Updating the hydrogeological model of the Gallocanta Lake (Spain): a contemporary approach

J. M. Orellana[ab], Arce, M.[c], Causapé, J.[a]

[a]Geological and Mining Institute of Spain, Zaragoza, Spain
[b]Department of Earth Sciences, University of Zaragoza, Zaragoza, Spain
[c]h2i Water + Innovation, Zaragoza, Spain

INTRODUCTION

Wetlands have been recognized has highly sensitive ecosystems in recent years, for this reason more and more of them have been continuously protected by authorities. However, due to their fragility, many of them suffer the pressure of human activities such as agricultural activity or change of land use. Those factors can lead to an alteration in how they function.

Hydrological studies are especially relevant in this context, both in terms of the supply of drinking water to the population and for the understanding of how certain contaminants and materials behave (i.e. their mobility, dispersion or effect on the environment). Therefore, those studies have become a very useful tool to evaluate complex ecosystems from an environmental perspective.

Based on this principle, Ebro Hydrographic Confederation carried out an in depth study during the early 2000s. The objective was to compile all the previous studies that took place in the area and establish a regulation for water use in the surrounding area of Gallocanta Lake. The main part of the study was to develop a flux numerical model simulating the hydrogeological functioning of the Gallocanta Basin.

The objective of this project is to use FREEWAT platform to update that study, with the goal of evaluating the vulnerability of the ecosystem, in the face of present and future scenarios of climate change and water management.

STUDY AREA

The Gallocanta Basin is located in a large endorheic basin in the central sector of the Iberian Range (Luzón et al. 2007), in the NE Iberian Peninsula. Its total area is about 540 km² and it has a lengthened morphology N-S. It is more than 40 km in length and about 25 km in width at its widest point. Elevation varies from 990 m at the lowest, where Gallocanta Lake is located, and 1400 m above the average sea level in the NW boundary. Gallocanta Lake is the largest saline wetland in Western Europe. It has a maximum length and width of 7.5 km and 2.5 km, respectively. The lake is included in the Gallocanta Lake Nature Reserve. It also is a Special Protection Area for the conservation of bird species and a wetland included in the RAMSAR Convention since 1994. Gallocanta has a bird sanctuary in NE Spain frequented by grey cranes on their annual migration from Scandinavia to northern Africa (Kuhn et al. 2011).

The middle of the catchment is filled with Tertiary and Quaternary sediments and forms a flat upland at 1000 m a.s.l. The catchment is bounded on its north and northeast sides by Palaeozoic rocks of Sierra de Santa Cruz, and to the south and southwest sides by carbonate and calcareous Mesozoic rocks of the Jurassic and Cretaceous. The marly and gypsum facies of the Upper Triassic (Keuper facies) are, together with the carbonate facies of the Middle Triassic (Muschelkalk facies), the underlying bedrock (Luzón et al. 2007). Those impermeable materials not only prevent water flow out of the basin and hinder interactions between surface and deep aquifers, but also contribute to the increase of the salinity of the lake, which is higher when water levels are low (Castañeda et al. 2015). Salinity ranges between 0.5 and 49.4 dS m^{-1} (García Vera et al. 2009).

The climate of the Gallocanta basin is Mediterranean semiarid, with a strong continental and altitudinal influence. Summer is hot and dry and winter is cold with little rainfall. Average annual rainfall is 442 mm, with peak rainfall in spring and fall but a strong inter-annual variation (i.e. max. 1958-1959: 732 mm and min. 1993-1994: 265 mm). Average annual temperature is 11.6 ºC but the aforementioned altitudinal and continental influence lead to a great temperature variation (i.e. min. of around -20 ºC and a max. above 35 ºC).

The main characteristic of the water volume in the lake is its inter-annual and inner-annual variability. Recording started in 1974, since then, the lake's water level dropped continuously until 1985, when the lake dried. After a recovery during the late 1980s, since the mid-1990s until 2010 extremely dry years alternated with years of open water.

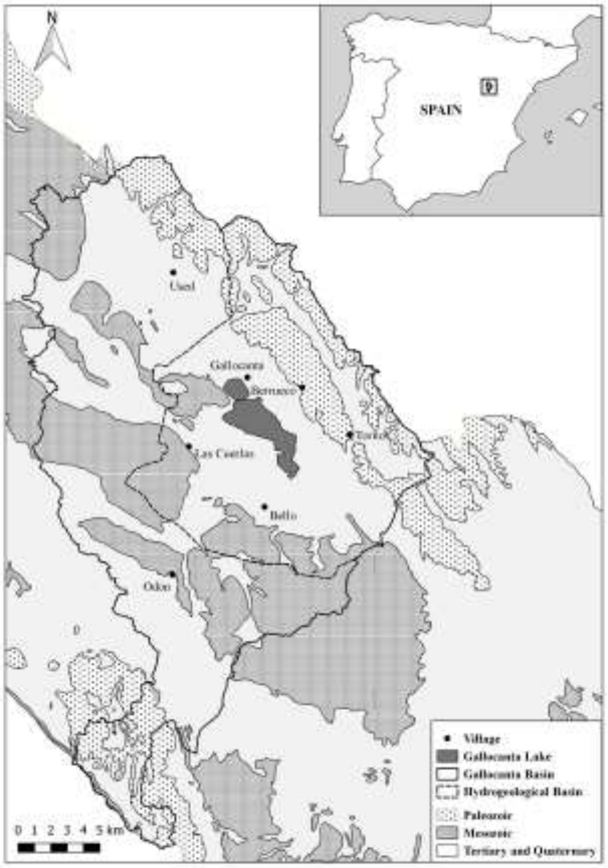

Fig. 1.Location and geology of Gallocanta Basin.

METHODS

FREEWAT platform was used as the main tool for modelling and processing data. FREEWAT is an open source and public domain GIS integrated modelling environment for the simulation of water quantity and quality in surface water and groundwater with an integrated water management and planning module (Rossetto et al. 2015). FREEWAT is installed as a plugin in QGIS and includes geoprocessing, post-processing tools and modelling settings. It uses SpatialLite as a geodatabase manager, and MODFLOW-2005 as the main modelling code. MODFLOW and its relating modelling codes are used since they are widely recognized as international standard for simulating groundwater conditions and their interaction with surface water (Cannata et al. 2017).

Conceptual Model

Gallocanta Basin is located within the Gallocanta Hydrogeologic Unit (GHU) (San Román, 2003). It is characterized by its hydraulically open boundaries in part of the basin and the different extensions of the groundwater basin and the surface basin. GHU is comprised of several aquifers: Jurassic and Cretaceous carbonated rocks (carbonated aquifers) and quaternary rocks (quaternary aquifer).

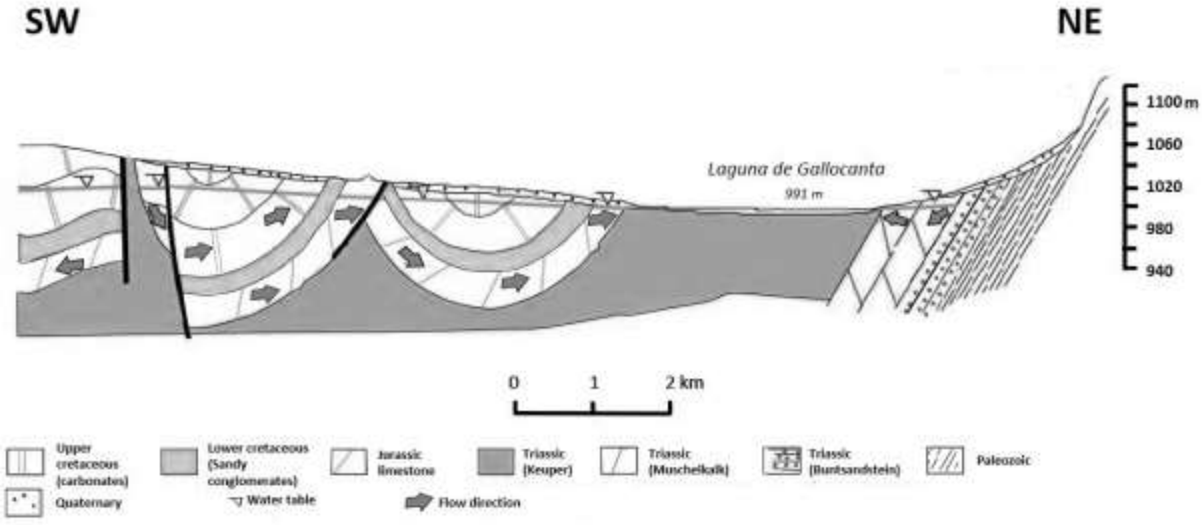

Fig. 2.Cross-section of the hydrogeological system. Adapted from San Román (2003).

In the model, inflows and outflows were simulated. Inflows are through rainfall (areally-distributed recharge), groundwater leakage and sporadic surface runoff whereas outflows are through evapotranspiration and groundwater extractions.

In accordance with the geology of the basin, different hydrogeological parameters were set. The study area has been divided into nine hydrostratigraphic units with specific hydrogeological characteristics, and variable thickness and outcropping surface. Due to the complex geology of the basin, vertical discretization has been divided into 43 layers. Hydrogeological parameters are based on the nine hydrostratigraphic units.

Table 1. Hydrostratigraphic units.

Hydrostratigraphic Unit	Thickness (m)	Hydraulic conductivity (m/d)			Specific storage (l/m)		Porosity (%)
		Horizontal KX	Horizontal KY	Vertical KZ	SS	SY	
Buntsandstein	130-150	0.001	0.001	0.00005	0.000001	0.001	0.1
Muschelkalk	140-200	1	1	0.005	0.00005	0.005	0.5
Keuper	140-500	0.0001	0.0001	0.00000005	0.0000001	0.001	0.1
Jurassic	200-260	25	25	0.125	0.00005	0.015	1.5
Utrillas- Ceno	100-250	0.02	0.02	0.0001	0.0001	0.001	0.1
Carbonated Cretaceous	200-300	2.5	2.5	0.0125	0.005	0.005	0.5
Loam-dolomitic cretaceous	150-200	0.5	0.5	0.0025	0.0002	0.002	0.2
Tertiary	50-350	0.01	0.01	0.00005	0.0001	0.001	0.1
Quaternary	5	50	50	0.5	0.25	0.6	20

Model implementation

As a test of the conceptual model and the software, the model was run under steady-state conditions. The modelling area is defined by a grid of 208 km² surrounding the lake with a resolution of 250 m by 250 m, 48 columns by 72 rows (3456 cells). Model vertical discretization consisted of forty three layers from 1150 m a.s.l. (layer 1) to 0 m a.s.l. (layer 43) with uniform thickness. From 0 m to 500 m, the thickness of each layer is 50 m. From 500 m to 980 m each layer is 20 m thick. Four layers (5 m, 10 m, 10 m and 20 m) span 980 m to 1020 m. From 1020 m to 1100 m there are 20 m layers again and from 1100 to 1150 is one layer of 50 m.

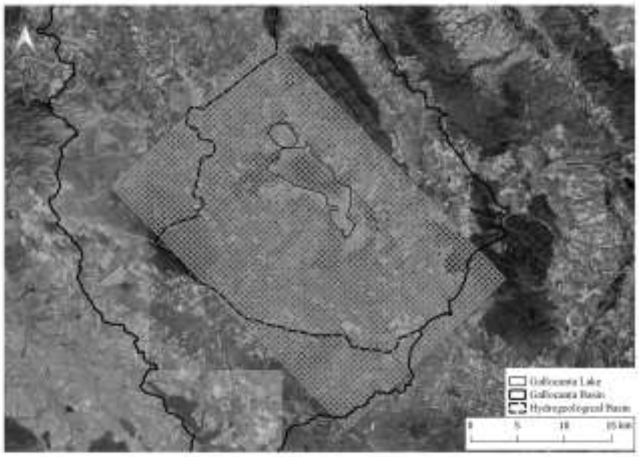

Fig. 4.Horizontal discretization of the model grid.

Since Gallocanta is an endorheic basin, one of the relevant updates to the model is the implementation of the Lake Package (LAK) for the Gallocanta Lake as a boundary condition. This package allows the simulation of hydraulic interaction between the lake and groundwater in the surrounding aquifers so that the effects of the changes in the conditions of one of the bodies of water are calculated on the other (Cannata et al. 2017).

The water budget was done by including the WEL Package, which was implemented to simulate the recharge by surface runoff, and the RHC package, used to recharge the aquifers based on areal distribution. In addition to that, a layer of heads observations was used for the calibration of the model. Rainfall, runoff, infiltration, evapotranspiration and extractions data from the previous CHE model were used for the water budget.

RESULTS and DISCUSSION

The model estimates inflows of 12724 m³ by rainfall and infiltration and 5612 m³ by surface runoff whereas outflows are estimated at 17723 m³ by evaporation through the lake and its surrounding area and 614 m³ by extractions.

The model calibration was done by including 20 heads observation across the study are while running the model. Correlation between estimated and observed heads is 0.58. However, the model tends to overestimate the observed heads (Fig. 4).

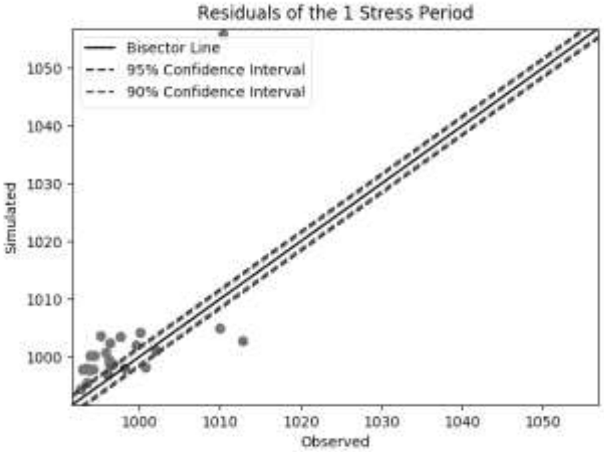

Fig. 4.Oberserved and estimated heads

The overestimation could be an indication of the presence of another outflow apart from the lake. This could be related to the hydraulically open boundaries of the system across the NW and SE limits. This hypothesis has to be verified.

CONCLUSIONS

Recovery and update of an old hydrogeological model of the Gallocanta Basin has been done. FREEWAT platform has proved to be an efficient and powerful tool in a complex basin like Gallocanta. However, according to the results, estimated heads are higher than observed heads, which means than another outflow apart from the lake should be considered in the basin. This overestimation could confirm that Gallocanta Basin is connected to the adjacent Jiloca river basin or Piedra River basin through groundwater interactions in the SE and NW boundaries of the Gallocanta Basin. This theory would lead us to rethink the current conceptual model of the basin, which would influence the protection of the Gallocanta Lake and its water management regulation. The extension and update of the model is necessary to confirm the change in the conceptual model and will provide information for facing future and present climate change and modifications in water management in the basin in the short and long term in Gallocanta wetland.

ACKNOWLEDGEMENTS

This paper is part of the PhD grant bestowed by regional government of Aragón (Spain) thanks to Funds FEDER (2014-2020), to J. M. Orellana who developed his project in the Geological and Mining Institute of Spain (IGME) and the University of Zaragoza (Spain). This work is included in project CGL2015-66016-R, funded by Ministry of Economy of Spain and Funds FEDER from the European Union.

REFERENCES

Cannata, M., Neumann, J., and Rossetto, R. 2017. Open source GIS platform for water resource modelling: FREEWAT approach in the Lugano Lake. *Spatial Information Research*.

Castañeda, C., Gracia, F. J., Luna, E., and Rodríguez-Ochoa, R. 2015. Edaphic and geomorphic evidences of water level fluctuations in Gallocanta Lake, NE Spain. *Geoderma*239–240: 265–279.

Dadaser-Celik, F., and Mete C. 2017. Modelling Surface Water-Groundwater Interactions at the Palas Basin (Turkey) Using FREEWAT. *Acque Sotterranee - Italian Journal of Groundwater* 6 (3):53–60.

García-Vera, M.A., San Román, J., Blasco, O., Coloma, P., 2009. Hidrogeología de la Laguna de Gallocanta e implicaciones ambientales. In: Casterad, M.A. and Castañeda, C., (Eds.)*La Laguna de Gallocanta: Medio natural, conservación y teledetección*. Memorias de la Real Sociedad Española de Historia Natural 7, España, pp. 79–104.

Grodzynskyi, M., and Svidzinska, D. 2017. Modelling the Impact of Rural Land Use Scenarios on Water Management: A FREEWAT Approach to the Bakumivka Catchment Case Study, Ukraine. *Acque Sotterranee - Italian Journal of Groundwater* 6 (3):39–50.

Kuhn, N. J., Baumhauer, R., and Schütt, B. 2011. Managing the Impact of Climate Change on the Hydrology of the Gallocanta Basin, NE-Spain. *Journal of Environmental Management* 92 (2):275–83.

Luzón, A., Pérez, A., Mayayo, M.J., Soria, A.R., Sánchez Goñi, M.F., and Roc, A.C. 2007. Holocene environmental changes in the Gallocanta lacustrine basin, Iberian Range, NE Spain.*The Holocene*, 17, (5): 649–663.

Rossetto, R., Borsi, I., and Foglia, L. 2015. FREEWAT: FREE and open source software tools for WATer resource management. *Rendiconti Online Società Geologica Italiana*35: 252–255.

San Román, J. 2003. *Establecimiento de las normas de explotación de la unidad hidrogeológica "Gallocanta" y la delimitación de los perímetros de protección de la laguna*. Confederación Hidrográfica del Ebro, Zaragoza, 402 p.