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ORIGINAL ARTICLE

Integrated water resources management on a local scale: a challenge for the user community—a case study in Southern Spain

Julio Pérez-Sánchez[1] · Javier Senent-Aparicio[1]

Abstract Associated with the vision of balanced, sustainable resource management, the end of the 20th century witnessed the paradigm of Integrated Water Resources Management (IWRM), whose application was based on considering the river basin as an operating unit. The last decade has seen a preference for a scaled abstraction of this focus in which the administrative and physical limits of the resource that is provided can be considered as water management subunits, albeit ever dependent on and under the supervision of the river basin authority to which it belongs. This article shows the advantages of applying specific IWRM-based measures that can be implemented on a local scale. In the case under study (a municipality in southeastern Spain) and based on the possibilities it offered, consideration has been given to joint management of the available water resources as feasible from the technical, economic, social and environmental points of view. The project compares two 20-year scenarios to reflect the consequences of incorporating the overexploited aquifer into the local water resources management scheme. Scenario 1 represents the existing non-joint water management, while Scenario 2 considers conjoint water management of surface and groundwater resources, examining variables related to climatic change and economic cycles. The simulations performed demonstrate that local scale management

appears to be a feasible solution for semiarid towns and villages: it increases supply compared to current management and guarantees that demand is met for all the irrigation communities and indicates an almost immediate widespread recovery of the water table, even under scenarios with increased demand and a moderate fall in water resources.

Keywords Decentralisation · Joint management · Integrated management · Artificial recharge

Introduction

At the beginning of the 21st century, the human race is facing a world water crisis. Having safe access to sufficient drinking water is acknowledged as a basic human right in international declarations and agreements (UN 2000).

Faced with mounting pressure on water resources and growth of around 33 % in agricultural demand over the next 40 years (Singh 2012), it becomes necessary to consider modifications to the independent use made of water resources to date. Owing to the interrelation between groundwater and surface water and the logical demand for considering the joint and/or alternating use of both, water must be analysed as a unique resource (Winter et al. 1998).

The benefits of the joint use of underground and surface reservoirs consist basically of attaining supply guarantees of almost 100 % at a relatively low cost. Obtaining these guarantees with surface reservoirs alone would be excessively costly and could not be assumed in environmental terms in most cases.

Associated with this vision of balanced and sustainable resource management, the end of the 20th century witnessed the paradigm of Integrated Water Resources Management, whose application is based on considering the

✉ Julio Pérez-Sánchez
    julioperezsanchez@gmail.com; jperez058@ucam.edu

    Javier Senent-Aparicio
    jsenent@ucam.edu

[1] Departamento de Ciencias Politécnicas, Escuela Universitaria Politécnica, UCAM Universidad Católica San Antonio de Murcia, Campus de los Jerónimos, n° 135, 30107 Murcia, Spain

river basin as an operating unit. The last decade has seen a preference for a scaled abstraction of this focus in which the administrative and physical limits of the resource that is provided can be considered as water management subunits, albeit ever dependent on and under the supervision of the river basin authority to which it belongs. Local water resource management is merely a complementary step, albeit not exclusive, in achieving the philosophies of effectiveness, sustainability and participation supervised and fostered by international bodies under the principles of the Dublin Statement.

Furthermore, owing to the lack of human and economic resources of the river basin authorities for the sustainable and joint management of surface water and groundwater in semiarid regions, especially in southern Europe, aquifers have been exploited by agriculturalists in a way that has led to widespread overexploitation in many of them. Nowadays, a combination of the reintroduction of former croplands, the occurrence of long-term droughts and political pressure in these countries, has forced an increase in pumped abstractions, with the consequent lowering of the water tables in these aquifers.

Due to the problems of sustainability with river basin management, the aquifer boundary might be the appropriate scale to provide a first step in meeting the goals of IWRM.

The aquifer selected for this study lies in a semiarid region in southern Spain, where average water tables have fallen by around 0.50 metres/year since the 1970s and where several important springs which used to have average flows of 100 l/s, disappeared at the beginning of the 21st century. The entire water body lies within a single municipality, which makes it a feasible water management sub-unit. The southern limit of this aquifer coincides with the main surface watercourses, where winter surpluses reach 3.67 hm^3/year—equivalent to nearly 50 % of the summer deficit. There is currently no joint management of the two resources, so two different scenarios have been designed to analyse how water demand could be guaranteed and to track water table evolution and water storage in the aquifer. Scenario 1 replicates current management, where there is no link between the exploitation of surface water resources and groundwater deposits, while the second one (Scenario 2) shows the consequences of joint local management when the aquifer is used as a large underground regulation unit that is recharged from the surface water surplus via the Hellín Canal.

Water resources management on a local scale

Water resources regulation

The coexistence of large permanent and seasonal settlements, extensive production areas, large irrigation areas and significant concentrations of industrial activity, almost always associated with the primary sector, are the common features of many of the countries located in the planet's semi-arid areas and, in particular, southeast Spain.

To accurately adapt resources to demand, (natural or artificial) reservoirs will be necessary to temporarily store surplus resources during periods of lower demand (in general terms, supposedly in winter) so that, by means of an adequate withdrawal programme (in the broadest sense of the term, i.e. including pumping in the case of underground reservoirs), the natural supply from rivers can be complemented during periods when said supply is below demand. The effective use of water will lie in its appropriate use in technical and economic terms, since the heart of almost every problem involving water scarcity is an absence of regulation of the resources. Likewise, filtration and evaporation from reservoirs can be an important factor when calculating the overall losses from the system, especially in semiarid areas. Shiklomanov (1998) considered that evaporation loss from reservoirs used for urban and industrial supply is quite significant. In the southeast of Spain, water loss due to evaporation reached average levels of around 10 % of the volume stored (Martínez-Granados et al. 2011). This reveals that one of the key factors for achieving our goal is to have sufficient storage capacity.

Groundwater reservoirs must perform several functions in the use of water resources: supply, storage, regulation and transport. Nowadays, there are still some semiarid regions (including our case study) which use the former, i.e. supply, almost exclusively and, albeit partially at the present time. Despite it being a function of great importance, it would not necessarily have to be the main one. Underground reservoirs have to play a decisive and irreplaceable role in relation to the parameters of time and space and the binomial of regulation of transport.

Current situation of integrated water resources management

In the 21st century, water resources management is facing huge challenges as a result of the heavy pressure brought by its economic, political and social value. Since the concept of sustainability became the flagship principle of the World Commission on Environment and Development in 1987 in the Brundtland Report, water has been acknowledged as one of the basic components for human development. The many conferences that took place in the second half of the 20th century within the framework of new trends that consider the need for including the sustainability of water resources gave rise to the concept of IWRM. It is seen as more of a process in itself than a goal (Jonch-Clausen 2004; Leidel et al. 2011). The goals that are to be achieved using IWRM are economic,

environmental and social sustainability, economic efficiency in the use of water and social equality. Thus, the challenge is to find a balance between protecting the resource itself and satisfying the social and ecological needs associated with economic development (Odendaal 2002) and it is the right scale for coordinating the river basin (GWP 2000). In Europe, the Water Framework Directive (European Parliament and Council 2000) adopts the same philosophy and, as part of the obligation to drawing up the Basin Plans of all its member states, it fosters the principles of Integrated Water Resources Management with the express requirement of genuine, widespread participation by all the players involved in the process (Richter et al. 2013).

However, not all the scientific communities support the ideas of IWRM. Biswas (2004, 2008) is particularly critical of this concept of a universal solution for the water problem. Biswas (2004) considers inadequate integration of administrations in one basin organisation for water management because he says that many of the institutions that are to be integrated have different users and, therefore, different interests. An integration may lead to a loss of representation of said interests and users, a concentration of power and a reduction in the transparency and control of the corresponding functions.

At the present time, authors such as Foster and Ait-Kadi (2012), who defend IWRM more as a process than a concept, acknowledge the difficulties facing countries when implementing the governing principles of the philosophy, especially in relation to the following: (i) insufficient coordination between administrations and extremely complex bureaucratic organisation of the water sector; (ii) stiff resistance to changing the resource policy for a policy based on demand and the targets set in integrated management; (iii) financing; and (iv) weak participation mechanisms.

Users' acceptance plays an essential role in the success of any initiative or idea that leads to a change or the adaptation of water resources management in terms of what has been considered or carried out to date (Mankad 2012). Therefore, participation on every level is essential and fundamental to resource sustainability: local, regional, national and global (Swatuk and Motsholapheko 2008), where the centralisation inherent to administration at basin level as recommended by the highest instances stands as a possible barrier for achieving this goal of widespread participation.

Decentralisation and joint management on a local scale

An attempt is being made to solve the problem caused by the increasing burden of functions on an ever shrinking number of institutions and the concomitant loss of representation. Likewise, the lack of control of some water bodies due to human and economic problems in administrations is another key element that IWRM aims to solve, by decentralising the decision-taking processes to lower levels of government and, as a result, increasing user participation.

IWRM principles can be implemented on a local scale in two ways (Moriarty et al. 2004): (i) by incorporating new, specifically created institutions in the local administration, referred to as 'full IWRM model'; and (ii) through local actions designed to implement IWRM, referred to as 'light IWRM model'. An identical view is taken by the ICLEI (2005), which considers the implementation of IWRM principles through two frameworks: framework level, which fosters coordination with other local administrations and other stakeholders at basin level; and micro-level, through actions coordinated by the local administration that do not interfere with the common goal at basin level.

The involvement of local administrations in water resources management is restricted (Smits and Butterworth 2006). Normally, any decentralisation process involves the assumption of more responsibilities which do not usually involve economic and/or technical resources. Since the full system can be seen as a huge task for a local administration, the light IWRM model seems much more feasible and sustainable for a local administration or even a user community. The goals that are to be achieved by a local corporation must focus on tasks which, based on IWRM principles and on current human and material resources, can be completed easily, simply and effectively and which, besides involvement in and direct action on water management, make it possible to check the results of these new systems first hand. In addition, light local management system is not conditioned only by the size of the administrative institutions, but also by the physical size or extension of the medium that provides the resource. As defined by hydrogeological criteria, aquifers have the capacity for being the appropriate structure on which the protection and management of resources can be centralised (Garduño et al. 2006), especially deep aquifer systems in arid and semiarid regions, where the underground water resource is the essential element of the supply for the various local consumer uses, especially agriculture, as presented in this study.

Case study

Hellín is a municipality in the province of Albacete in Southeast Spain (Fig. 1). It has a surface area of 780.81 km^2, 31,262 inhabitants and a resulting population density of 40.04 inhabitants/km^2. In socio-economic terms, the farming sector, which accounted for 20 % of the working population in the municipality in the 1980s, fell

Fig. 1 Location of Hellín
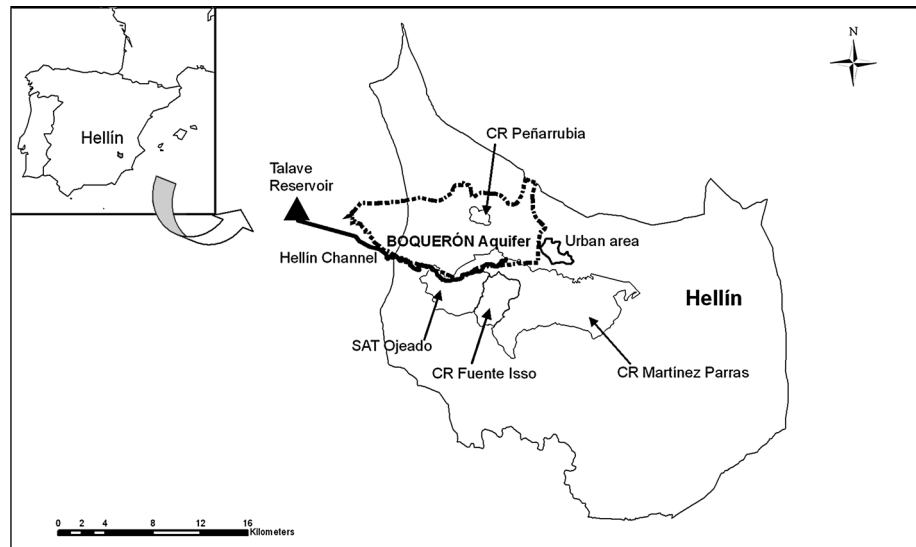
drastically as from the beginning of said decade and, in the 1990s, stood at around 10 %. With the appearance of the world economic crisis, much of the working population has returned from sectors such as industry and construction to farming (Fig. 2), and current percentages are above 20 %. As a result, crop areas that had been abandoned decades earlier are being reused and there is a consequent increase in water requirements to supply new demand. In 2013, a new licence of 2.25 hm^3/year from the El Boquerón aquifer was granted to a cropland that had lain abandoned for 20 years. This has also been backed by the recent construction of wells on local aquifers to guarantee the demand by the new areas that have been prepared for production.

With regard to the resources in the municipality of Hellín for satisfying agricultural demand, the river basin authority demarcation to which the area belongs (Hydrographic Confederation of the River Segura) estimates 48.74 % from surface resources from the River Mundo, which crosses the municipality in the west, especially the so-called Hellín canal, which accounts for 38.04 % of all the municipality's water supply. The remaining 51.26 % comes from different aquifers under the surface of the municipal district of Hellín. This high use of underground water resources in the area is due to the fact that around 96 % of the municipal district is located on large-capacity aquifers with exploitation possibilities. This percentage shows the great importance of the aquifers and their associated resources for the area's economic activity and development.

The Hellín canal is the largest local surface infrastructure. It crosses the municipality from east to west up to the town centre and also satisfies domestic requirements. However, in view of the seasonal nature of demand throughout the year, especially in farming, the flow
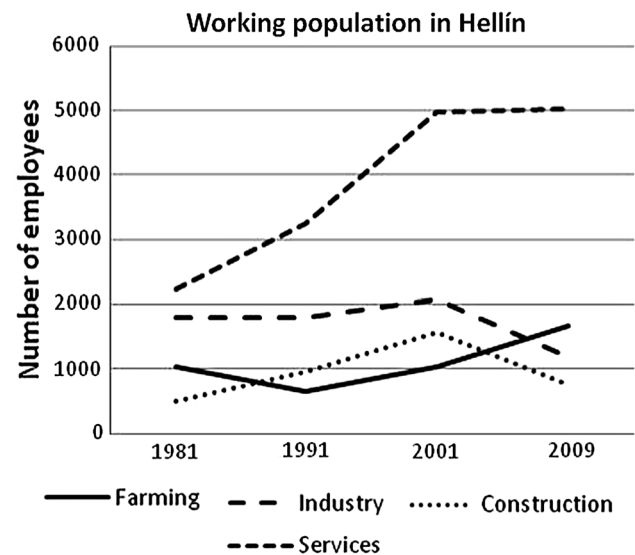
Fig. 2 Evolution of the working population in Hellín

volumes provided by the canal reach surplus levels between October and April (Fig. 3). The said surpluses (3.67 hm^3/year average) are not used or stored by the municipal water system and it loses the power for regulating the resources awarded by the river basin authority to which it belongs. Similarly, in summer (June–September), there is a high deficit in the irrigation activities (8.66 hm^3/year average) associated with the canal and they are compensated by water from different aquifers, especially the so-called El Boquerón aquifer, whose southern limit coincides with the course of the Hellín canal (Fig. 1). The stored volume in El Boquerón at the end of the 1970s was some approximately 500 hm^3 (Senent et al. 1975) and the useful volume (5–10 %) was around 20–40 hm^3.
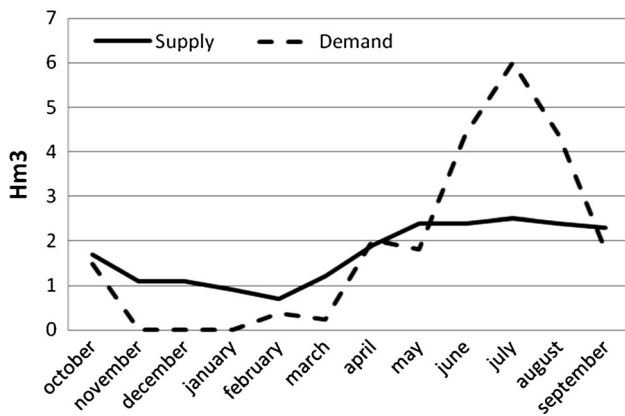
Fig. 3 Average ratio of water supply/demand in irrigation corresponding to the Hellín Canal

Furthermore, the evolution of water level in piezometers installed in the aquifer of El Boquerón show that there has been a negative year-on-year balance since the end of the 1970s, which has led to an annual average drop of 0.50 m since then. In fact, the piezometer in the southern aquifer, which has the largest and complete data series, shows that the water level has fallen 17 m since the 1970s (Fig. 5). The drop in water levels has accelerated over the last decade, indicating the overexploitation of this aquifer. This overexploitation is also confirmed by the reduced flow from the various springs associated with this geology. Due to the high gradient of the aquifer towards the southeast, the flow in the Isso Spring was about 100 l/s on average until the 1990s but since 2002 it has been dry (except for sporadic flows related to heavy rainfall events) with the consequent damages for the irrigation communities that drew water from these springs and that currently obtain water pumped directly from the aquifer and the ecosystems related to the sources and whose development and wealth in terms of species have contracted over time.

According to recent research carried out by IGME (2010) regarding the balance in this aquifer, the average annual recharge is calculated as 10.66 % of the rainfall over the permeable outcrops, *i.e.* a mean annual rainfall of 11.24 hm^3/year would give an average recharge of 1.20 hm^3/year. Nowadays, due to the overexploitation, there are no transfers to/from other aquifers because the water levels have fallen below the level of the interconnections. However, the pumping licences from this aquifer for crop irrigation in this area (4807 ha) have reached 8.75 hm^3/year, leading to a negative balance of 7.55 hm^3/year, which demonstrates the overexploitation of this water body.

In view of the problem in the municipality caused by the reduced supply guarantees in summer and the overexploitation of the aquifer of El Boquerón to compensate seasonal deficits and the economic and ecological consequences, a study has been made of the consequences of maintaining the current water management system in the mid-term and has been compared with the possibility of artificially recharging the aquifer of El Boquerón with the surplus water in the Hellín canal by building injection wells whose positive results were shown by the experiences gained in this area (Senent et al. 1975). These test wells are still used today by the irrigation communities, albeit sporadically and void of planning.

Methodology

A model has been designed that is capable of representing the elements that make up the local water system under study, together with the relations between them (existing and programmed) to simulate different scenarios: (i) current management with no interrelation between surface and underground water; and (ii) joint local management that includes the aquifer of El Boquerón as a 'large underground regulation deposit' through recharges using the Hellín canal surplus as produced in the system. This will make it possible to set down the basis for comparing each of the proposed scenarios.

The application of the AQUATOOL model (Andreu et al. 1996) developed by Universidad Politécnica de Valencia (Polytechnic University of Valencia) is a quick and an effective option for modelling the joint management of water resources since it enables the incorporation of aquifers into the surface water subsystem as another regulation 'deposit' to store water when there is a surplus and supply it when there is a deficit. This model is a decision support model and is endorsed by its use in most of our country's river basin authorities, as well as many studies on the possibilities of operating a supply system in different areas of Spain (Henche et al. 2002; Murillo and Navarro 2008). The definition of just a few elements allows the model to be fitted to any management scheme. The elements considered are: reservoirs, pipelines, water demands, water inputs, return elements, pumping, and aquifers. The water inputs can be introduced as average monthly values identical over the whole time series studied or as historic monthly values. The demands are introduced as average monthly values. Once the elements of the system and the relationships between them have been configured, the model is defined as an optimization problem that can be expressed across a target function and a set of limitations (Paredes et al. 2010), as follows:

$$\left.\begin{array}{l}\text{Min} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij} \\ \sum_{i=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = 0 \qquad \forall i = 1, \ldots, m \\ x_{ij} \geq l_{ij} \quad \forall i = 1, \ldots, n \quad \forall j = 1, \ldots, m \\ x_{ij} \geq u_{ij} \quad \forall i = 1, \ldots, n \quad \forall j = 1, \ldots, m, \end{array}\right\}$$

where x_{ij} is the flow between nodes 'i' to 'j'; c_{ij} is the 'virtual cost' assigned to the flow, l_{ij} and u_{ij} are the upper and lower limits of the flow that goes from the node 'i' to node 'j'. This problem is solved by using the Out-of-Kilter algorithm (Ford and Fulkerson 1962), whereby non-linear elements are taken into account using an approximation for sections or for successive iterations until convergence. Said algorithm determines the flow in the system and seeks to satisfy the multiple targets for minimising deficits as far as possible. The results of the model include the evolution of all the variables of interest (including water tables in aquifers) in monthly and annual terms, the average values for the simulation period and guarantees. Thus, for surface subsystems, the flow is calculated simply by continuity or water balance, whereas for underground subsystems or aquifers, the AQUIVAL module (Capilla and Andreu 1996) has been used.

Aquival is a cluster of the AQUATOOL model that allows the modelling of aquifers by means of finite differences in a system of water resources and his later integration in the module of joint management. The AQUIVAL model uses the eigenvalues method to produce a distributed model of linear aquifers behaviour. This method is particularly appropriate for integration in a water resources simulation model owing to its low computational effort requirements. The application of the eigenvalues method is possible when we are considering completely saturated confined aquifers or else unconfined aquifers where drops in the piezometric surface decreases are negligible with regard to the saturated thickness. Under these conditions, the equation that describes the variation in water flow over a time interval (Δt) can be expressed according to the following matrix relation: $T \cdot H + Q = SF \cdot \Delta H \cdot \Delta t - 1$, where $T(n,m)$, is the symmetrical band matrix, which depends on the transmissivity, the contours and the spatial discretisation (m^2 day^{-1}), $H(n)$, is the vector of piezometric levels (m), $Q(n)$, is the vector of external flows (m^3 day^{-1}) and $SF(n,m)$, is the diagonal matrix that depends on the spatial discretisation and on the coefficient of storage in every cell (m^2). If the matrixes T and SF are independent of H and are constant over time (linear aquifers), the previous equation can be transformed into: $H_k = A \cdot E \cdot A^{T}SF \cdot H_{k-1} + A \cdot [I-E] \cdot \alpha^{-1} \cdot A^{T} \cdot Q$ (Sahuquillo 1983), where k is the number of the time periods to evaluate and n is the number of cells into which the aquifer is discretised, $A(n,n)$ is the eigenvalue matrix of

the problem (m^{-1}), α is the eigenvalue vector of the problem and $E(n,n)$ is a diagonal matrix where each element $e_{ii} = \exp^{-\alpha i \Delta t}$.

This equation is simplified using the concepts of elementary actions and control parameters. The elementary actions (Q^b) are a set of unitary actions (whose sum of components is equal to 1) that reflect—in the basis vector—the change in external actions from one period to another one k (pumping, recharge, irrigation returns, etc.), while the control parameters (C_k) are the indicator values of the simulated aquifer (water table, stored volume, outflow, etc.). Finally, if a new parameter L_k (state vector) is defined as $H_k = A \cdot L_k$, then the equation remains $L_k = E \cdot L_{k-1} + [I-E] \alpha^{-1} \cdot A^{T} \cdot Q^b \cdot B_k$, where B_k is the vector of intensities of the elementary actions and the expression $H_k = A \cdot L_k$ transforms into $C_k = A_R \cdot L_k$, where A_R is the reduced matrix A and each row is a control parameter.

To solve the above equations, the Aquival model requires discretisation of the aquifer defining the cell dimensions, contour conditions and properties of transmissivity and storage coefficient of every cell. Based on information from previous hydrogeological studies of the aquifer (Senent et al. 1975; IGME 2010), the size of the cell selected was 1000×1000 m^2, giving a matrix of 16 rows and 8 columns (Fig. 4), of which 52 cells are considered ineffective due to the limits of the aquifer. According to previous research, with the exception of the northern shore, the boundaries of the aquifer are perfectly defined by anticlines, dipping vaults and faults along the whole perimeter, which protect it from external transfers. The northern boundary (cell (1.10)) is open and subterranean waters used to transfer between both aquifers up until the end of the last century. However, this water transfer is practically non-existent nowadays due to the reduction in the levels in the adjacent aquifer, as a result of over-exploitation, and as such has not been taken into account in this study. With regard to the aquifer's natural water outlets, there are a few minor outlets along the east border (cell (3.16)) and the Isso outlet (cell (8.13)) located along the south border, the contour conditions of which have been taken into account in the model. Again based on this previous research, the average permeability coefficient considered was 1.13 m/h, with a storage coefficient of 3 %.

Recharge to the aquifer was obtained using the program Visual Balan (Samper et al. 1999), which allows the application of different hypotheses of calculation to daily level, ETP, ETR, direct and deferred infiltration, superficial run-off and other factors that affect the recharges, such as interception. The results of the simulation show a significant annual average ET of 80 % of total rainfall. In fact, the annual average replenishment is 1.60 hm^3/year directly
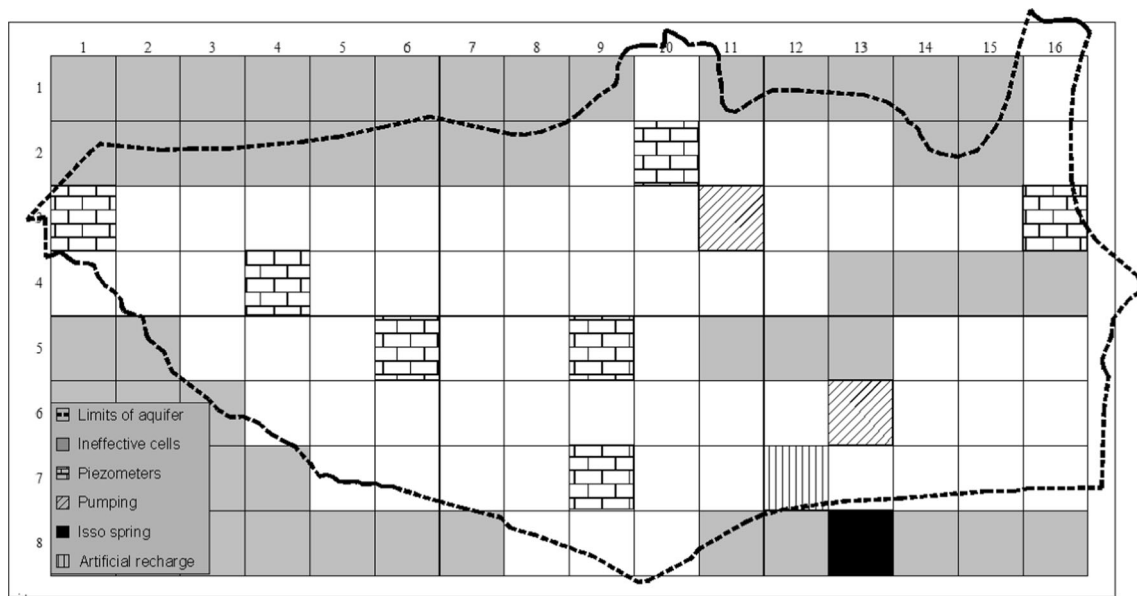
Fig. 4 Model of Aquifer El Boquerón

from rainfall, which is about 10 % of the total rainfall over the pervious area. This value is similar to the ones obtained from previous studies of the aquifer with pumping tests (Senent et al. 1975) and the chloride method (IGME 2010).

The remainder of the input comes from flows under natural regime (1.90 hm^3/year) from the northern aquifer. Nowadays, however, this input flow has nearly disappeared due to the widespread overexploitation of the aquifers and so it was not taken into account for the simulations of future scenarios. In contrast, the relationship of flow transfers with the upper aquifer was used for validating the aquifer model for the historical period simulated (1970–2012), yielding a figure of 1.73 hm^3/year (Senent et al. 1975; IGME 2010).

The elementary actions considered were the recharge of the aquifer, both natural (rainfall and transfers) and artificial (in the future simulations), pumping and springs (Isso). The control parameters selected were the total volume stored in the aquifer and the water table in a subset of the model cells. These selected cells (Fig. 4) coincide with the piezometers distributed over the aquifer. However, in most cases, the data series are reduced to a period of 5–10 years—except for the so-called PA-2845, which has water table data from 1970 to the present day [cell (2,10) in Fig. 4].

As shown in Fig. 5, the results from the modelled aquifer differ from the records of water table in the field, being higher over almost the entire series. This is caused by the lack of totally trustworthy information with regard to the pumping due to the lack of administrative controls over them. Nevertheless the correlation coefficients (r^2) for all

the series are above 0.80. For the piezometer PA-2845 (Fig. 5), this coefficient is 0.9429.

Having validated the aquifer model as seen above, it was linked to the decision support model Aquatool, and its elementary actions (natural and artificial recharge to the aquifer, pumping and springs) and control parameters (total stored volume in the aquifer and the water table level in the control cells are imported to the water management scheme).

The project has considered the 20-year study of two comparative scenarios that could reflect the consequences of incorporating the aquifer of El Boquerón into the water system as described: (Scenario 1) current water management (business as usual) with no joint management of surface water and groundwater; (Scenario 2) joint water management.

Thus, the models developed (Fig. 6) show that the subsystem comprises three consumption nodes:

(1) the agricultural demand fed from the Hellín canal (surface resources, denoted CR Martinez Parras, with an average demand of 22.48 hm^3/year.

(2) the agricultural demand met from groundwater resources (El Boquerón aquifer) by three different irrigatorś associations (CR Fuente Isso, CR Peñarrubia and SAT Ojeado). In this case, the average demand is 5.84 Hm^3/year

(3) the urban water demand from Hellín (3.12 hm^3/year), which is supplied mainly from surface water (Hellín canal and an abstraction from the Talave reservoir). However, if these surface water sources fail, demand is made up from the El Boquerón aquifer.

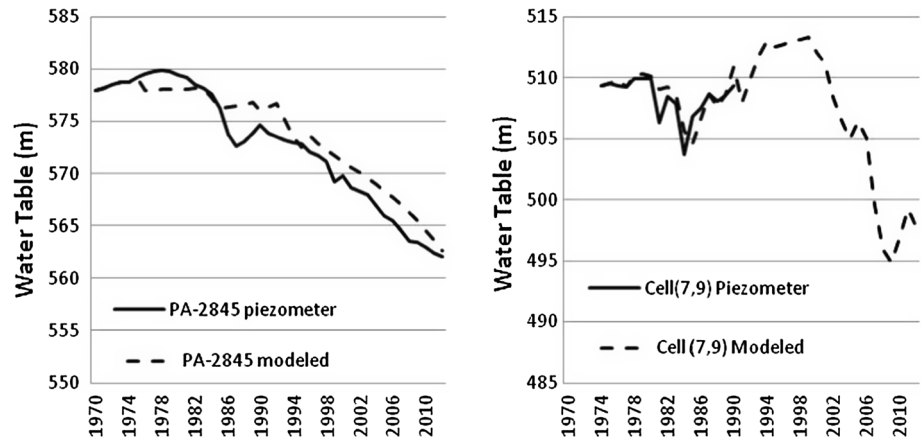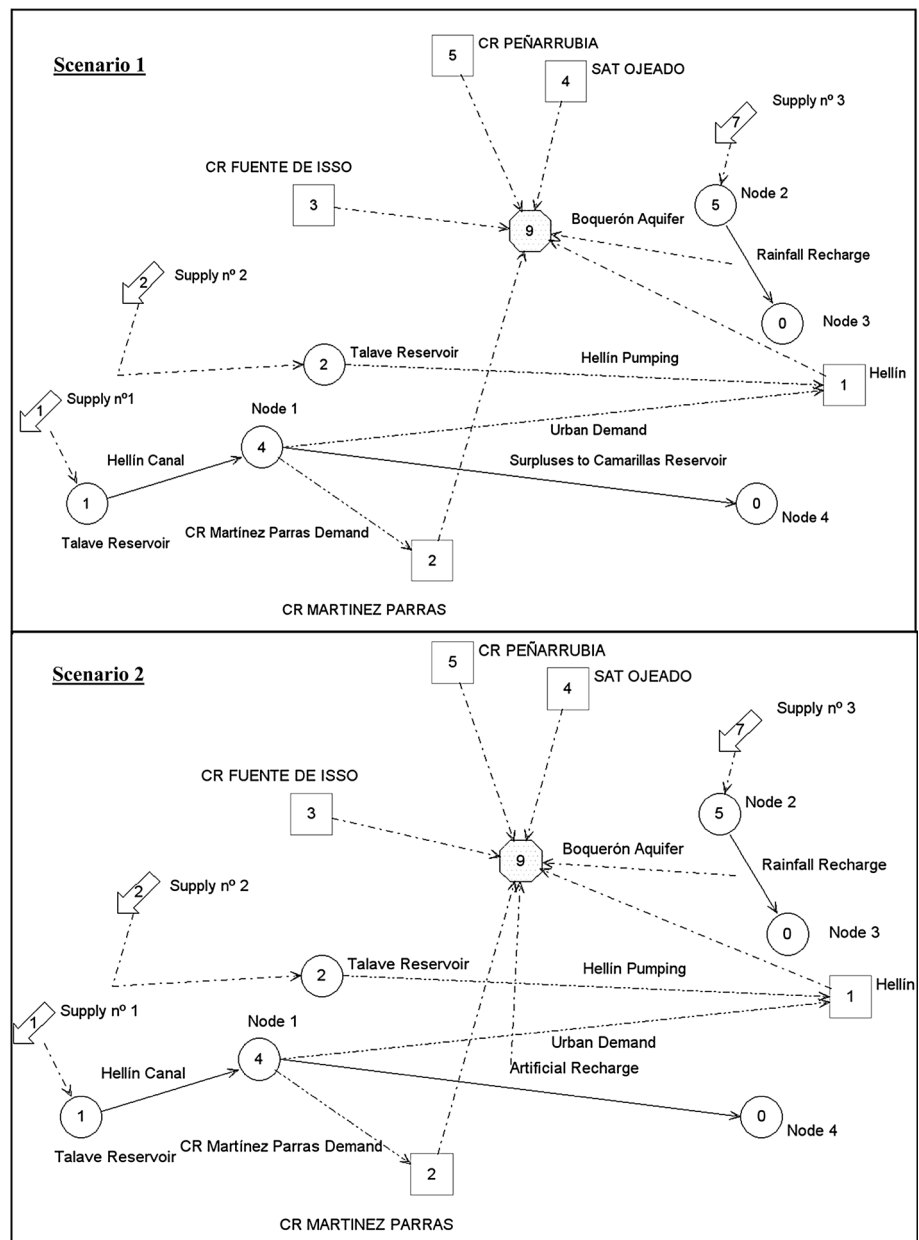**Fig. 5** Validation of the modelled aquifer

Fig. 6 Schematic of the water management Scenarios

The supply nodes in the system correspond to the Talave reservoir via the Hellin Canal (supply n° 1; with a total average of 20.6 hm³/year), the Hellin pumped urban supply from the Talave reservoir (supply n° 2; 2.4 hm³/year) and the aquifer of El Boqueron which is recharged only through infiltration during rainy periods under Scenario 1 but also from surpluses from the Hellin Canal under Scenario 2. Current monthly average distribution of both demands and supplies are shown in Fig. 7.

The system to be simulated in Scenario 1 takes into account the current behaviour pattern. In this scenario, there is no joint use of surface or subterranean waters. The surplus water supplied by the Hellín canal is returned to the surface sub-system when not consumed. However, in the case of urban water demand, there will be no surplus water as the water introduced into the sub-system is stored in surface-regulated water towers located in the town itself. For this reason, there is no connection between the Hellin canal and the Boquerón aquifer. The only aspect taken into account regarding the replenishment of the aquifer is that due to the filtration of rainwater.

Under the second scenario, the consideration of supply and demand is the same as Scenario 1, except that the aquifer of El Boquerón, besides its natural source of supply from the rainfall over permeable outcrops of this formation, will be recharged artificially with the monthly surpluses from the surface waters of the Hellín canal (mainly from November to March). Besides the possible benefits of a large regulation element in the water resources management of the system,

economically unviable at this moment in time in the municipality, it is also important to remember the other benefit drawn from recharging the aquifer, i.e. the recovery of the water levels and, as a result, its environmental condition. Nowadays, infrastructure in nearly all the croplands served have been subsidised by the regional administration and farmers have often failed to invest in drilling deeper wells than the existing ones because pumping costs would make their end-product unprofitable. Therefore, in this study, the current well depths are considered to define the limit of groundwater abstraction from Boquerón aquifer.

According to Iglesias (2009), the effects of climate change in terms of (increased) demands in the basin will reach approximately 7 %. However, due to the uncertain economic future, other authors prefer to consider a sensitivity analysis of plus and minus 10 % irrigation demand to represent a pessimistic scenario dominated by physical changes, and an optimistic scenario driven by policy adjustments (Pulido-Velázquez et al. 2011). Regarding the water resources, the results are highly scenario-dependent and the reduction in precipitation in the area might be anything from 7 to 40 % (Iglesias 2009; IPCC 2007; Lloyd-Hughes and Saunders 2002). Accordingly, within both the studied scenarios (current management and joint water management), the considered variations in demand were set at plus or minus 10 %, with a reduction of 10, 20 and 40 % in available water resources.

A code is used to summarise each of the water schemes evaluated under the two scenarios. These are devised as

Fig. 7 Current average monthly evolution in demands and supplies in the system
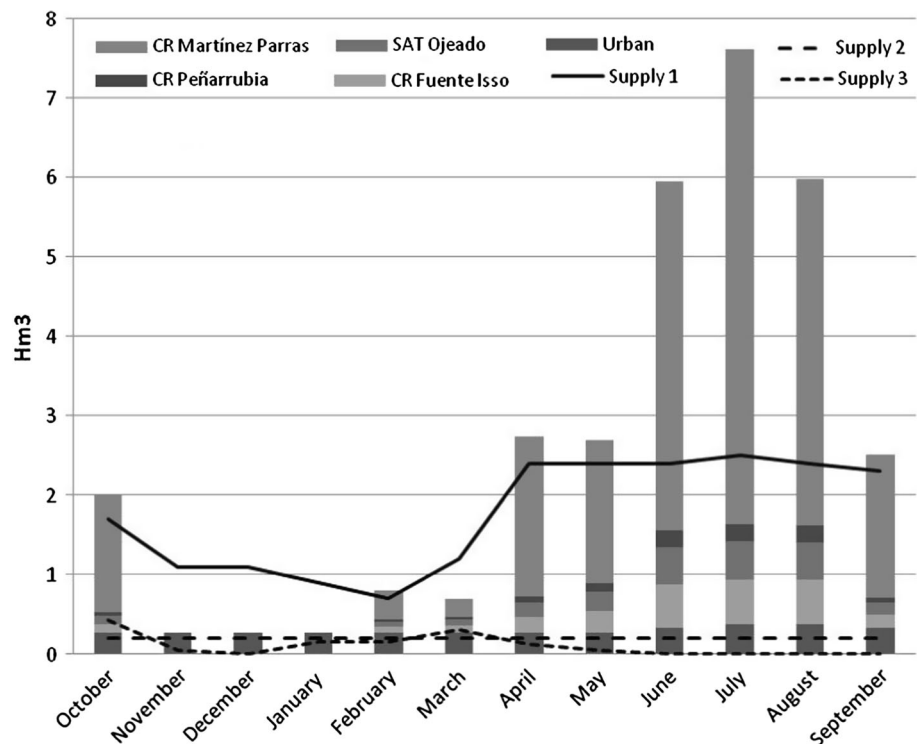
follows: Scenario 1 or 2 plus the variation in demand plus the variation in resources. Thus, Scenario 1-0-0 represents current management with no variation in either demand or resources, Scenario 2+10-10 represents conjoint use with a demand that is +10 % greater than at present and water resources that are −10 % lower, and so on.

Results

Figure 8 compares the two scenarios of variation in demand and resources (as described above) in terms of demand deficit (Fig. 8a), stored groundwater (Fig. 8b) and trend of the water table in the pumping area (Fig. 8c).

Demand deficit: Fig. 8a, top

Concerning the demand deficits for crop irrigation (Fig. 8a), the first scenario ('business as usual') indicates that a 10 % reduction in the size of the croplands would also reduce deficit in the demands of all three croplands (all three 'irrigation communities') that depend on groundwater supply, even if rainfall are reduced by 40 %.

On the other hand, under the scenario of current management with no variation in either resources or demand, the model predicts an average deficit of 16.85 % for the croplands that depend on groundwater for irrigation supply, and a 31.17 % deficit for those depending on a surface water supply.
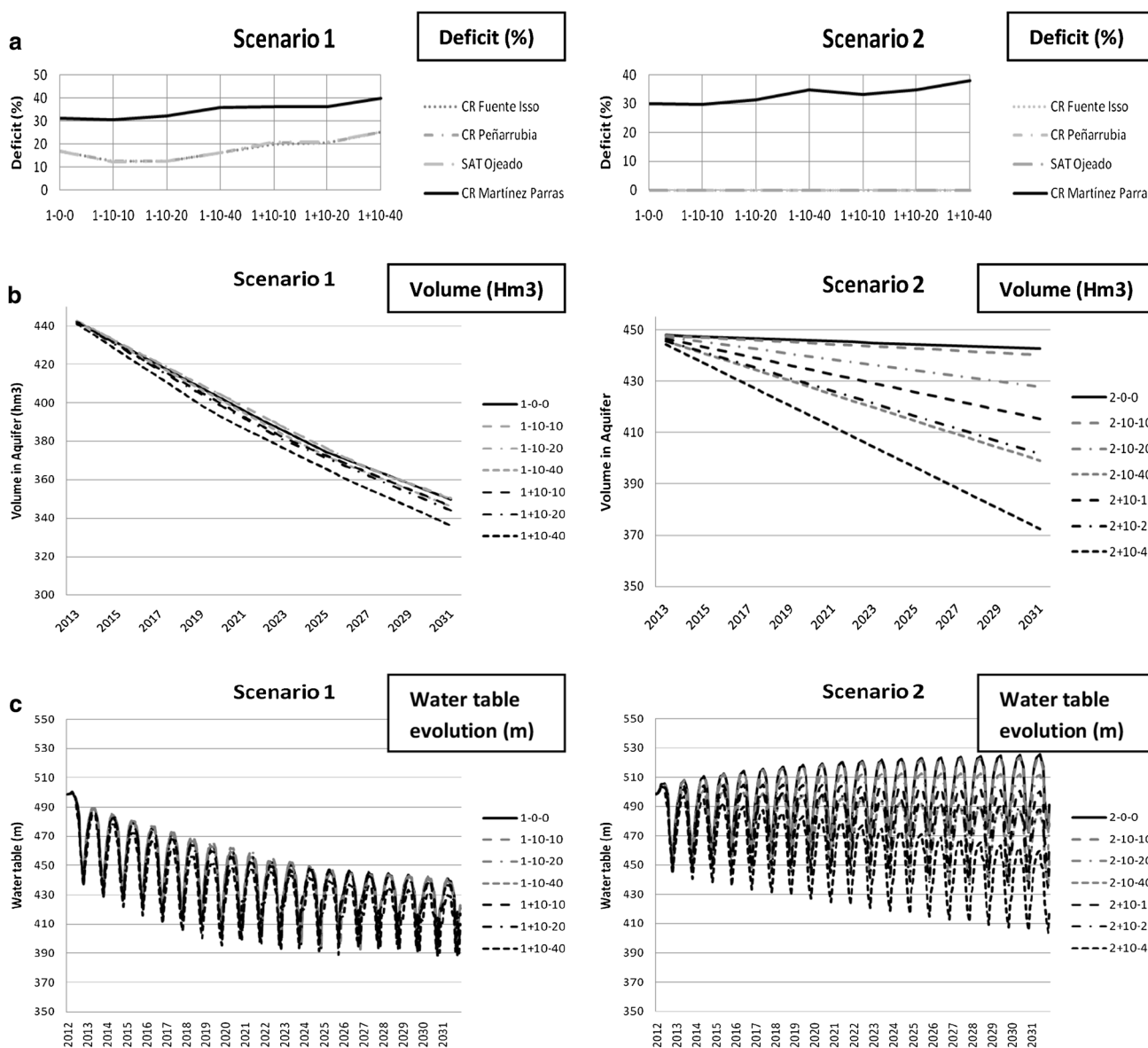

Fig. 8 Model results: **a** demands deficit, **b** water stored volume, **c** water table evolution in pumping cell

If the 10 % reduction in demand is accompanied by a reduction in water resources, the result is positive for the croplands that are fed from the aquifer (deficit of between 12.5 and 16.2 %). However, the same is not true for the croplands that use mainly surface resources. Here the deficit increases to 30.6 % if water resources fall by more than −40 %. However, an increase in demand under Scenario 1 leads to a deficit of more than 10 % for all croplands compared to all the scenarios analysed above.

In contrast, with conjoint management (Scenario 2) the deficit for each of the agricultural demands is reduced, independent of the type of variation (demand/resource) considered. Due to the artificial recharge of the aquifer, over a 20-year period there would be no deficit in any of the croplands fed by groundwater, even when water resources are reduced by 40 %, provided that the surpluses from Hellín canal were used to recharge the Boquerón aquifer. With regard to CR Martinez Parras, given its strong dependence on surface water resources, there would be a 5 % reduction in the deficit compared to the current management scenario.

Stored volume of water—Fig. 8b, middle

Under Scenario 1 (present day simulation), the stored water in Boquerón aquifer (Fig. 8b) falls sharply for any of the variations in demand or resources analysed. The total volume of water stored—currently estimated to be around 450 hm³—would fall to around 350 hm³ in 20 years time under each of the sub-scenarios tested, except for the case where there is a 10 % increase in demand in conjunction with a 40 % fall in resources (sub-scenario 1+10-40). In this last case, the storage would be 335 hm³, which represents three quarters that of the current situation.

With conjoint use of water resources (Scenario 2), the reduction in stored water is largely influenced by the variations caused by climate change and economic evolution over the medium term. While a 10 % reduction in demand and a low-moderate reduction in resources would lead to a drop in the volume of water stored by no more than 4 %, a bigger reduction in resources produces a drop in stored volume of 9 %.

If, instead of considering a 10 % fall in demand, we analyse the consequences of a 10 % rise in demand (Scenarios 2+10), then the stored water volume in the Boquerón aquifer would range from 415 hm³ (Scenario 2+10-10) to 375 hm³ (Scenario 2+10-40). This is equivalent to a drop in water stored of 7 and 17 %, respectively.

In addition, whereas, under Scenario 1, it would be necessary to reduce the monthly allocation for the farms by around 80 % average in order to obtain a balance between recharge and abstraction over a period of 20 years, under Scenario 2, it would be necessary to reduce it by only 10–30 %, depending on the sub-scenario considered. This could be achieved by rationalising the use of water, modernising some of the irrigation systems (López-Gunn et al. 2012) and/or increasing the effectiveness of part of the obsolete installations, as well as renewing some of the pipes with greater losses estimated than mentioned above.

Trend in water table: Fig. 8c, bottom

Finally, regarding the trend in the water table in the southern part of the area (*i.e.* where pumped abstractions are made; Fig. 8c), it is shown that under Scenario 1, the lowering of the water level is virtually independent of the sub-scenario considered, falling from a current level of 498 metres above sea level to 411 MAMSL on average.

With conjoint management under Scenario 2, whereby the El Boquerón aquifer is incorporated into the system as a regulation reservoir, the year-on-year fall in water table is strongly influenced by variations in demand and water resources—as shown in Fig. 8c. Any reductions in demand under Scenario 2 would cause water tables to rise if water resources fell by no more than 20 %. The same would be true if the demand rose by 10 % and the resources fell by no more than 10 % (sub-scenario 2+10-10). Nevertheless a combination of increase in demand and moderate-high reduction in resources would cause a generalised lowering of the water table in the aquifer—for example, from 498 MAMSL to 420 MAMSL under sub-scenario 2+10-40 by 2032.

Discussion

The simulation is performed by characterising the current water management system with no interconnection between surface and underground waters and it reveals the unsustainability of the rate at which the aquifer of El Boquerón is exploited in the mid-term owing to the fall in local water table, which would limit the profitability of existing irrigation products. Having reached maximum drilling depth, all the irrigation communities in the area would be affected directly by the loss of flow volumes and, consequently, their allocations. This would drastically reduce guarantees and, as a result, the profitability of agricultural production.

The above situation requires consideration of an alternative water resources management system that includes the integration of the aquifer of El Boquerón in the local system under study, operating as a large natural regulation deposit. By taking advantage of the course of the Hellín canal as it runs near the southern limit of the aquifer, there is a possibility of supplying surplus surface water during the periods in which said volumes are not required by the associated irrigation communities. Thus, local joint water resources management would take the form of an ASR

(Aquifer Storage Recovery) based on El Boquerón, which would receive and store volumes of water from surface infrastructures during the surplus periods and, in times of drought or peaks in demand, it would supply the necessary flow volumes that could not be compensated with surface resources.

The simulation performed with the Aquatool model of the scenario that shows joint management demonstrates that the recovery of the water table is almost immediate near the recharge area even in scenarios with an increase in demand and moderate water resources decrease and the falls along the rest of the aquifer are cushioned. This ensures maintenance of today's farms in the mid-long term, together with an increase in supply guarantees for all the irrigation communities that are directly or indirectly related to El Boquerón for all the studied scenarios.

This new view of water planning not only offers economic and social benefits by ensuring irrigation for the farmlands of Hellín, but also makes it possible to achieve one of the targets set by the Water Framework Directive by achieving the global balance of the aquifer, reducing consumption to below 10–30 % depending on the climatic change scenario and economic future. This is compatible with the modernisation of the local irrigation infrastructure and the increase in system effectiveness (Madramootoo 2012). The recovery of the levels also enables the reappearance of springs (now dry) and the regeneration of the associated ecosystems.

Conclusions

The main conclusion drawn from the study is that, in situations in which there are no legal or institutional frameworks for the efficient, balanced and environment-friendly planning and allocation of water resources, or said frameworks do not exist, a 'partial' management of the water resources appears to be a feasible halfway solution that counters the imbalances and deficits that exist in many towns and villages, especially in semiarid areas, such as the Mediterranean Arc and, in particular, South and East Spain. The idea on which the 'partial' focus is based is that if all the players in the subsector apply good IWRM practices in their own work and on their own levels, this will contribute to better water resource management on a global scale and ensure direct, genuine participation of all the players directly or indirectly involved in water planning; this will be a first step in the IWRM process. As one possible measure, this work proposes joint water resources management for the specific case under study (surface surplus-underground regulation) owing to the possibilities and guarantees it offers, even in pessimistic future scenarios, together with the fact that it can be easily implemented by

the corresponding local entity or entities. However, it is very important to be aware that there is little probability of the partial management of water resources in the subsector being able to take all the complex decisions on 'integrated' water resources management. Therefore, the agreement of and communication with the river basin authority on which it depends in each case must be ensured.

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