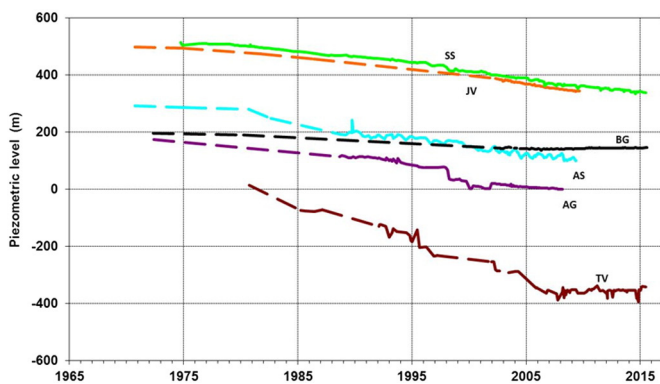
In irrigated areas served with canals and wells, in which both surface water and groundwater are available, local and even imported surface



**Fig. 5.** Example of a thick aquifer system in recent formations filling a tectonic graben: W–E hydrogeological cross-section along the Guadalentín river valley, in the Segura river basin (García-Aróstegui et al., 2013). In pale blue the current aquifer; in white the area that has been drained due to water table drawdown. The blue line (single triangle) is the water table in 1971 (about 250–280 m elevation) and the red line (two triangles) is the water table in 2008 (about 120–150 m elevation to the W and 110–140 m to the E). The cross-section is about 60 km long and 1 km thick. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



**Fig. 6.** Piezometric level evolution (in m above sea level) in the most exploited aquifers of the High and Mid Vinalopó river basin. Provided by Diputación de Alicante.



**Fig. 7.** Piezometric level evolution in some of the more intensively exploited aquifers in the Segura river basin. SS = Serral-Salinas (641 m), JV = Jumilla-Villena (currently Jumilla-Yecla, 556 m), BG = Bajo-Guadalentín (265 m), AS = Ascoy-Sopalmo (416 m), AG = Alto Guadalentín (272 m), and TV = Triásico de Los Victoria (179 m), in the Campo de Cartagena, with a long period of about 10 m/year of drawdown rate. Figures in brackets are the elevation of the monitoring wells. Updated from Cabezas (2011) and García-Aróstegui et al. (2013).

water is cheaper to the farmers and of better quality than groundwater. So, it is preferred. In those areas, groundwater becomes a reserve to be intensively used when surface water supply fails during droughts. This is shown in Fig. 10 for the Campo de Cartagena. In other areas not served by surface water canals groundwater is always preferred to other water sources, as commented later on.

Natural recharge derives from rainfall infiltration, with a small effect of snow in some areas and a limited contribution of occasional storm runoff. Return irrigation flows in the agricultural areas contributed significantly to local recharge in the past. Nowadays, the highly efficient irrigation methods in use have significantly reduced return flows to those needed to avoid salt accumulation in the soil. Irrigation return flows can be highly saline. Induced recharge from rivers is significant only in a few intensively exploited areas close to the Segura river.

Few detailed recharge calculations are available. They have been carried out in Sierra de Gádor (Alcalá et al., 2011; Cantón et al., 2010), Campo de Cartagena (Baudron et al., 2014; Jiménez-Martínez et al., 2010), highlands of the Río Mundo (Hornero et al., 2013), and some of the karstic formations in the north-eastern sector (Andreu-Rodes et al., 2011; Martínez-Santos and Andreu-Rodes, 2010; Touhami et al., 2012, 2013). Only a few times results have been calibrated against



**Fig. 8.** Piezometric level evolution in some wells in the Campo de Dalías aquifer. Drawdown is continuous in the intensively exploited deep aquifers, while in the almost unexploited upper aquifers water levels go up due to increased recharge from loses in the water distribution network for irrigation and return irrigation flows. The final trend to recovery is due to the extraordinary wet 2009–2011 period, during which recharge in the Sierra de Gádor aquifers increased and decreased water demand. Modified after Domínguez-Prats et al. (2013).

groundwater level and spring flow data, mostly because these data are either not available or too sparse. This makes recharge evaluation quite uncertain, even when numerical simulation models are available, like in the Vinalopó basin, as detailed hydrogeochemical and isotopic studies have not been carried out and calibration is not well constrained.

Despite the difficulties of aquifer recharge evaluation, monthly recharge series have been obtained using mathematical simulation models like SIMPA (Estrela et al., 1999). In the Júcar River Basin Plan, the PATRICAL code (Pérez-Martín et al., 2014), a variant of SIMPA, has been used. Calibration can be performed using discharge flows into rivers, groundwater level series, and lateral groundwater transfer data. The recharge values vary almost two orders of magnitude in the considered area as it is highly heterogeneous.

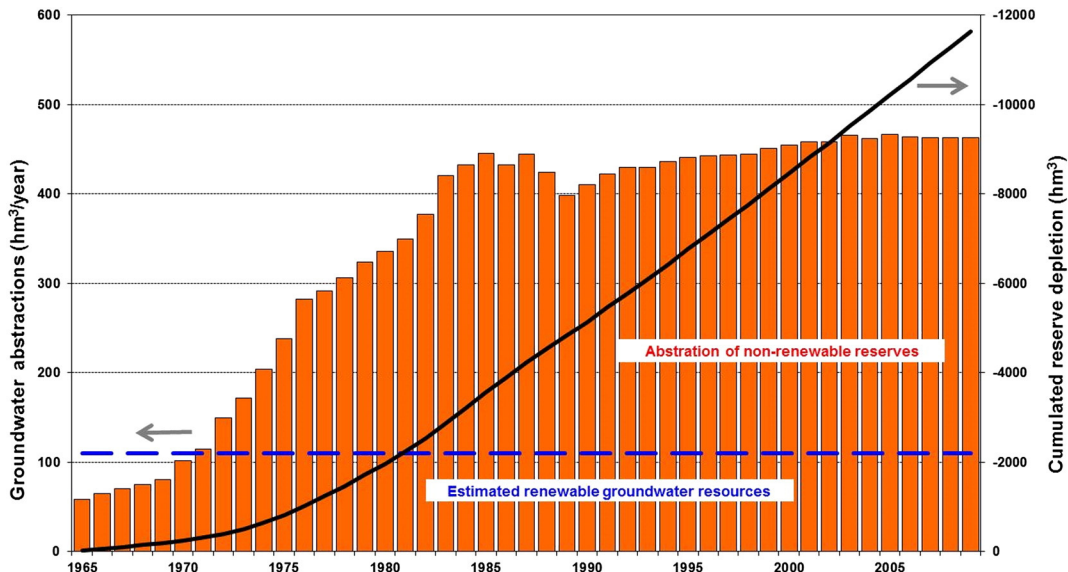
In the whole south-eastern Spain, groundwater abstraction is about 700 hm<sup>3</sup>/year. It is estimated that at least 300 hm<sup>3</sup>/year can be considered as depletion of reserves that are not recoverable in less than two human generations.

The most intensively exploited aquifers are some of the coastal ones located close to the large irrigation, urban, and tourist areas, those of the

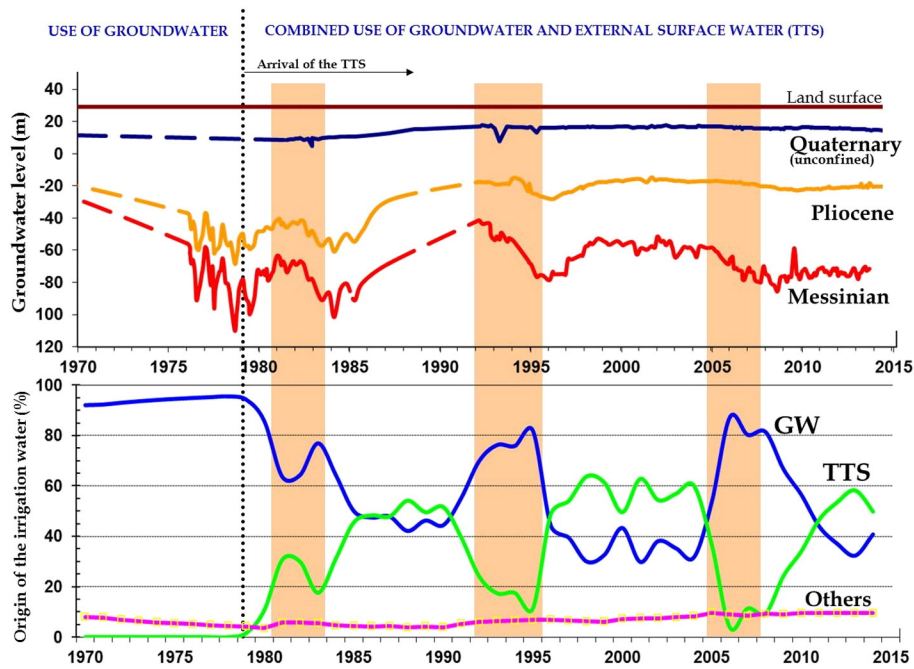
highlands of Murcia (*Altiplano Murciano*) and the High and Mid Vinalopó basin, further to the Campo de Dalías and other areas in the south-western part of the area. There, groundwater demand and the old water rights exceed recharge, so most aquifers tend to sustained groundwater reserves depletion, except those in the Segura river headwaters area.

In the Vinalopó-Alacantí area, the Júcar River Water Plan (CHJ, 2105) has allocated 113 hm<sup>3</sup>/year of groundwater resources, which equals current groundwater abstractions. This value exceeds the estimated 48 hm<sup>3</sup>/year of calculated available groundwater resources. The Water Plan rules that abstraction from aquifers must decrease so that in year 2027 (the end of the third six-year water plan phase of the European Union) abstraction should be reduced to 48 hm<sup>3</sup>/year. In the meanwhile, the deficit of 63 hm<sup>3</sup>/year will have to be met with alternative water resources: water transfer from the Júcar river (up to 80 hm<sup>3</sup>/year), seawater desalination (up to 18 hm<sup>3</sup>/year), and increased urban waste water reclamation.

Groundwater mining has been mostly the result of intensive aquifer exploitation by individuals and some public and private groups, without regard to the sustainable use of groundwater resources. Many of the



**Fig. 9.** Evolution of groundwater abstraction in the most intensively exploited aquifers of the Segura river basin (Cabezas, 2011; García-Aróstegui et al., 2013) and estimated cumulated reserve depletion. The estimated total recharge is about 110 hm<sup>3</sup>/year.



**Fig. 10.** Piezometric level evolution in the three main formations of the Campo de Cartagena multilayer aquifer, before and after the arrival of the Tagus-Segura surface water transfer (TTS), and origin of irrigation water. The shaded periods correspond to droughts. Normally, groundwater use (GW) amounts 30% of total water use, but rises to 70% during periods of surface water scarcity.

Modified from Senent-Aparicio et al. (2015), García-Aróstegui et al. (2013), and Cabezas (2011); with permission.

urban and small town water supplies in Alacant/Alicante province depend on groundwater. Only recently has sea water desalination been incorporated to supply the large urban and tourist areas along the coast. The experience shows that the cost of obtaining water does not refrain from deep groundwater abstraction, but mostly salinity and other water quality problems.

The groundwater reserve depletion was preliminary evaluated around  $15 \text{ km}^3$  in 2014, which largely corresponds to groundwater mining rates of about  $0.5 \text{ km}^3/\text{year}$  (the figure given previously is more than  $300 \text{ hm}^3/\text{year}$ ). This value derives from the difference between abstraction and recharge in each aquifer. This difference is very uncertain, except when abstraction largely exceeds recharge. Groundwater reserve depletion can also be calculated as the emptied volume times the drainable porosity, both is also quite uncertain. The coarsely estimated recovery time of the most intensively exploited aquifers, after a hypothetical cease of abstraction, varies between 20 years and more than 500 years, most frequently between 50 and 200 years. In other aquifers the recovery time is about or less than 20 years. The remaining groundwater reserves in the water mined aquifers may still allow maintaining groundwater development for 15 to 120 years. However, these figures are quite uncertain. In fact, predictions made in the 1980s of total depletion of some aquifers have not happened due to a combination of evaluation uncertainty, decrease of abstraction, and underestimation of recharge in wet years.

To try to know how much groundwater is stored and can be exploited, detailed studies have been carried out in different aquifers, even the small ones, by the *Diputación de Alicante* (provincial authority) with the help of the Geological and Mining Institute of Spain (IGME). Most of these studies are in internal, unpublished reports. The objective has been to calculate the relationship between groundwater level and groundwater exploitable reserves for each aquifer, as shown in Fig. 11 for some of the most important ones. These calculations combine geological, hydrogeological and geophysical data and are extrapolated to the deeper parts of the aquifers. They are used for forecasting the evolution of the groundwater reserves available as a support for planning future investments in the infrastructure needed to guaranty water supply. In some cases recharge is significant, but in others it is irrelevant due to

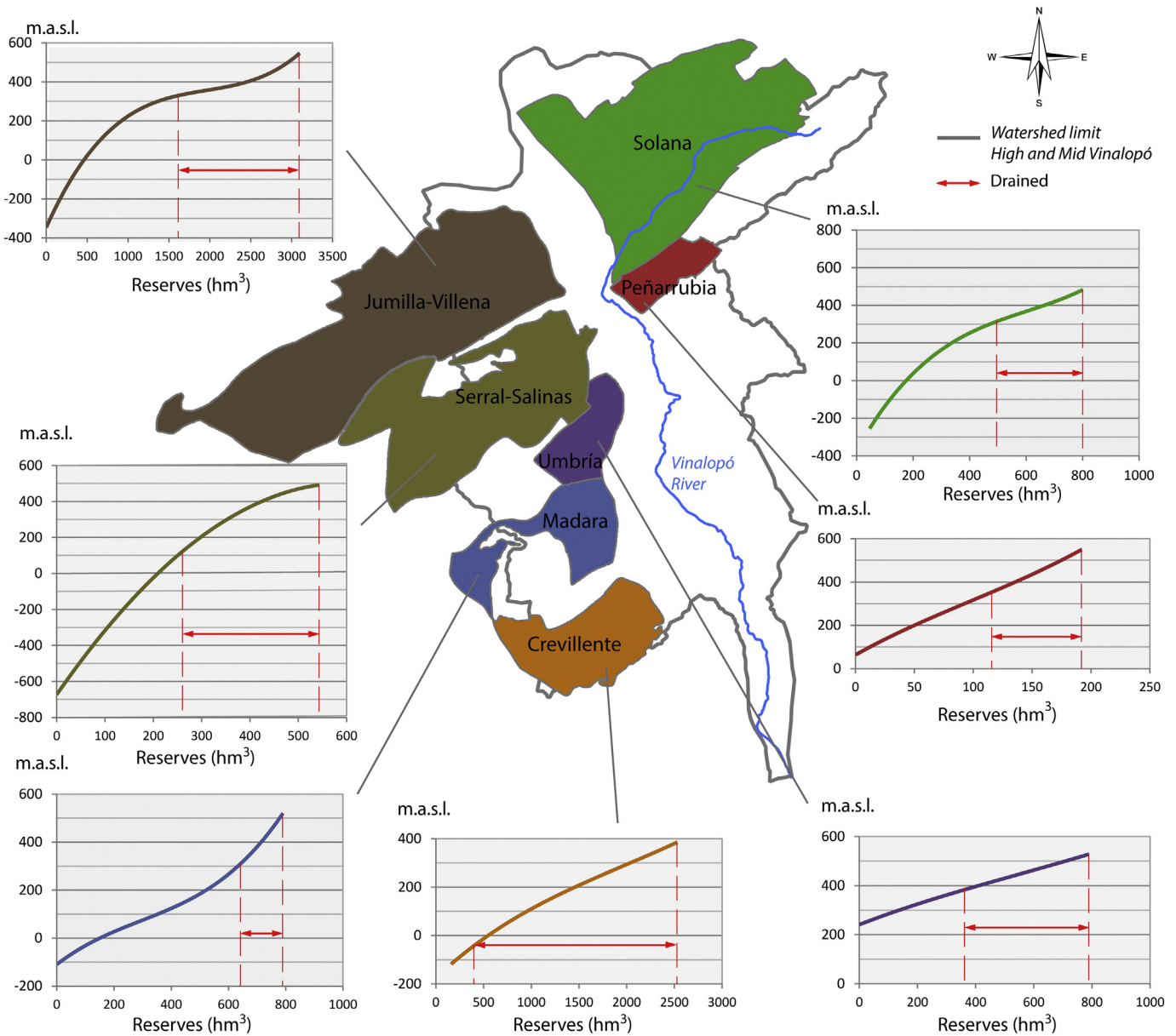
the fast depletion of reserves produced by the high pumping rates in wells located in fractured and karstified rock. Until now only a few small aquifers have been exhausted, their contribution being easily substituted by nearby aquifers. In some cases where groundwater salinity becomes too high due to lithology effects and no other water source is available, small reverse osmosis de-brackishing plants have been installed by the provincial authority to supply some villages.

## 5. Environmental consequences of groundwater development in south-eastern Spain

In south-eastern Spain the flow of the main rivers has been deeply modified by the construction of dam and storage reservoirs. Thus, river flow has progressively decreased or ceased in some tracts or in the whole river. The causes are complex, although intensive groundwater exploitation for irrigation and for water supply is often the main origin. The larger springs are or were located in the Segura river basin, with a total discharge that according to some inventories exceeded  $2 \text{ m}^3/\text{s}$  (see data in Custodio, 2015). Current spring discharge is not well-known, but it seems that barely attains  $1 \text{ m}^3/\text{s}$ . However, the springs in the headwater areas are almost unaffected, although they have important natural flow fluctuations. Many springs in the highlands and the middle and low parts are highly affected or have dried out. In the low parts some spring flow is currently sustained by the dwindling return irrigation flows, as is the case of the springs and ravine base flows around the Mar Menor. The Mar Menor is a large coastal saline water lagoon (albufera) of high ecological value, dominated by seawater but with special salinity characteristics due to the continental water contribution. Its ecological functioning has been greatly modified as spring flow and seasonality, origin of water, and water quality have been deeply altered, partly due to groundwater abstraction and use.

Most of the intensively pumped aquifers are weakly connected to rivers. Carbonate aquifers, mainly in the area between the Segura and Vinalopó rivers, sustained springs that currently are desiccated because water table lowering. Relatively small wetlands in this area as well as in the lower Guadalentín river valley and in the Campo de Dalias also disappeared due to aquifer level drawdown. In other carbonate aquifers





**Fig. 11.** Relationship between piezometric level and groundwater reserves in different aquifers of the Vinalopó river basin. Provided by Diputación de Alicante.

that are well-connected to rivers, groundwater abstraction has been restricted to avoid surface water depletion.

An important exception to lagoon desiccation is the Laguna del Sapo in Campo de Dalías. It is a formerly desiccated wetland that has been deepened to get clay for greenhouses in the area. Most groundwater abstraction is currently from confined deep carbonate aquifers, while the water table aquifer is currently almost unexploited due to its small yield and poor water quality. The area has become a lagoon supplied by water leakages and return irrigation flows, which is growing and invading greenhouse areas. Its ecological value is scarce due to poor water quality and inability to sustain waterfowl due to its excessive depth.

In non-rare situations an impairment of groundwater quality has been produced. Aside from agricultural pollution, this impairment is mostly due to dissolution of salts in Triassic formations containing gypsum and even halite. Triassic sediments, in some cases forming domes and diapirs, are frequently found as they were the sliding level involved in the intense tectonic disturbance of the area. The deep-seated groundwater is more saline due to slower renovation rates. So groundwater

mining is accompanied in some areas, although not always, by progressive water quality impairment, mostly an increase in sulfate content (Andreu-Rodes et al., 2010; Pulido-Bosch et al., 1995). In the Guadalentín river valley, near Lorca, some deep wells produced CO<sub>2</sub> rich water after completion (Cerón et al., 1999; Solís et al., 1994), probably of geogenic origin and related to deep faulting.

In the Campo de Dalías there is a direct connection between the carbonate aquifer and the sea through the former Agudulce spring in the shore. This important freshwater spring dried out some decades ago due to intensive aquifer exploitation. Nowadays it is a path for seawater intrusion toward part of the aquifer system. Other areas of the aquifer system are also subjected to direct or indirect seawater intrusion. This is a complex system, not fully understood, in which groundwater mining is due to both groundwater level drawdown and replacement of freshwater by sea water.

Land subsidence is also an environmental problem derived from intensive groundwater exploitation, although a local one. The intensive exploitation of the local water table aquifer underlying the city of

Murcia during the dry periods 1992–1995 and 2004–2008 produced a subsidence between 2 and 8 cm. This raised an important citizen reaction as differently founded, contiguous high buildings suffered relative movements and some of them got cracks (Mulas et al., 2003, 2010; Aragón et al., 2006). A quite important areal land subsidence of up to 1.5 m due to groundwater abstraction has also been produced in the surroundings of Lorca, in the sedimentary filling of the Alto Guadalentín valley (González and Fernández, 2011). A deadly and destructive earthquake in Lorca in 2011 was assumed by some authors (González et al., 2012) the consequence of the large piezometric lowering in the deep aquifers of the area (up to 300 m deep), but this seems unlikely.

## 6. Groundwater economic issues

Groundwater is an important asset in the economy of south-eastern Spain. It has been one of the main motors of economic development (Tobarra, 2001) and it still contributes significantly to current economy. Part of the benefits comes from groundwater mining, as it happens in other arid and semiarid areas in the world (Foster, 1993; Foster and Loucks, 2011; Custodio, 2012). Decades of intensive use of groundwater has made local economy largely dependent on irrigation, but some authors (Martínez-Fernández, 2001) doubt that there are real benefits when social, environmental, and negative externalities are taken into account. This has happened in a context dominated by irrigated cash crop production. Large areas are dominantly agricultural, with extensive cultivation in green-houses and under plastic covers. Food processing industries have economic relevance as well as tourism in some coastal areas of Alicante/Alacant and Almería.

As it is a worldwide common practice, it is considered that water in nature, and so also water in the aquifer, has no value. Thus, environmental and opportunity costs, and those costs that refer to the present value of goods needed in the future by the coming generations are not considered. The use of a non-renewable or very slowly renewable resource has also a scarcity cost. Indirect costs and other negative externalities are not included in accounting, such as the damage of groundwater exploitation on other groundwater exploiters and environmental effects. Actually these costs have been and are being paid by the society in general. Due to the slow groundwater behavior the costs will be largely paid by the forthcoming generations. The cost of carrying out the needed monitoring, administration and surveillance is also unpaid.

Water prices refer to what is paid in bilateral transactions between private owners when this is possible. They involve small water quantities and are poorly known. Public prices are those officially approved by public institutions for the water they offer from their own facilities, such as desalinated or reclaimed waste water. They may vary according with the kind of buyer in order to force social and political compensations. Public prices include subsidies that have to be paid by other means and finally by citizens. Sustained subsidies finally create in water users the feeling that they have the right to receive them. This perception has already permeated many locals.

In south-eastern Spain, groundwater abstraction costs for irrigation vary between 0.15 and 0.5 €/m<sup>3</sup>, most frequently close to the upper limit, depending on circumstances (Calatrava and Martínez-Granados, 2012; Martínez-Vicente et al., 2013; CHJ, 2015). Environmental costs due to groundwater abstraction should be added. Water costs increase as energy gets more expensive, especially taking into account the deep pumping levels. Current energy prices in Spain are higher than the average ones in Europe. This is a serious handicap for selling the products in international markets.

Groundwater from the most intensively exploited aquifers and presenting the most intense mining effect is not always the most costly water, as local conditions have an important weight. This refers to the cost of making relatively small water flows available at the place of use and at a given moment. For large water flows, the economies of scale count. The consequence of groundwater availability at an affordable price, even if high, is a low demand for other water sources. This

means low production at many of the expensive sea water desalination facilities in the area. Some of them are actually functioning at 10% capacity, which is the minimum to keep them operative. Under these circumstances, real production costs are much higher than those calculated for full production, but these costs are not charged. Non attaining full capacity explains the failure of a relatively large private desalination plant in the SW of the area. Plant production is currently increasing during the present drought conditions. Desalinated water price is 0.30 to 0.5 €/m<sup>3</sup> plus VAT, which is rather low due to direct and concealed subventions.

Farmers willingness to pay for water in south-eastern Spain may go up to 0.4 €/m<sup>3</sup> and temporally up to 0.9 €/m<sup>3</sup> for small complementary emergency water quantities in case of drought (Calatrava and Sayadi, 2005; Colino and Martínez-Paz, 2007). These values are frequently in the range of groundwater abstraction costs under current conditions.

In the situation of intensive use and mining of groundwater in south-eastern Spain, the current evolution of water costs has a small effect on present groundwater abstraction, although a reduction of the irrigated surface area may happen in the mid- and long-term. Economic data on groundwater use in agriculture vary slightly inside the area. Some average values are shown in Table 1.

In the Campo de Dalias (Dumont et al., 2014), which is almost entirely under plastic cover cultivation, the agricultural income is between 8 and 13 €/m<sup>3</sup> at market prices, leaving an economic net margin of 1.3 to 5 €/m<sup>3</sup> when familiar labour is used and scarce to 3 €/m<sup>3</sup> in the case of contracted labour. The economic productivity of water applied to golf courses has been evaluated in Almería as 1.3 €/m<sup>3</sup>. Groundwater mining introduces an unfair economic concurrence with respect to those that preserve their water resources as an asset for the future. This is the reasoning behind the norms that reject groundwater mining, as does the European Union. However, groundwater mining has been and may continue to be the development motor that level economic and social differences inside Europe and a substitute for the inter-regional compensation funds. It is argued that often these inter-regional compensations have been poorly used in agriculture, while mined groundwater seems to have been used more efficiently.

## 7. Legal, administrative, and managerial issues of intensive exploitation and mining of groundwater in south-eastern Spain

### 7.1. Legal circumstances

The first Spanish Water Act was enacted in 1866. It was soon followed by the 1879 Water Act, which lasted until 1985. The 1879 Water Act declared surface water a public domain and groundwater mostly a private domain. The public water administration did not intervene in groundwater affairs, except for permissions to carry out works and to protect public water rights. The 1985 Spanish Water Act declared all waters a public domain, but allowed existing groundwater rights to continue in the case that right-holders did not exchange their rights for a concession of public water (Molinero et al., 2011; Embid, 2007; Fornés and de la Hera, 2007). Most right-holders decided to keep their rights. So, at present all waters are a public domain, but in practice a large part of groundwater rights remain private as they come from before the enactment of the 1985 Water Law. The incorporation of Spain

**Table 1**

Average agricultural economic data of groundwater use in the Segura river basin before the sudden energy cost increase of 2008 (see Custodio, 2015).

	Total	Per ha	Per m <sup>3</sup>
Water abstraction	450 hm <sup>3</sup>	6000 m <sup>3</sup>	–
Water application	360 hm <sup>3</sup>	4800 m <sup>3</sup>	–
Cost/payment	60 M€	300–1500 €	0.13–0.74 €
Water productivity	900 M€	6700–21,600 €	1.4–4.5 €
Net margin to farmer	315 M€	900–10,000 €	0.20–2.5 €

to the European Union in 1986 forced readjustments in the Spanish Water Act to transpose the European Water Directives, especially the Framework Directive (WFD) of 2000 and the so called Groundwater Daughter Directive of 2006.

The Water Act of 1985 rules that any change in the conditions of the private water right needs asking for a concession. This is poorly defined in the law and derived laws, so civil courts have produced variable and even contradictory orders. Changes may be significant in areas with groundwater mining due to the continued decline of piezometric level. Legal changes introduced in 2012 try to ease the administrative task to force private water rights into a concession in the case where substantial changes have been made in the exploitation conditions, but there is no experience on the application.

The attempts to solve intensive aquifer exploitation by declaring the affected aquifers legally "overexploited", in agreement to what is ruled in the Water Act, have been little or no effective at all until present. Some provisional declarations have been done in south-eastern Spain during the last fifteen years. They require the formation of a groundwater users' association and a management plan for each aquifer. No one has currently attained the definitive declaration.

## 7.2. Management action

The fact that a large part of groundwater rights remain private should not limit the management of intensive exploitation and mining of groundwater, as private rights can be constrained to serve the common good. But this has not been widely addressed, except in especial cases.

Some of the current main actions for management derive from the lack of a complete-enough inventory of existing rights. This combines with a) the scarce flexibility of legal treatment of water rights and to force them to serve social interests and common good, b) an excess of paternalism of the governmental institutions, c) the lack of detailed studies, d) inadequate monitoring, control and administrative means, e) an abusive interpretation of juridical security, f) not properly addressing water governance, g) insufficient incorporation and fostering of water users' participation, and h) the scarce political will to cope with water problems.

The important, intensively exploited and mined aquifers shared by two different water districts require specific management organizations at aquifer level. They exist in theory, but are mostly non-operative in practice. Different rules are often applied to each of the parts. This is important in south-eastern Spain.

Management action is mostly directed to increase water offer. This is administratively and politically easier but may be socially expensive. It is often done without full cost recovery and applying subsidies paid by society. Management of demand has a relatively low priority and is mostly centred on increasing water use efficiency in agriculture. Increased application efficiency is rarely translated into a reduction of water use, as saved water is often used to compensate for deficits, to enlarge the irrigation period by obtaining successive crops, and sometimes to increase the irrigated area. However, in south-eastern Spain this tends to be halted due to improved control by water authorities.

Some studies have been carried out to analyse different alternatives of water management in four intensively exploited aquifers in the

Segura river basin, compared to no action (business as usual). See Table 2.

In early times some costly groundwater caption works were financed privately through shares to obtain water to be sold. These initiatives started a private groundwater trade, mostly in the Vinalopó area, still subsisting, but that currently is mostly anecdotal.

Public water trading is possible after the current Water Act, but it is under public administration control and strict conditions. It refers mostly to deals to import surface water to south-eastern Spain from outside the area during droughts, mostly using public systems for water transportation and storage. Public importation of surface water from the Tagus and Guadalquivir Water Districts needs each time the governmental approval of the volume, moment, and public price. Regulations are being drafted to ease the procedure.

Taking into account the economic and social importance of groundwater in the semiarid environment of south-eastern Spain, with important water demand for irrigation and urban supply, the current level of hydrogeological knowledge, monitoring, and institutions' development is insufficient. However, the trend in many public institutions in the last two decades is to decrease efforts, partly due to the current economic crisis, but also to a social and governance crisis. Notwithstanding, the Vinalopó area is in rather good condition due to the efforts of the provincial government in what refers to town and village supply.

Uncertainty of groundwater estimations is an unavoidable handicap for groundwater management as users, the civil society, and politicians are increasingly demanding a secure water supply. The availability of diverse water resources and the incorporation of new ones help in decreasing the uncertainty of total water resources availability and favor integrated water resources management. In many areas of south-eastern Spain, groundwater is still a main water source and foreseeably will continue to be in the coming decades. The associated large reserves help to smooth the effects of uncertainty.

The current water management situation in south-eastern Spain is to some extent due to the erratic behavior of part of the public administrations' action without the involvement and contribution of the private sector and society under a flexible-enough system of water rights. This is accompanied by a loss of technical capability that is substituted by a growing political involvement, while the counterbalance of water users and civil society is still weak.

In many areas of south-eastern Spain, surface water rights often exceed available average resources and groundwater exploitation is greater than recharge. The water needs of ecosystems and the preservation of their services have been largely ignored. Current water plans are introducing some corrections as a requirement of the Water Act and the European Water Framework Directive, but they are not supported by detailed hydrological, economic, and social studies. There is no significant popular reaction against groundwater intensive use and mining and its consequences.

Trends to correct and curb down the negative consequences of aquifer intensive exploitation and mining in south-eastern Spain started in the 1990s. They are mostly due to the increasing cost of energy but also to the offer of public water at regulated prices, including desalinated seawater and reclaimed urban waste water. The increase of energy cost also affects desalinated and reclaimed waste water should subsidies not be applied. Public water pricing is used to try to influence water resource management. However, for the intensive cash crop cultivation in south-eastern Spain this pricing is poorly effective due to the decreasing contribution of water payment to the total cost of economic activities. Corrective action has not progressed in a sustained and systematic form. This is not only due to the current economic crisis, actually it helps by reducing water demand, but to the loss of technical capability, insufficient monitoring, and lack of long-term vision. This is not an uncommon situation in other areas of Southern Europe, but water scarcity makes this more negative.

The use of groundwater and its reserves increases water security. This is an insurance to cope with meteorological droughts, both for

**Table 2**

Management alternatives to reduce intensive and mining groundwater exploitation in significant aquifers of the Segura river basin (Ascoy-Sopalmo, Serral-Salinas, Jumilla-Villena, and Cingla). 2009 is the reference year. Total groundwater exploitation is 146 hm<sup>3</sup>/year, recharge is 35 hm<sup>3</sup>/year, and the estimated groundwater reserve depletion is 3 km<sup>3</sup>. Values are cost increase relative to no action (Molina et al., 2009, 2011).

Alternative	Volume, hm <sup>3</sup>	Cost, €/m <sup>3</sup>
Reducing water abstraction	45	1.07
Applying sea desalinated water	43	0.32
Water import from other areas	9–111	0.32–2.20

town and village supply, especially for those not receiving water from supply networks, and for irrigation. Many of the intensively exploited aquifers, even those subjected to groundwater mining, may contribute this reserve. During the drought of years 2004–2010, the aquifers played the important role of contributing water from their reserves. Both publicly and privately owned “drought wells” exist as emergency backup. However, their operation is not integrated with the other water resources, so full aquifer recovery during wet years is not assured. This is not a planned joint use of surface and groundwater, even if modelling efforts have been done in some areas.

In the Vinalopó-Alacantí area, the average ratio of withdrawal to groundwater resources is greater than 2. To attain a balance, costly infrastructures, which are valued at about 500 M€, have been implemented to bring water from the Júcar river, to the North, and water produced in a new, large seawater desalination plant (CHJ, 2015). But a pumping of about 700 m rise is required. Supplied water is destined to stop part of groundwater abstraction by private right holders. In the High Vinalopó area, the current average cost of groundwater is much less than the cost of water to be transferred, even if only operating costs are considered. This discourages the substitution, should significant subsidies be not applied. Water users consider that the reduction in groundwater abstraction must be accompanied by the guarantee of implementation of the water transfer at bearable water prices, similar to current water costs. This involves an important subvention to cover part of the initial cost of water. But this is doubtfully sustainable and does not comply with the principle of cost recovery of the European WFD, although they help in attaining the goal of no further deterioration of aquifers.

### 7.3. Groundwater governance and institutions

In the quite complex and water stressed conditions of south-eastern Spain, governance is needed. It has to overcome the resistances and vices inherited from the past and the fears of losing power or prerogatives by those currently in charge. This is a non-easy task, even if asked by legal regulations, civil society and the Academia, and by pressure from the European Union. Groundwater mining, where it happens and is admissible, should be a component of the Integrated Water Resources Management (IWRM), a subject of water planning, and included in water governance. Intensive groundwater development and mining may imply important environmental consequences and also energy, land and labour issues. They have to be considered besides water resources.

Groundwater stakeholders, civil society, and academic institutions are poorly developed to participate and foster groundwater governance. Moreover, fostering them and their involvement do not appear as a priority, neither in the Water Plans of the River Basin Districts nor in the reports on important topics that precede them. However, these institutions are needed for acceptability and feasibility of water plans and to get the needed mid- and long-term vision. They are also needed for monitoring and control. The balance between the costs of improving knowledge and monitoring and those of carrying out groundwater governance under uncertainty has not been addressed.

The quite important local experience in collective action for groundwater is mostly directed to get and use the water made available, but not to manage the water resource. The compulsory formation of a groundwater users' association in the officially provisionally declared “overexploited” aquifers has been a failure. Successful bottom up born Groundwater Users' Communities (GUCs) exist in Spain since 1975. They are public institutions according to the Water Act. GUCs effective operation implies shared management and loss of free initiative of Water Authorities, but management is improved. But despite the good conditions existing in south-eastern Spain, GUCs are scarcely developed, partly due to the reluctance of farmers to joint efforts. A GUC exists in the Campo de Dalías. In the Júcar Water District there are major successes in fostering users' associations to improve dialogue with the water administration, to ensure economic sustainability of exploitations

through self-control and to collectively manage new public infrastructure to obtain more water resources. Two GUCs exist in the Vinalopó area. One is in Serra Mariola (Ferrer and Gullón, 2004); the other is in the Vinalopó-Alacantí system, where groundwater mining is important.

### 8. Groundwater, society, future development, and prospective in south-eastern Spain

The intensive aquifer exploitation, and specifically groundwater mining, allowed economic and social sustained development since the late 19th century, especially through irrigated crops. In fact, in Almería, as an example, the gross economic product rose from about 60% of the Spanish average in the 1960s up to more than 90% in the 2010s. About half of the agricultural irrigated surface area is supplied permanently or occasionally with groundwater. Moreover, groundwater use has clearly avoided water supply problems to villages far from water supply networks and of irrigation during the recent droughts and also has contributed to increase water supply security. However, without detailed studies it is not possible to evaluate the social and economic net results of groundwater mining in south-eastern Spain.

Future water demand is very uncertain, especially that of the agriculture sector, which uses currently about 80% of available water in south-eastern Spain. The demand of agriculture products depends greatly on the behavior of foreign markets, the concurrence of other nearby countries and regions of Spain, the changing European agricultural policy, and the expenses to purchase inputs for the production processes. Farmers have no control on these factors. Thus, their water costs have to be decreased to try to increase the net agricultural margin. Consequently, the farmer looks for the cheapest water sources in the place at the time of application, besides increasing water use efficiency up to an affordable level. When surface water flows are not available, groundwater is preferred, even if its cost increases progressively due to water level drawdown. As a result, in many areas only groundwater is used except when other heavily subsidized water sources are made available or legally forced. These effects are much less sensitive for water supply to urban and tourist areas, where the impairment of water quality has often a higher economic effect than the payment for water quantity. Groundwater mining is often a transient situation inside an evolution that allows important social changes by using the natural capital, provided it is correctly managed and the social benefits are capitalized. Afterwards, the economic and social activity has to change in some moment, looking for a new paradigm of water use in which social sustainability should be based in other premises.

In south-eastern Spain this change of paradigm is needed and has to be done progressively. It has to be confronted as soon as possible to lessen the associated social stress. The large water reserve in the aquifers favors a possible smooth transition during which costs increase and the progressive scarcity of water force the progressive introduction of changes. This has to be known, subsidies should not interfere, and political distortion must be avoided. A possible way out is a combination of tourism, services, food processing, and selected cash crops. As the increased guarantee of water availability is often accompanied by the loss of “water culture”, this reduces the pressure for the change. Also, there is the risk of avoiding or delaying the change when subsidized water is offered without a well-planned and mutually agreed policy. A delay may lead to more difficult and stressed future situations and to a less smooth evolution. Some changes in irrigation will be forced by the new European Community Agrarian Policy, which intends to shift the emphasis from production to product quality and environmental preservation.

The current water plans of the three Water Districts in south-eastern Spain propose delaying the end of groundwater mining to the end of the third European Water planning period of 2021–2027. The solution they propose is a progressive increase of water import from other Water Districts. However, as this is an almost impossible goal, some drastic actions should be taken during the coming 2016–2021 water planning

period, such as the abandonment of large irrigated areas and the increase of food and forage imports. This means increasing the import of virtual water.

Despite what has been said above, in south-eastern Spain local groundwater developers favor continuing the intensive and mining exploitation of aquifers as this water is cheaper in the place of use and more secure than the alternative water sources except imported surface water. This relies partly on the fact that most investments to get water are already done and amortized. To change this pressure, significant subsidies are applied to induce the use of other water sources. But this has a high economic and social cost. Subsidies modify the differences between the prices of the diverse water resources, and as a consequence they affect integrated water resources system.

A medium- and long-term vision, which should be that of the public water administration and of the civil society, and also that of the new groundwater users, asks for progressive reduction of groundwater abstraction. This is needed to achieve the economic sustainability of existing groundwater abstractions and also to comply with the requirements of the WFD. This needs improved water governance and mutually agreed win-win solutions.

All what has been said involves ethical and moral issues, as the situation is non-sustainable in the mid- and long-term and affects the current and future society. However, it produces not only damages but also benefits. These benefits should allow for a smooth evolution, provided that besides private gains there are also social benefits, and that abusive actions are avoided and controlled (Llamas and Martínez-Santos, 2005; Delli Priscoli and Llamas, 2011).

In south-eastern Spain water ethics is not currently a priority, even if there is groundwater mining. This is partly due to the improved security of urban water supply and to the decreased water stress in irrigated agriculture, despite the relatively high water prices. Social interest has shifted toward other issues. The ethical and moral aspects of groundwater mining and the proposal of alternative solutions to the intensive and mining exploitation of groundwater have not been openly addressed in the area.

## 9. Conclusions

Intensive and even mining exploitation of groundwater is a common fact in south-eastern Spain. This has to be evaluated under the particular hydrogeological and social circumstances existing there. As the stage on water resources development is an advanced one, translated into intense water stress, some general knowledge can be derived. It can be used in other areas which are in an earlier stage of groundwater development to improve social benefits, to try to avoid mistakes and obstacles, and to foster the needed institutional framework. This is to confront problems and base action on sufficient and reliable data. The transfer of knowledge needs finding similitudes. Similar situations to those in south-eastern Spain are found in other water stressed and mined areas around the Mediterranean Sea, north-western Africa, the arid part of the Pacific coast of South America, and the Middle East. They are quite different from those found in other water stressed and mined aquifers such as the Ogallala in USA or the Nubian aquifer in northern Africa.

Large groundwater level lowering is possible in many cases. The involved high cost of abstracting water may be saved by early action if abstractors agree on rules that guarantee improved economic and social efficiency of water use, while preserving development and the evolution to a new water use paradigm. These rules are not for a closed group of groundwater abstractors but should set the condition for others to join. Costly water supply investments can be delayed by planned groundwater mining. Unplanned (wild) action has often a high cost which is transferred to coming generations if the recovery time after abstraction failure is of several decades.

Groundwater intensive development allows starting and sustaining the economic and social development of many areas, generally starting

with intensive irrigated agriculture. This is the case of south-eastern Spain, although with decreasing intensity due to increasing costs, administrative restrictions, and making available other water resources. However, groundwater mining is unsustainable in the long-term and in some areas even in the mid-term. It has to come to an end in some moment, due to physical, water quality and economic circumstances, or as a consequence of legal regulations. It is currently the case of south-eastern Spain. This is often a slow process that allows making sound decisions.

Private groundwater development is made with full recovery of direct costs, but damage to the environment and its services and other negative externalities are not included. Damage has to be paid by present and future human generations, which raises ethical and moral questions. In any case, groundwater has an increasing cost which may attain levels at which alternative water resources, such as the public offer of seawater desalination and urban wastewater reclamation. But even if desalination plants are built in areas close to the coast, substitution of the water source is often delayed due to the high cost of produced water and of transporting the water to the locations of use. This involves a low use of costly facilities and increases the cost of produced water. The public production of alternative water to decrease or bring to an end groundwater mining often involves subsidies to reduce public prices, which have to be paid by society, although the externalities of intensive and mining exploitation of groundwater are also paid by society. Sustaining subsidies during economic crises is critical to avoid future social problems. The benefit from investing economic and social resources in subsidies, compared to the possibility of other beneficial uses of these funds, is not known. A key question is whether alternative water resources must be subsidized to recover the aquifers or intensive groundwater exploitation can continue in the future.

Water governance appears as an essential element, together with implementing an appropriate water planning framework and the necessary infrastructures to achieve integrated water resources management. Groundwater governance is crucial given the multiplicity of actors. Groundwater user's communities, civil society institutions, improved hydrogeological knowledge and monitoring, and adequate means and administrative tools are essential elements to reduce groundwater mining. Governance includes cooperation among groundwater developers and a social evolution toward new paradigms with different, less intensive, and more economically effective use of water. This appears as a non-easy task with many handicaps. The early identification of obstacles as well as levelling them is crucial. This is a partial failure in south-eastern Spain.

The role of groundwater changes over time. It moves from the trigger and motor of economic and social development toward integrated water resources management, incorporating industrially produced water. In the late stages groundwater regulates and secures water availability in droughts. Water planning has to consider this evolving role to guarantee that aquifers are in due condition, operable at reasonable costs, and with good water quality. This needs an administrative decision, supported by civil society, and with the involvement of water stakeholders. It should be addressed as soon as possible during the evolution stage, even before the water stress is high. This has been also a partial failure in south-eastern Spain, but it provides an example of the early steps to be followed through studies, monitoring, well-trained administrators, and involvement of society.

The experience shows that after a period of rather good water availability and service, people lose interest in water affairs and consider water and water security for granted. This is accompanied by deteriorating interest and investment in studies and monitoring. This fact is reflected in the low priority of water issues during the current economic crisis in Spain, and also in the reluctance of politicians and water authorities to establish water prices that allow for maintenance and full cost recovery. The current popular apathy toward water issues is at odds with the strong negative popular reaction that often appears when water scarcity is felt or forecasted. This also happens when an

increase of domestic water tariffs and agricultural water prices is proposed. To counterbalance this trend, information campaigns are needed as part of administrative action and water planning, with the involvement of civil society, institutions' representatives, and the Academia.

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