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THEMATIC ISSUE

Integrated water resources management in the basin of the Segura river (southeast Spain); an example of adaptation to drought periods

I. Alhama[1] · G. García-Ros[1] · F. Alhama[2]

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Abstract
The integrated management of the Sinclinal de Calasparra aquifer and surface waters of the Segura river during periods of drought represents an example of sectoral implementation of the European regulatory framework in terms of adaptation to climate change, thanks to the continued effort of the resource management agency, Confederación Hidrográfica del Segura, over almost 30 years of operation. The effective network of piezometric control and gauging stations distributed throughout the basin has made it possible to meet groundwater demand in situations of declared drought in a predominantly agricultural region, while monitoring the effects on the environment of resource abstraction. The agency has promoted the use of numerical models of aquifer behavior as a management tool, as presented in this work, which has served to anticipate the effects of the abstractions planned for the period 2015–2021 on the Gorgotón spring and on the flow of the Segura river as it passes through the aquifer.

Keywords Drought management · Groundwater modeling · Environmental impact

Introduction

Within the general lines of action of the European Union in terms of adaptation to climate change (European Commission 2014a), the Climate Action program considers it a priority to anticipate the possible adverse effects of climate change by adopting mitigation measures since it is considered that good planning has a beneficial impact on the environment and on the economy. Among the less forceful but necessary measures for creating a culture and raising awareness about the problem, the program highlights the provision of information and the integration of planning in the sectoral policies of each EU country, focusing on the most vulnerable sectors: water resources and agriculture (European Commission 2014b). Thus, one of the approaches outlined in the common agricultural policy of the European Union in its agenda for Horizon 2020 (European Commission 2017) is protecting the environment through more sustainable agricultural practices, research and dissemination of knowledge to address climate change repercussions on biodiversity loss, soil deterioration and water quality. Regarding the precepts on water, mostly included in the Water Framework Directive (European Commission 2000), the intervention of the state and sectoral administrations in adapting to climate change must include actions during prolonged drought cycles, which could be further accentuated as a consequence of climate change. Such actions would result in sustainable management of the resource with minimal impact on the environment. At a national level, the EU recognized the progress

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✉ I. Alhama
ivan.alhama@upct.es

G. García-Ros
gonzalo.garcia@upct.es

F. Alhama
paco.alhama@upct.es

[1] Civil Engineering Department, Technical University of Cartagena, Paseo Alfonso XIII 52, 30203 Cartagena, Spain

[2] Applied Physics Department, Technical University of Cartagena, Paseo Alfonso XIII 48, 30203 Cartagena, Spain

of the Spanish state in the implementation of good practices in this matter (European Commission 2007). The guidelines to follow have been defined in the Spanish National Climate Change Adaptation Plan (Plan Nacional de Adaptación al Cambio Climático-PNACC-Ministry of the Environment, MMA 2006) which considered the environmental variables that may be affected by the alteration of surface and groundwater resources as a consequence of prolonged drought cycles. At a sectoral level, in the Iberian Peninsula, water resources management is centralized in Hydrographic Confederations, which, in the case of the Segura river basin and its water masses, is the Confederación Hidrográfica del Segura (CHS).

Located in the southeast of the Iberian Peninsula, the basin of the Segura river extends through several provinces over its 19,025 km^2 area. The province of Murcia, with 98.82% of its territory within the basin, is the largest (60% of the total). The area has a semi-warm Mediterranean climate of average annual temperature around 19 °C and rainfall between 300 and 400 mm/year. According to the data of the National Meteorological Agency (Agencia Estatal de Meteorología, AEMET), temperature and rainfall have changed in the last 10 years, with temperatures above 20 °C and rainfall below 300 mm/year. It is a predominantly agricultural region, where the activity of the horticulture sector represents 26% of its total income, with exports that contribute 0.12% of annual national GDP [see balance of 2017 (CARM 2017; MAPA 2018)]. Spain is the EU country with the highest production in tonnes in this sector, averaging 25% for the years 2014–2016 (MAPA 2019) and the Murcia region contributes 3% of the total.

In the Segura river basin, the demand for water for agricultural purposes is channeled through 75 bodies constituting 41 Irrigation Communities, with an annual demand oscillating around 86.2% of the water available in the basin (CHS 2015), about 1518.7 hm^3 per year (CHS 2014). Water regulation is managed through its surface reservoirs, with a total capacity of 1140 hm^3, from the variable contribution that comes from the Tajo River Basin, with a maximum of 600 hm^3 per hydrological cycle (BOE 2013), and from the 63 defined groundwater bodies, 18 of which are in a situation of overexploitation (Senent-Alonso and García-Aróstegui 2014). The incorporation of groundwater as a reservoir for integrated management is part of the usual practice in some hydrographic confederations (Berbel et al. 2018), as is shown by the fact that Spain is the second country in the European Union with the highest abstraction of groundwater for agriculture, with an average volume of 4713 hm^3 per year over the period 2006–2015 (Eurostat 2015). Of the basin's groundwater resources, around 540.7 hm^3 per year (85.6%) are destined for agrarian purposes, although this figure may increase in periods of drought, such as the years 2004–2006 (BOE 2005).

Part of the responsibility of the Segura Hydrological Confederation is the progressive implementation of the policies mentioned above: quantification of the reservoir and identification of water bodies in the whole basin, exhaustive monitoring of water pressure and quality using an extensive network of piezometers, river flow measurement from the gauging stations distributed throughout the basin and environmental impact studies for each of the resource exploitation proposals. All this information has had an impact on the understanding and optimization of the regulation of water resources exploitation in drought situations, such as the current period of 2015–2018 (MITECO 2018).

As an illustration of the technical requirement on the part of the CHS to control the exploitation of water resources within the basin, we present the numerical model of the Sinclinal de Calasparra aquifer, which predicts the effect of groundwater abstraction on piezometric measurements, on the Gorgotón spring and on the Segura river flow and stream stage by implementing meteorological regime variation conditions that reflect the current drought situation. The numerical modeling is among the requirements imposed by the CHS on applicants for water resources during the drought period declared between 2015 and 2018, since it is considered as a tool in the integrated management of water in this context. There are many proven cases in the literature that demonstrate the fundamental contributions of numerical models to the knowledge and management of water resources in the Mediterranean area (El Kanti et al. 2018) and in other parts of the world (Feng et al. 2011).

Sinclinal de Calasparra aquifer model

The Sinclinal de Calasparra aquifer (Fig. 1) is located in the meridional sector of the Segura river basin (northwest of the Region of Murcia).

Although it is a small aquifer, with an area of 332 km^2 and estimated annual natural resources of around 12 hm^3 (22.5 hm^3 if recharge from irrigation is considered) and given that the fruit and vegetable production derived from the exploitation of its waters is valued at around 42 million gross euros per year (CHS 2015), its management is strategic and CHS has controlled its exploitation since 1992. During this period, drought has been declared twice (2004–2006 and 2015–2018) and the annual groundwater demand from Irrigation Communities, private wells and CHS wells can then reach up to 54 hm^3/year. For this reason, to achieve the necessary level of commitment to climate change adaptation, the measures adopted by CHS in the management of the aquifer translate into:

- Forecast and monitoring of the environmental impact on piezometry and water quality of the adopted measures.

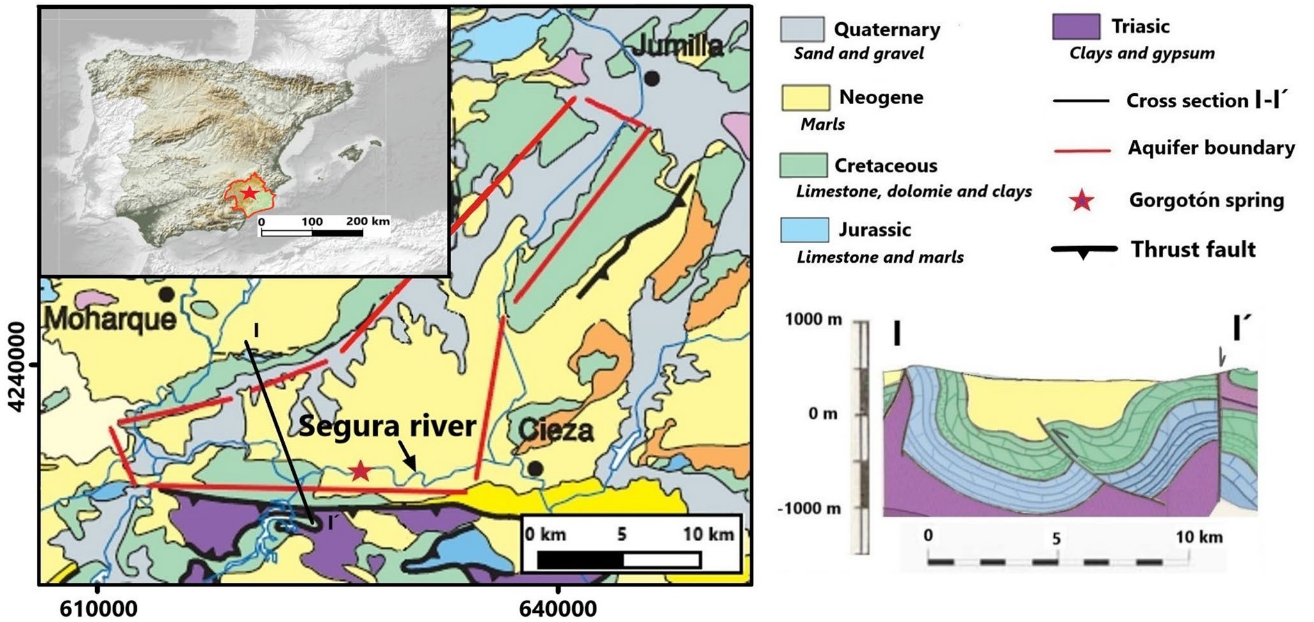

Fig. 1 Sinclinal de Calasparra aquifer regional geological situation in the Segura river basin (CHS 2013, coloured red in the Iberian Peninsula map). Modified from Mapa Geológico de España (Nieto Albert et al. 2008) and Mapa Hidrogeológico de España (IGME 1985)

- Action proposals to ensure sustainable management of the resource.

The aquifer is composed of upper Cretaceous limestones and dolomites, with an average thickness of 300 m, completely saturated, connected to each other by tectonic faults (IGME 1985; Rodríguez-Estrella and Conradi 2006) that contribute to a broad range of hydraulic conductivities of between 1 and 100 m/day, according to aquifer pumping tests carried out during the period 1992–2005 in 19 wells drilled by CHS for drought situations periods. The aquifer is located between the lower Cretaceous clays substrate ("Weald Utrillas Facies", Rodríguez-Estrella 1979) and the Quaternary and Miocene materials at the top, which confer on it unconfined and confined characters, respectively (Fig. 1).

The piezometric levels vary between 170 and 210 m ASL depending on the extractive regime and rainfall, so that the connection between the river and the aquifer also depends on this condition. The river recharges the aquifer upstream of the Gorgotón spring along the Cretaceous limestone outcrops, while downstream, the aquifer discharges into the river as it runs over marls. When the spring dries up, the river becomes a losing stream all along its course in the aquifer. This situation is controlled by evaluating the level in a piezometer located next to the spring (see P-3 in Fig. 5); when its level is below the spring absolute height of 189.2-m ASL, the spring dries up, a situation that has occurred at different times in the first decade of the twenty-first century, coinciding with periods of drought and increased abstractions (Fig. 2). In the model, the spring condition is implemented by means of a drain that allows groundwater to come out when the piezometric level is higher than that of the spring.

The first numerical model of the Sinclinal de Calasparra aquifer was carried out by the Spanish Geological and Mining Survey (IGME) in 1985 at the request of the CHS, for the coordinated management of surface and underground water resources in the Segura basin. Subsequently, and in order to contribute to the management of the aquifer in periods of drought, such as the one that took place between 2004 and 2006, new models were developed in 2003, 2005 and 2008 with Modflow, a software package from the US Geological Survey for the resolution of the water flow equation in porous media (Harbaugh et al. 2000). They were based on the previous model but, this time, in a transient regime incorporating the historical piezometry data in the calibration and updating the available hydrogeological information (IGME 2015). More recently, during the 2015–2018 drought period, other numerical models based on the previous ones were implemented to study the impact on piezometry of the extractive regime programmed in the aquifer to compensate for the impact of the lack of rainfall on agriculture (CHS 2016).

The numerical model presented in this work was also developed with Modflow. The purpose of the simulations was to evaluate the effects on piezometry and stream stage of the Segura river of the pumping program that was proposed to mitigate the effects of the drought during the years 2018–2021. By means of 20 abstraction wells, the proposed extractions would be distributed as shown in Fig. 3.

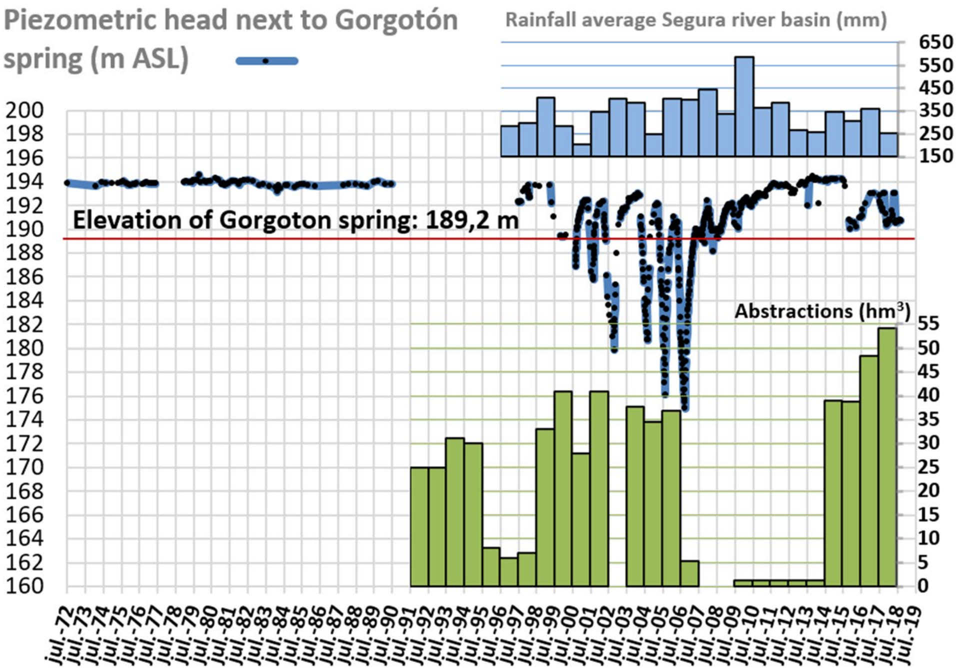

Fig. 2 Piezometric head next to Gorgotón spring (P-3), average rain over the Segura river basin and abstractions from the Sinclinal de Calasparra aquifer. Data available in: https://www.chsegura.es/chs_en/cuenca/redesdecontrol/estadisticashidrologicas/

The model is based on the previous model of 2016 but incorporates new conductivity data obtained from stratigraphic columns and pumping tests. The calibration of the conductivity was made from the piezometry historical series of 6 piezometers, considering continuous monthly information for the period April 2012–February 2018 (Fig. 4).

Making use of parameter estimation tool PEST, which enables control of the partial weight of data introduced (Welter 2015), those piezometers located near the pumping wells (P-2, P-3, P-5 and P-6), whose real schedules are fixed and conductivity measurements are more realistic, were weighted 100%; while P-4 and P-1, located far from the Gorgotón and nearby wells with an uncertainty associated with their schedule, were weighted 50% during the calibration process. A total of 16 complete iteration processes were performed before the final distribution of parameters was achieved, reaching a compromise between the time required for each calibration process and the differences between real and simulated piezometry (fixed at variations below 7% with respect to the total head). The main boundary conditions and the model geometry are summarized in Table 1.

Model results; effects on the spring and the Segura river stream stage

According to the planned extractive regime, the sharpest decreases in the simulation will occur at the end of 2020, reaching the lowest piezometric levels around the

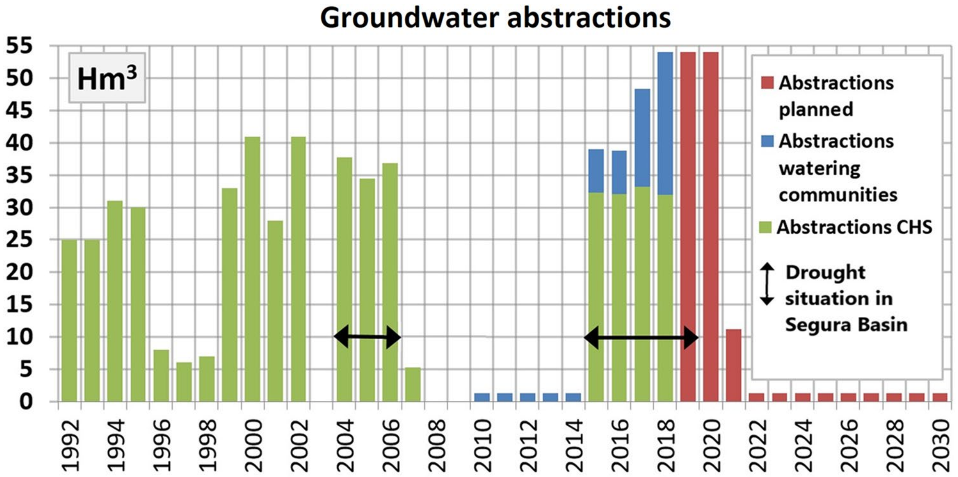

Fig. 3 Abstractions in the Synclinal de Calasparra aquifer during the period 1992–2030. 2003 and 2008–2009 data are not available

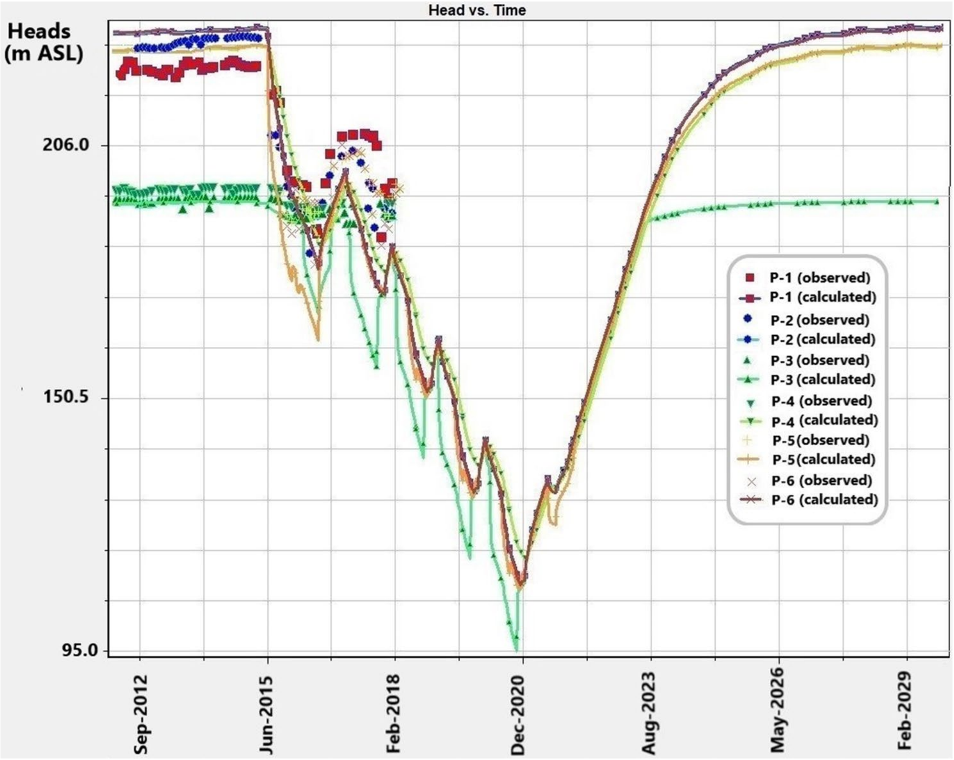

Fig. 4 Calculated and observed data for piezometers P-1 to P-6 after the calibration process

Table 1 Geometric and boundary conditions of the Sinclinal de Calasparra aquifer numerical model

Surface extension	346 km^2	Hydraulic conductivity	2.4–100 m/days
Deep extension	300 m	Rainfall recharge	10 hm^3/year[a]
Number of files	15	Recharge from irrigation	2 hm^3/year
Number of columns	18	River infiltration	10.5 hm^3/year
Unit cell size	2000 × 2000 m^2	Abstractions from pumping wells	0.3–5.9 hm^3/year each
No. calibration piezometers	6	Effective porosity	0.02–0.26
No. pumping wells	20	Gorgotón spring	Drain ($k>$ 100 m/days); topographic height 189.2 m ASL
Time period simulated	2010–2030 year		

[a] 5 hm^3/year considering pessimistic forecast

CHS intakes of 94–96 m ASL (Fig. 4). The recovery of the water upwelling through the spring and the restoration of its optimum flow rate, around 55,000 m^3/day, will take place 5 and 7 years later, respectively. Considering a decrease in water recharge to an extreme value that would perpetuate the current declaration of drought (a reduction of total rainfall by half), the maximum decrease reached in December 2020 would be an additional 11 m, which would mean less than 10% of the total decrease; while the recovery of the spring would occur with a lag of 10 months compared to the normal situation of average yearly rainfall.

As an example of the effect of the first steps in the implementation of the abstraction plan, a piezometric map obtained from the monitoring network and simulated modeling in the vicinity of Gorgotón spring is shown in Fig. 5. A general decrease in piezometry, between 4 and 15 m compared to the natural condition, took place in the area. From the shape of the constant head lines, it is deduced that the Gorgotón spring continued to flow and so the river continued in a gaining stream condition from that point; while upstream, the losing stream condition governed the groundwater–surface water connection.

In the interpretation of the piezometry, it must be taken into account that the Sinclinal de Calasparra aquifer has porosity due to both intergranular spaces and karst conduits. Modflow solves the fluid flow equation in granular media

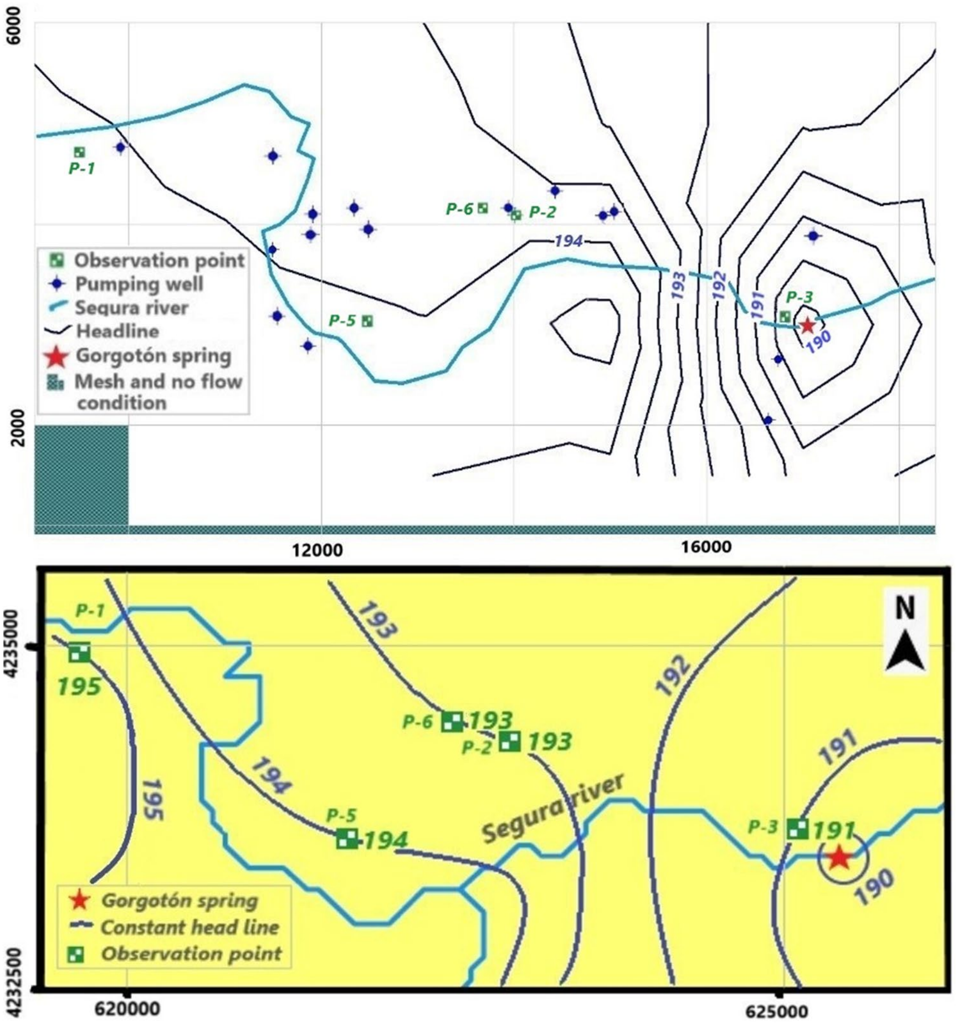

Fig. 5 Spatial distribution of piezometric levels in December 2017; calculated (above) and field monitoring results (below)

by means of finite elements, evaluating the balance of water in space and time in a volume of control of the medium to which Darcy's law is applied. The hydraulic conductivity parameter *k* (m/day), which governs the flow, depends on fluid and soil skeleton properties that cannot be applied to fluid in conduits (see any classical book on groundwater, e.g., Harr 1962). On the other hand, the simulation of aquifers with permeability by karstification is usually complex (Scanlon et al. 2003; Worthington 2009) given that it is difficult to reproduce the heterogeneous distribution of karstic ducts and groundwater preferential circulation channels by the presence of faults. Hence, the global permeabilities of the model do not reliably reproduce the karstic ducts: high permeabilities and karstification channels imply low hydraulic gradients and a wide radius of influence; while the piezometry in aquifers with permeability due to porosity (such as those simulated with Modflow) is more sensitive to the effect of pumping, where the hydraulic gradients are more pronounced and the radius of influence smaller. Therefore, the results of the simulation are considered pessimistic regarding the establishment of temporary piezometry thresholds for the cessation of pumping based on modeling results, allowing for a margin of safety. On the other hand, according to the simulation, the spring should have dried up for the first time in the summer of 2016 but, according to the data of the piezometer P-3, this situation has not yet occurred. This is explained by the fact that some of the aquifer abstraction authorizations have not yet been granted, since they must wait for public exposition periods, postponing the start of some abstractions to 2019. This fact delays future calibrations to 2021 when the real schedule and abstractions will be known with precision. However, the fact that the exploitation of the aquifer has been regulated since 1992 offers the CHS the experience accumulated during the first drought declared in the basin (between 2004 and 2006), when the exploitation of 109.2 hm^3 implied a medium piezometric fall of 40 m in the whole aquifer and a recovery of the levels a year and a half after the cessation of pumping, with the complete recovery of the spring upwelling 6 years later. The quarterly monitoring of the piezometric control network and

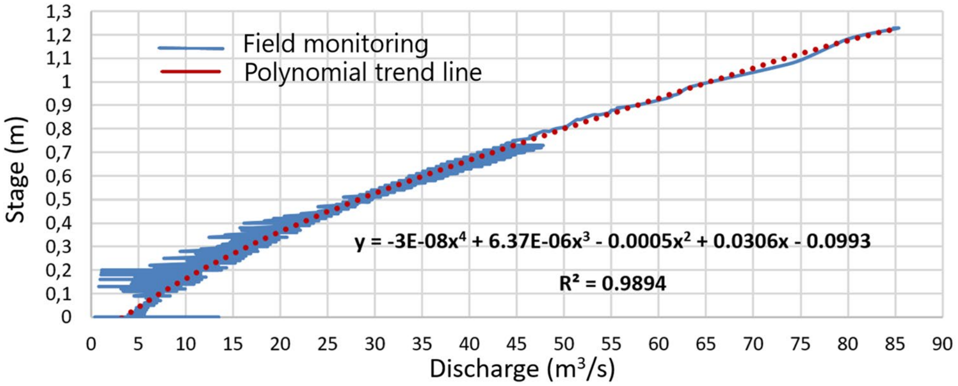

Fig. 6 Rating curve of the Almadenes canyon gauging station, based on CHS data. https://www.chsegura.es/chs/cuenca/redesdecontrol/estadisticashidrologicas/visoraforos/visorjs.html

the gauging stations will allow the CHS to act early and stop extractions if the piezometry is below the minimum threshold reached in December 2006 of 94 m ASL.

Before considering the effects on surface waters, it's important to put in context that CHS coordinates two projects co-financed by European Life + programs (Life + Segura River link and Life + Ripisilvanatura, CHS 2014) that seek the improvement of the conditions of different ecosystems coexisting along the margins of its rivers, as well as the determination of the environmental parameters necessary for maintaining them. For this purpose, among the effects that any intervention on groundwater could cause, it is necessary to consider the effect on both the river flow and the stream stage (height of the water surface). As regards river flow loss, according to the results of the simulation, the spring will stop discharging 20.0 hm^3 per year into the river during the 2019–2024 period. When the spring dries, the river will become a losing stream, which will mean an additional maximum loss of 1 hm^3/year along the stretch that runs over the outcrop of Cretaceous limestones. To mitigate this net flow loss, CHS pours all the groundwater abstracted by its own wells into the river stream, from which the relevant water derivations will be made, and requires between 20 and 40% of the groundwater pumped by the various irrigation communities to be returned to the river. According to the extraction data (Fig. 3) and in terms of absolute gain–loss of river flow, these measures will correspond to an increase of 24 hm^3/year during the period 2018–2020, a loss of 17 hm^3/year for the 2020–2021 interval and a loss of 21 hm^3/year for 2021–2025, this last due to the combination of dry spring and the cessation of river-recharging from pumping wells. The impact on the stream stage could be studied by applying the Manning equation (Manning 1895), which relates the circulating flow to the rugosity, the cross section and the slope of the river in the area of the Gorgotón spring. Given the difficulty in obtaining and estimating some of these parameters, the available stream stage and discharge data from the Almadenes gauging station (located 100 m upstream of the Gorgotón spring) was used. From these, the rating curve of Fig. 6 has been derived.

In an unfavorable hydrological year (such as 2014), in which the discharge variation would fluctuate between 0.7 and 1.4 m^3/s, the expected flow reductions would mean a variation in the stream stage of between − 0.03 and 0.03 m. For the average hydrological year, the variation in the water surface elevation would range between − 0.014 and 0.022 m. Thanks to the return flow of part of the groundwater to the river, the impact on the stream stage and, consequently, on ecosystems linked to the river can be considered practically negligible.

Conclusions

The integrated management of surface and underground waters carried out by CHS, the competent sectoral body, in the Segura river basin during the drought period 2015–2018, is an example of a work methodology that allows the combination of the sustainable exploitation of resources and the implementation of European and national policies in terms of adaptation to climate change in semi-warm Mediterranean climate regions, where the horticultural production that depends on this resource is one of its main sources of income.

The exploitation of the Sinclinal de Calasparra aquifer is proof of this. Since 1992, exhaustive monitoring of piezometry, river flows and groundwater extractions has been carried out and studies are required to foresee possible impacts on piezometry and stream stage when extraordinary extractive measures are approved in periods of drought. The numerical model presented in this paper has served for this purpose and has allowed, taking into account the preventive measures imposed by the administration consisting in returning between 20 and 40% of the water pumped from the aquifer and establishing a maximum piezometry threshold of 94 m ASL (recorded historical minimum), to conclude that:

- The period of maximum extractions would have to cease before the beginning of the year 2021.
- The total recovery of the spring by which the discharge of the aquifer in the river takes place, considering an unfavorable situation of reduction of rainfall by half, will occur between 5 and 7 years after the cessation of the most intense extractions at the end of 2020.
- Considering an unfavorable year in the analysis of the flow history of the nearest gauging station, it has been determined that the cessation of the discharge flow from the spring to the river, estimated at 20.0 hm^3/year, would mean a maximum decrease of 0.03 m in the stream stage, which will not have a significant environmental impact.

The comparison between the results of the model and continuous monitoring during the period of implementation of the measures will allow us to verify the extent to which the model predictions are fulfilled and to act accordingly. Subsequent calibrations of the model, once the real pumping schedule and the piezometric monitoring records are known, will allow the precision of the numerical tool to be increased and become useful in management. The experience in the 2004–2006 drought, with a control on the extractions and measurements of the aquifer response, has served not only for the elaboration of the model itself but also as an additional criterion in the decision-making process.

References

Berbel J, Expósito A, Mateos L (2018) The importance of the groundwater governance in the global change context: a proposal for a Mediterranean aquifer (Llanos de la Puebla, Spain). Groundwater and global change in the western mediterranean area. Springer, Cham, pp 35–42

BOE, Boletín Oficial del Estado (2005) Real Decreto 1265/2005, de 21 de octubre, del Ministerio de Medio Ambiente por el que se adoptan medidas administrativas excepcionales para la gestión de los recursos hidráulicos y para corregir los efectos de la sequía en las cuencas hidrográficas de los ríos Júcar, Segura y Tajo. BOE núm. 256, de 26 de octubre de 2005, pp 35066–35070. Ref: BOE-A-2005-17620. ISSN: 0212-033X. Website: https://www.boe.es/eli/es/rd/2005/10/21/1265/dof/spa/pdf

BOE, Boletín Oficial del Estado (2013) Ley 21/2013, de 9 de diciembre, de evaluación ambiental. BOE núm. 296, de 11 de diciembre de 2013, 86p. Ref: BOE-A-2013-12913. ISSN: 0212-033X. Website: https://www.boe.es/buscar/pdf/2013/BOE-A-2013-12913-consolidado.pdf

CARM, Comunidad Autónoma de la Región de Murcia (2017) Estadística Agraria de Murcia 2016/17, Vol 25. Dirección General de Innovación, Producciones y Mercados Agroalimentarios. Consejería de Agua, Agricultura, Ganadería y Pesca. Retrieved from: https://www.carm.es/web/pagina?IDCONTENIDO=2589&IDTIPO=100&RASTRO=c1415$m1174. Direct download from: https://www.carm.es/web/integra.servlets.Blob?ARCHIVO=ESTAD%C3%8DSTICA%20AGRARIA%20DE%20MURCIA%202016-2017.pdf&TABLA=ARCHIVOS&CAMPOCLAVE=IDARCHIVO&VALORCLAVE=147657&CAMPOIMAGEN=ARCHIVO&IDTIPO=60&RASTRO=c1415$m1174,2589. Accessed 28 Nov 2018

CHS, Confederación Hidrográfica del Segura (2013) Unidades hidrogeológicas, Cartografía Básica de la Cuenca del Segura, escala 1:800.000. Oficina de Planificación hidrológica de la CHS, enero de 2013. Website: https://www.chsegura.es/chs/cuenca/resumendedatosbasicos/cartografia/ Retrieved from: http://www.chsegura.es/export/descargas/cuenca/resumendedatosbasicos/cartografia/docsdescarga/06_5UNIDADES_HIDROGEOLOGICAS_A3.pdf. Accessed 11 Dec 2018

CHS, Confederación Hidrográfica del Segura (2014) Memoria anual 2014. Oficina de Planificación Hidrológica. Depósito Legal: Mu-1.719-2006. Retrieved from: https://www.chsegura.es/chs_en/informaciongeneral/elorganismo/memoriaanual/index.html. Accessed 20 Nov 2018

CHS, Confederación Hidrográfica del Segura (2015) Plan hidrológico de la demarcación del Segura 2015/21; Anejo 3 de usos y demandas, pp 332. Retrieved from: https://www.chsegura.es/chs/planificacionydma/planificacion15-21/index.html. Accessed 20 Nov 2018

CHS, Confederación Hidrográfica del Segura (2016) Anexo 8. Estudio hidrogeológico sobre la puesta en explotación de los pozos de sequía del acuífero Sinclinal de Calasparra (MASUB 070.022) en el periodo febrero-septiembre 2016. Intecsa-Inarsa and MAPAMA. Retrieved from: https://www.jpao.es/wp-content/uploads/2017/01/Anexo-8-ModeloSinclinal2016.pdf. Accessed 20 Nov 2018

El Kanti SM, El Mansouri B, Arjdal Y, Larabi A (2018) Numerical groundwater modelling as an effective tool for management of the deep aquifer at the Dakhla Bay (South of Morocco). In: Groundwater and global change in the western mediterranean area. Springer, Cham, pp 127–135

European Commission (2000) Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Off J Eur Commun Lex 327, vol 43. 22 December 2000. ISSN 0378-6978. Website: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2000:327:TOC. Accessed 23 Nov 2018

European Commission (2007) Addressing the challenge of water scarcity and droughts in the European Union. Communication from the commission to the European Parliament and the Council. Brussels, 18-07-2007, COM (2007) 414 final. Retrieved from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0414:FIN:EN:PDF. Accessed 23 Nov 2018

European Commission (2014a) Adaptation to climate change. Publications Office of the European Union. ISBN: 978-92-79-44523-1. Website: https://ec.europa.eu/clima/policies/adaptation_en#tab-0-1. Retrieved from: https://ec.europa.eu/clima/sites/clima/files/docs/factsheet_adaptation_2014_en.pdf. Accessed 23 Nov 2018

European Commission (2014b) The European Union explained: Climate Action. Publications Office of the European Union, Luxembourg. ISBN: 978-92-79-41342-1. https://doi.org/10.2775/83031. Website: https://op.europa.eu/en/publication-detail/-/publication/d5e0f096-8fc9-4ab7-9010-eecc71e12d41/language-en. Accessed 22 Nov 2018

European Commission (2017) The European Union explained: Agriculture. Publications Office of the European Union, Luxembourg. ISBN: 978-92-79-59592-9. https://doi.org/10.2775/358697. Website: https://op.europa.eu/en/publication-detail/-/publication/f08f5f20-ef62-11e6-8a35-01aa75ed71a1/language-en. Accessed 22 Nov 2018

Eurostat (2015) Annual freshwater abstraction by source and sector. Water statistics on national level. Office for Official publications of the European communities. Agri-Environmental Indicators.

Website https://ec.europa.eu/eurostat/web/agri-environmental-indicators/indicators and https://ec.europa.eu/eurostat/en/web/products-datasets/-/ENV_WAT_ABS. Accessed 22 Nov 2018

Feng S, Huo Z, Kang S, Tang Z, Wang F (2011) Groundwater simulation using a numerical model under different water resources management scenarios in an arid region of China. Environ Earth Sci 62(5):961–971. https://doi.org/10.1007/s12665-010-0581-8

Harbaugh AW, Banta ER, Hill MC, McDonald MG (2000) Modflow-2000, the US Geological Survey modular ground-water model-user guide to modularization concepts and the ground-water flow process. Open-file Report. US Geol Surv 92:134

Harr ME (1962) Groundwater and seepage. McGraw-Hill, New York. ISBN: 07-026740-5

IGME, Instituto Geológico y Minero de España (2015) Encomienda de gestión para la realización de trabajos científico-técnicos de apoyo a la sostenibilidad y protección de las aguas subterráneas. T.: 32 Cap.: VIII. Masa de agua subterránea 071.022. Sinclinal de Calasparra. Download the pdf file from IGME. Retrieved from: http://info.igme.es/SidPDF/147000/999/147999_0000007.pdf. Accessed 04 Dec 2019

IGME, Instituto Geológico y Minero Español (1985) Mapa hidrogeológico de España, E. 1/200.000. Hoja 72, Elche. Servicio de publicaciones del Ministerio de Industria y Energía, IGME 1985. Website: http://info.igme.es/cartografiadigital/tematica/Hidrogeologico200.aspx?language=es. Accessed 11 Dec 2018

Manning R (1895) On the flow of water in open channels and pipes. Trans Inst Civil Eng Irel 4:179–207

MAPA, Ministerio de Agricultura, Pesca y Alimentación (2018) Avance comercio exterior anual 2018. NIPO: 003190942. Website: https://www.mapa.gob.es/es/ministerio/servicios/analisis-y-prospectiva/Informe_anual.aspx. Retrieved from: https://www.mapa.gob.es/es/ministerio/servicios/analisis-y-prospectiva/avanceanualcomercioexterior2018_tcm30-511407.pdf. Accessed 04 Dec 2019

MAPA, Ministerio de Agricultura, Pesca y Alimentación (2019) Cifras del sector de Frutas y Hortalizas. Subdirección General de Frutas y hortalizas y vitivinicultura. Dirección General de Producciones y Mercados Agrarios. Website: https://www.mapa.gob.es/es/agricultura/temas/producciones-agricolas/frutas-y-hortalizas/informacion_general.aspx. Retrieved from: https://www.mapa.gob.es/es/agricultura/temas/producciones-agricolas/cifras_del_sectorfyh_tcm30-502367.pdf. Accessed 28 Nov 2018

MMA, Ministerio de Medio Ambiente (2006) The Spanish National Climate Change Adaptation Plan. Centro de publicaciones del Ministerio de Medio Ambiente y Medio Rural y Marino. NIPO: 310-08-065-9 or 310-08-066-4 (internet), Depósito Legal: M-48.058-2008. Website: https://climate-adapt.eea.europa.eu/metadata/publications/the-spanish-national-climate-change-adaptation-plan-pnacc. Retrieved from: https://www.miteco.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/folleto%20pnacc_ing_tcm30-70395.pdf. Accessed 23 Nov 2018

MITECO, Ministerio para la Transición Ecológica (2018) Real Decreto 1210/2018, de 28 de septiembre, por el que se prorroga la situación de sequía declarada para el ámbito territorial de la Confederación Hidrográfica del Segura por el Real Decreto 356/2015, de 8 de mayo, por el que se declara la situación de sequía en el ámbito territorial de la Confederación Hidrográfica del Segura y se adoptan medidas excepcionales para la gestión de los recursos hídricos. Boletín Oficial del Estado, BOE-A-2018-13188:93864–93867. ISSN: 0212-033X. Website: https://www.boe.es/eli/es/rd/2018/09/28/1210. Retrieved from: https://www.boe.es/eli/es/rd/2018/09/28/1210/dof/spa/pdf. Accessed 22 Nov 2018

Nieto Albert LM, Cabra Gil P, Santos García JA, Martín Serrano A (2008) Mapa Geológico de España, Escala 1:50.000. Hojas: Cieza (891) 26–35. Instituto Geológico y Minero de España (IGME). Website: http://info.igme.es/cartografiadigital/geologica/Magna50.aspx. Retrieved from: http://info.igme.es/cartografiadigital/datos/mgd50/memorias/Memoria891.pdf. Accessed 11 Dec 2018

Rodríguez Estrella T (1979) Geología e Hidrogeología del sector de Alcaraz-Liétor-Yeste (prov. de Albacete). Síntesis geológica de la Zona Prebética Colec Mem IGME 97:566

Rodríguez Estrella T, Conradi C (2006) Uso sostenible y controlado en el acuífero kárstico del sinclinal de Calasparra (Murcia). Capítulo del libro: Karst, cambio climático y aguas subterráneas. (AQUA in MED, Málaga). Publicaciones del IGME. Editores: JJ Durán, B Andreo y F Carrasco. Serie: Hidrogeología y Aguas Subterráneas 18:173–183. ISBN: 84-7840-628-X

Scanlon BR, Mace RE, Barrett ME, Smith B (2003) Can we simulate regional groundwater flow in a karst system using equivalent porous media models? Case study, Barton Springs Edwards aquifer, USA. J Hydrol 276(1–4):137–158

Senent-Alonso M, García-Aróstegui JL (2014) Sobreexplotación de acuíferos en la cuenca del Segura. Evaluación y perspectivas. Murcia, Fundación Instituto Euromediterráneo del Agua. ISBN: 978-84-92988-22-8. Website: https://www.chsegura.es/chs/informaciongeneral/mediatecadigital/libros/libro_0178.html

Welter DE, White JT, Hunt RJ, Doherty JE (2015) Approaches in highly parameterized inversion—PEST++ Version 3, a Parameter ESTimation and uncertainty analysis software suite optimized for large environmental models: U.S. Geological Survey Techniques and Methods, book 7, section C12. https://doi.org/10.3133/tm7C12. Website: https://pubs.er.usgs.gov/publication/tm7C12. Direct download from: https://pubs.usgs.gov/tm/07/c12//tm7c12.pdf

Worthington SR (2009) Diagnostic hydrogeologic characteristics of a karst aquifer (Kentucky, USA). Hydrogeol J 17(7):1665. https://doi.org/10.1007/s10040-009-0489-0