Resources Assessment of a Small Karstic Mediterranean Aquifer (South-Eastern, Spain)

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Abstract Groundwater from small aquifer systems is frequently used for urban supply in southeastern Spain. Aquifers such as the Ventos system, located in Mediterranean semiarid environments, are sensitive to climatic and anthropogenic changes. Many of them have been severely depleted due to intensive pumping. Drawdowns in the Ventos aquifer amount to approximately 80 m over the last three decades. Adequate knowledge of groundwater resources is necessary for water planners and managers to guarantee suitable abstraction. This paper presents a methodology to estimate groundwater recharge in these kinds of quick-response semiarid karst aquifers. A distributed model has been used to evaluate the fraction of rainfall that ultimately results in aquifer recharge, as well as the correlation between the magnitude of rainfall events and infiltration rates. Modelling results are then compared with direct observations of the recharge processes and discussed to evaluate the implications of time scales.

1 Introduction

Groundwater resources contribute substantially to the supply of water in Alicante, southeastern Spain. The use of groundwater has increased significantly during the

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last decades, largely due to an increasing population and to the development of the agricultural, tourism and industrial sectors. This has had an impact both on the quantity and quality of groundwater resources. Knowledge of groundwater resources is thus important to guarantee suitable abstraction levels and environmental flows.

The Alicante province consists of 144 councils, whose population amounts to two million inhabitants. Aquifers play a relevant role in local supply because groundwater is often the only water source. Thus, approximately 51.8% of urban supplies are met by groundwater. In turn, approximately 27% of these supplies come from aquifers located within the same (or neighbouring) municipalities (DCH 2007). Ventos is an example of this. It is a small karst unit which is solely exploited for urban supply purposes. Since the 1970s the Ventos aquifer provided drinking water to Agost, a 5,000-inhabitant town. Apart the importance of water for this small town, this system was specifically selected because the conceptual model seems quite simple and large datasets are available to develop and calibrate models.

Determining which of a wide variety of techniques is likely to provide reliable recharge in karst aquifer estimates is not a simple problem (Lenner et al. 1990; Scanlon et al. 2003). Recent times have witnessed an increasing interest on the part of the scientific community to comprehend the above the recharge processes. A big part of these efforts focuses on techniques and numerical models to calculate the magnitude of the recharge (Zagana et al. 2007; Andreo et al. 2008).

The aim of the present study is to quantify the resources in the Ventos aquifer and to establish the conceptual model of the system. A distributed model has been developed for this purpose.

2 Hydrogeological Characteristics

The region where the aquifer is located presents a typically Mediterranean climate, where long dry periods alternate with short wet sequences and hot dry summers follow short mild winters. Average temperature is 18.5 °C, and potential evapotranspiration estimates range between 870 and 1120 mm/yr. Mean precipitation is 275 mm/year, and presents marked seasonal variations. Most rainfall takes place in autumn.

Ventos aquifer is made up of Cretaceous limestones whose thickness ranges between 80–120 m (Fig. 1). The aquifer, about 7 km^2, is completely isolated from other aquifer formations. It presents a synclinal structure with its main axis tilted to the southwest.

Before the 1970s the aquifer behaved in an undisturbed manner. Rainfall infiltration is the only system input. Water follows a downward circulation path from the upper part of the mountain range to the area where Agost is located. Discharges originally took place through the Agost spring, which dried up some time after pumping from the aquifer began. Today, the sole output of the system is groundwater pumping (200,000 m^3/year). Pumping take place by one well, which works only a few hours a day.

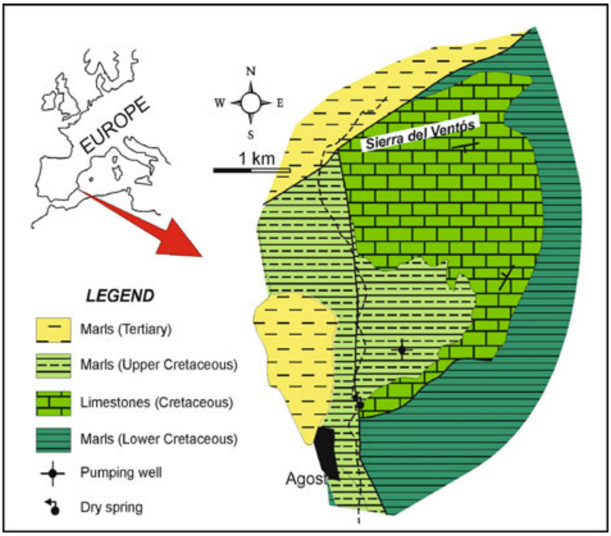

Fig. 1 Geographical location and geological setting. Isolated pumping well and spring (nowadays dry) placement are shown

Though abstractions do not seem overly large, groundwater pumping has cause the level to drop by 80 m. Short-term changes in groundwater levels suggest that aquifer replenishment only responds to significant rainfall episodes. Thus, automated piezometric records reveal that rises in the water table are observed a few hours after each storm. These are followed by a slow recovery during the ensuing weeks, the replenishment rate gradually decreasing in magnitude over time (Touhami et al. 2008). On the other hand, it has been shown that similar rainfall values yielded significantly different recovery rates. This can be attributed to the joint influence of a variety of parameters, such as, frequency between rainfall events, precipitation intensity, soil moisture content and temperature.

3 Numerical Modelling

The numerical model is implemented in Visual Modflow Pro 4.1, one of the most widely available three-dimensional groundwater flow and solute transport simulation systems (WHI 2005). Using Modflow to estimate recharge presents two potential pitfalls, one mathematical and one physical. These refer to the numerical approach used to compute recharge, as well as to the peculiarities of karst systems.

Thus, parameter fitting is used to estimate recharge rates based on hydraulic heads, hydraulic conductivity and other parameters. Scanlon et al. (2002) however argue that recharge and hydraulic conductivity are highly correlated from the numerical viewpoint, and that inverse modeling estimates the ratio between those two parameters rather than their absolute values. In other words, several combinations of these two parameters may render a good adjustment between observed and calculated heads. Therefore, estimating recharge via inverse modeling may yield inaccurate results. This can be prevented by constraining the hydrodynamic parameters of the model, which in turn implies the need to count on sufficiently comprehensive field data.

On the other hand, the use of Modflow in karst environments remains controversial. This is because Modflow assumes porous flow, whilst karst systems may exhibit turbulent regimes. From the modelling standpoint this is tackled through defining an equivalent porous medium. Equivalent porous media models may be problematic in aquifers with well-developed conduit networks, but perform reasonably in those aquifers where karstification is poorly developed. This allows Modflow and other finite-difference distributed codes to provide sufficiently good results at the regional scale (Pulido-Bosch 1989; Scanlon et al. 2003; Martínez-Santos et al. 2005; Quinn et al. 2006).

The relatively simple behaviour of the system, together with its small size, allows for straightforward grid modelling. The aquifer is thus described as a single layer whose thickness varies with the relative elevation of the land surface and the impervious basement. Cells are uniform in size, covering an area of 50×50 m each. No-flow boundaries are prescribed in all directions. Active cells are defined for the aquifer area expected to remain saturated throughout the simulation process, and recharge is assumed uniform across the system. Hydraulic conductivity and specific yield are defined in agreement with pumping test data.

A steady-state simulation was carried out to replicate natural system conditions. This yields average spring discharges in the order of 0.5 Mm^3/year. Transient calibration ensued, taking into account the variability of pumping and recharge rates over time. Calibration considers monthly time steps, spanning a nine-year period (1999–2007).

Model calibration relies on observed groundwater levels, since the springs dried up long before the modelled interval. Figure 2 presents the calibration results. As shown, the model replicates the observed trend to a reasonable extent. Hydrodynamic parameters were modified for sensitivity analysis purposes. Storage coefficient was thus identified as the most sensitive parameter. Optimal correlation was obtained for storage values of 0.33 to 0.40%, the best adjustment standing at 0.36%. Doubling the existing estimate brings the R^2 coefficient to below 0.5, whereas halving it renders an R^2 in the order of 0.20. In both cases the trend remains recognizable, if considerably more detached from field observations.

The model suggests that correlation between rainfall and recharge is nonlinear. This confirms the hypothesis that temporal scales are crucial to reach more refined recharge estimations. From a conceptual standpoint the model assumes that recharge in the saturated zone is instantaneous. This ignores observed storage and transfer functions proper to the epikarst and vadose zones. As a result, the effect of individual recharge episodes is lost.

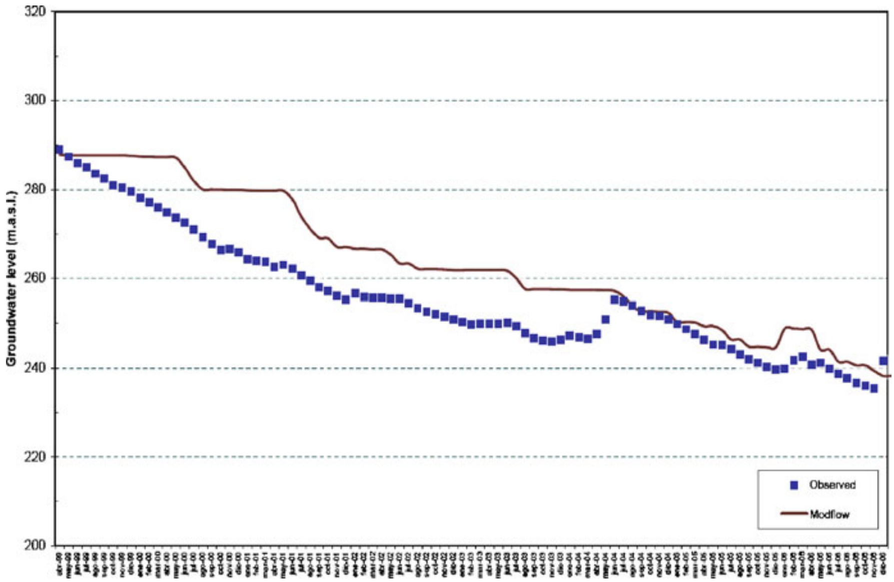

Fig. 2 Observed and predicted piezometric levels during 1999–2006 period

4 Conclusions

Ventos aquifer is a small aquifer located in a Mediterranean climate, where present abstraction rates exceed several times their yearly resources. Knowledge of the resources has a crucial importance to water supply of small town of 5000 inhabitants. In order to estimate water balance, groundwater recharge to this aquifer has been presented and validated through the application of a distributed model (Modflow). The main results show that there is no linear relation between rainfall and recharge. Instead, the fraction of rainfall that results in recharge seems to increase exponentially with the magnitude of the precipitation event. Infiltration coefficients estimated vary widely, between 5 and 36%, and entail that the average yearly infiltration coefficient is less than 10%. Despite the limitations that stem from defining aquifers as equivalent porous media, this model provides an intuitive estimate of the system's behavior and replicates the observed trends reasonably well. This, together with direct observation of the system, suggests that this approach provides a sufficiently accurate representation of reality.

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