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Water balance and flow rate discharge on a receiving water body: Application to the B-XII Irrigation District in Spain

Maria C. Moyano[a], Lucia Tornos[a], Luis Juana[b,*]

[a] Centro de Estudios Hidrográficos (CEH), CEDEX, Paseo Bajo de la Virgen del Puerto 3, 28005 Madrid, Spain
[b] Unidad de Hidráulica, Hidrología y Riegos, Departamento de Ingeniería Agroforestal, ETS Ingenieros Agrónomos, Universidad Politécnica de Madrid, Ciudad Universitaria Avenida Complutense 3, Madrid, Spain

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SUMMARY

The quantification of the main water balance components becomes necessary to diminish the pollutants load from drainage, and its harmful effect on the environment, aggravated within a context of increasing water scarcity. As a first approach to the hydrological study of the 15,000 ha B-XII Irrigation District in Spain, a conceptual lumped model entitled WATEN has been developed, aiming to calculate the monthly flow rate discharge to the Guadalquivir River over the period 2002–2012. The model requires as inputs, irrigation, precipitation and potential crop evapotranspiration. Main model parameters are the total and readily available moisture in the soil, the effective rainfall and the irrigation efficiency. Energy consumption for drainage discharge was used for calibration. Both classical optimization and a robust approach based on Monte Carlo were performed. In order to diminish computational requirements, Monte Carlo was not haphazardly applied, but conducted on a similar manner to genetic algorithms, entitled Parameters Estimation on Driven Trials (PEDT). The model attained an average Nash–Sutcliffe coefficient $e_2 \cong 0.90$ between observed and estimated drainage discharge. It was detected a significant crop evapotranspiration reduction compared to potential values. The volume of water discharged to the river might be sufficient for leaching irrigation water salts.

1. Introduction and objectives

Irrigated agriculture reinforces land productivity and crop diversity, particularly in arid and semi-arid areas (Tanji and Kielen, 2002). However, intensive agriculture at catchment scale, directly impacts on downstream water bodies (FAO, 2012). To diminish the negative effects, the European Water Framework Directive (EU, 2000) pursues an integral approach in terms of water quality and quantity allocation.

Irrigated agriculture is the largest water consumer, accounting for 70 percent of freshwater withdrawals (WWAP, 2012). The increasing global water demand is aggravating the competition between agriculture and the environment for fresh and good quality water. Drainage water, containing agrochemicals and salts, may degrade water quality in receiving water bodies (Ongley, 1996), intensifying water scarcity, especially where regulations are slightly enforced (FAO, 2012). It is predicted that climate change will worsen this situation (Turral et al., 2011).

Climate change may aggravate water scarcity in the Mediterranean basin (IPCC, 2012), affecting crop productivity in the coming decades (Tubiello and van der Velde, 2010). Irrigated agriculture has been practised for millennia in the Guadalquivir river basin (Spain), rising by 500% since 1900. This tendency, mostly pronounced over the last decade, has leaded to the reduction of the assigned water per irrigation district (Rodríguez-Diaz et al., 2007).

The B-XII Irrigation District of the Lower Guadalquivir Irrigated Area (B-XII ID) is one of the largest irrigated areas in Spain. It is referred to as a nitrate vulnerable zone (CHG, 2013) following the European Commission nitrates directive (EU, 1991). As pointed out by Barros et al. (2011), the management and quantification of water balances becomes necessary to diminish the pollutants load from drainage and its harmful effect on the environment, particularly at irrigation district scales. On this line, the European Commission has joined forces to elaborate physical water balances models at basin levels (EU, 2014). Experience has shown that water balances often need to be implemented at different stages, including extended information as needs arise (FAO, 2012).

The lack of robust data is a restrictive factor when it comes to conduct complex or physically based models (Wagener et al., 2003). When not enough data is available, the successful

* Corresponding author. Tel.: +34 91 336 56 76.
E-mail address: luis.juana@upm.es (L. Juana).

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application of a conceptual rainfall–runoff model (CRR), in particular rainfall-return flow in this study, depends on the accuracy of calibration (Diskin and Simon, 1977).

Classical calibration research has been based on mathematical optimizations of either single or multi-objective functions. The complexity of finding a unique set of parameters to optimize a CRR model has been historically reported. Numerous studies have relied on the improvement and comparison of optimization algorithms (e.g., Duan et al., 1992; Yapo et al., 1998; Vrugt et al., 2003; Kollat and Reed, 2006; Skahill and Doherty, 2006). The considered objective function often presents local minima which do not guarantee to find the optimized parametric vector. Beven and Freer (2001) pointed to numerous model structures and parameters vectors which may reasonably approach observed data. Robust parameter optimization is an alternative to classical optimization (Bárdossy and Singh, 2008). It is no longer based on algorithms which optimise objective functions, but on a geometric Monte Carlo simulations process search for robust parametric vectors (Cullman et al., 2011). It has been widely applied in successful applications (e.g., Seibert, 1999; Choi and Beven, 2007; Rientjes et al., 2013).

In this study, we have developed a conceptual lumped model WATEN, aiming to calculate the flow rate discharged from the B-XII ID to the Guadalquivir River over the period 2002–2012. Actual evapotranspiration and soil moisture deficit result as ancillary model outputs. The aim of this work is to approach the hydrological study of an Irrigation District lacking of robust data in such a manner that the water balance is performed from less to more process complexity.

The present study is intended to be the basis for similar worldwide studies, and to serve as a guide for future alike applications. The characteristics of the B-XII ID are analogous to many others coastal irrigation districts with drainage discharge to receiving water bodies, as is the case of many irrigated areas of Egypt, Pakistan or India amongst others (Ritzema, 2009).

2. Study area

The B-XII ID covers an area of about 15000 ha. It is part of the Guadalquivir Marshland, located near the Atlantic coast of South-West Spain, close to the estuary of the Guadalquivir River (Fig. 1).

A soil reclamation project was conducted in the second half of the XX century. After decades of salt leaching, irrigation was set up over the 1980s and nowadays, agriculture represents the main economic activity in the area.

For the irrigation system, three secondary canals receive water from Melendo reservoir. Water is pumped and distributed to the fields through sprinklers, furrow or drip irrigation. A system of subsurface drainage controls the groundwater table and permits the leaching of salts. From the fields, drainage flows into progressively larger drainage canals which dispose the effluent to the river through a system of tidal gates and pumping stations. Tidal gates are only used at occasional peak water levels.

3. Methodology

3.1. Data availability

Monthly data of land use, precipitation, irrigation and energy consumption at drainage pumping stations has been accessible for the period 2002–2012.

Fig. 1. Location and aerial view of the B-XII ID of the Lower Guadalquivir Irrigated Area.