A model for water discharge based on energy consumption data (WATEN)

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1 Introduction

- In this study, we have developed a lumped model WATEN, aiming to calculate the flow rate discharged from the B-XII Irrigation District in Spain to the Guadalquivir River over the period 2002-2012.
- Intended as a first step to quantify the discharge of nitrates and salts from an irrigation district with scarce data availability to a receiving water body, and will serve as a baseline for similar worldwide studies and future alike applications.

2 Study area

- The 15000ha-B-XII Irrigation District is one of the largest irrigated areas in Spain.
- 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, installing subsurface drainage.

Figure 1

3 Methodology

3.1 Water balance and model equations

- Series of crop evapotranspiration (*ET*), drainage (*D*) and soil moisture deficit (SMD) or (S-S_{i-1}) were determined based on precipitation (*P*), irrigation (*I*) and reference evapotranspiration (ET_o).
- All the variables in Eq. (1) are positive, greater than or equal to 0.

$$P + I = ET + D + S - S_{i-1} \quad \text{Eq. (1)}$$

Model equations

$$SMD = (SMD_{i-1} + ET - P\cdot R_P - I\cdot R_I)\cdot(0 < SMD_{i-1} + ET - P\cdot R_P - I\cdot R_I < TAM) + TAM\cdot(SMD_{i-1} + ET - P\cdot R_P - I\cdot R_I > TAM) \quad \text{Eq. (2)}$$

$$D = P\cdot(1-R_P) + I\cdot(1-R_I) + (P\cdot R_P + I\cdot R_I - SMD_{i-1} - ET)\cdot(P\cdot R_P + I\cdot R_I - SMD_{i-1} - ET > 0) \quad \text{Eq. (3)}$$

$$ET = (ET_c\cdot C_{ET})\cdot\left((SMD \le RAM) + \frac{TAM - SMD}{TAM - RAM}\cdot(SMD > RAM)\right) \quad \text{Eq. (4)}$$

Model parameters

- ***TAM***: Total Available Moisture in the soil
- ***p***: mean fraction of *TAM* used up from the root zone before water stress occurs
- R_P: fixed percentage for effective precipitation
- R_{I1}, R_{I2} irrigation efficiency
- C_{ET} coefficient of crop evapotranspiration $ET_c' = ET_c\cdot C_{ET}$; $ET_c = ET_o\cdot K_c$

3 Methodology

3.2 Model calibration

Energy consumption data (E_i) was compared to energy consumption data derived from model results (E_{Di}) $E_{Di} = D_i\cdot E_{ui} + \varepsilon_i$ where $E_{ui} = \sum_{i=1}^{n} E_i \Big/ \sum_{i=1}^{n} D_i$

One-way and two-way sensitiviy analysis

Calibration process: Monte Carlo Simulation (MCS) process and objective function optimization through algorithm GRG2.

3.3 Water balance discrimination per crops

- Irrigation (*I*) proportionally distributed considering crop water needs and land use.
- Series of *ET*, *SMD* and *D* resulted per individual crop. Model calibration was performed by MCS (6000 simulations), driven in a similar manner to genetic algorithms (*PEDT*).

4 Results

4.1 Analysis of available data series and preliminary water balance

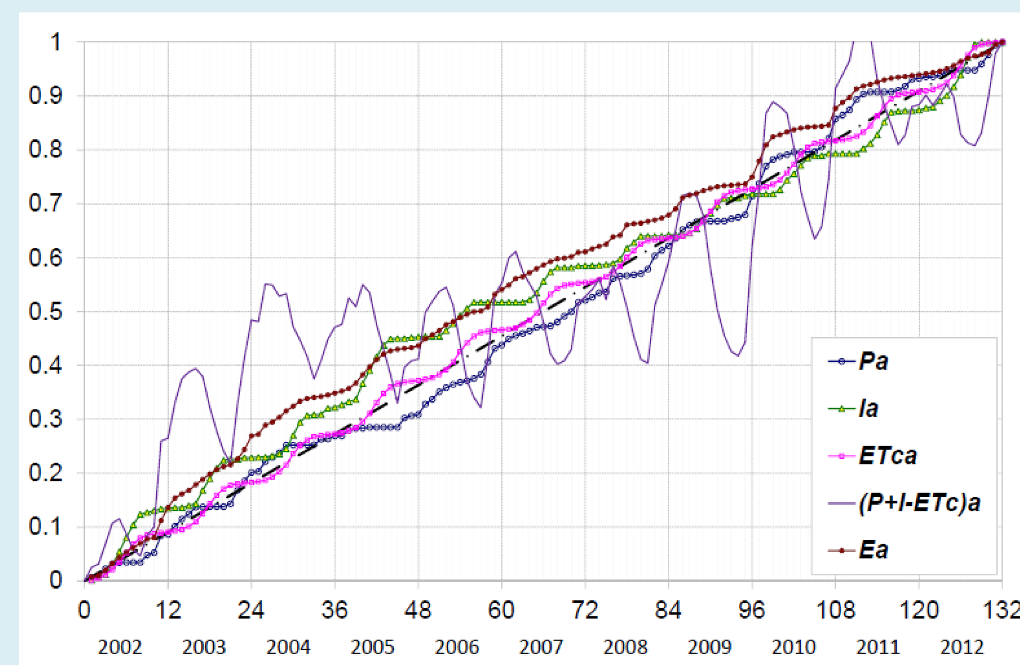

Figure 2

- A double-mass curve permitted to analyse data trends over the studied period (Fig. 2).
- Figure 2 shows accumulated series of the available components of the water balance: precipitation (P_a), irrigation (I_a), potential evapotranspiration (ET_{ca}), and energy (E_a).

4.2 Model results

- Potential crop evapotranspiration (ET_c) and actual crop evapotranspiration (*ET*) considering Reference 0[1] (Fig. 3)

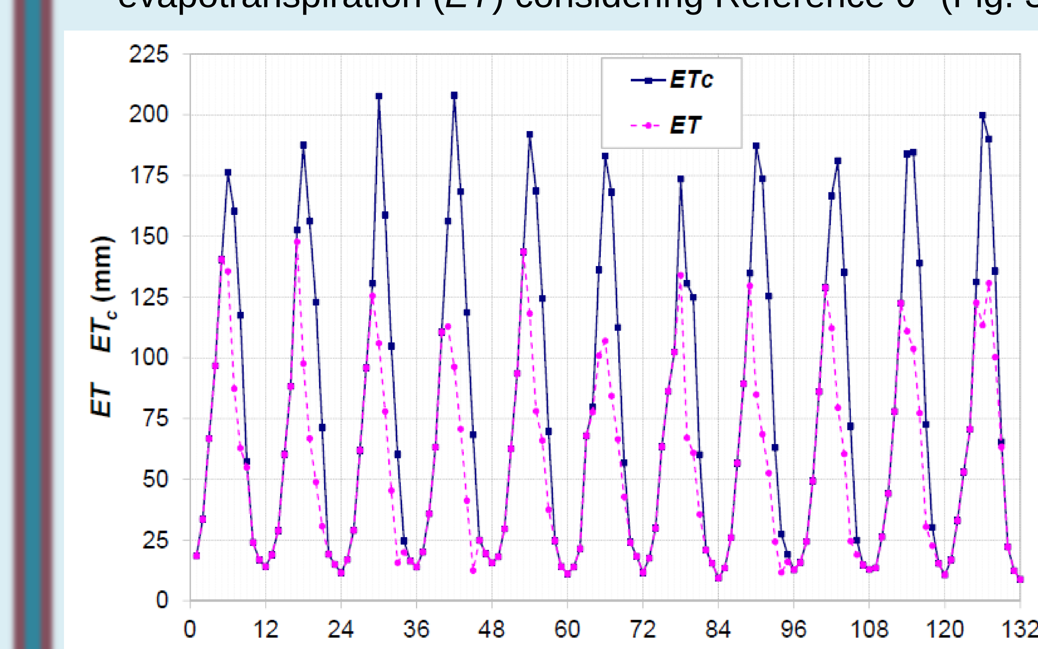

Figure 3

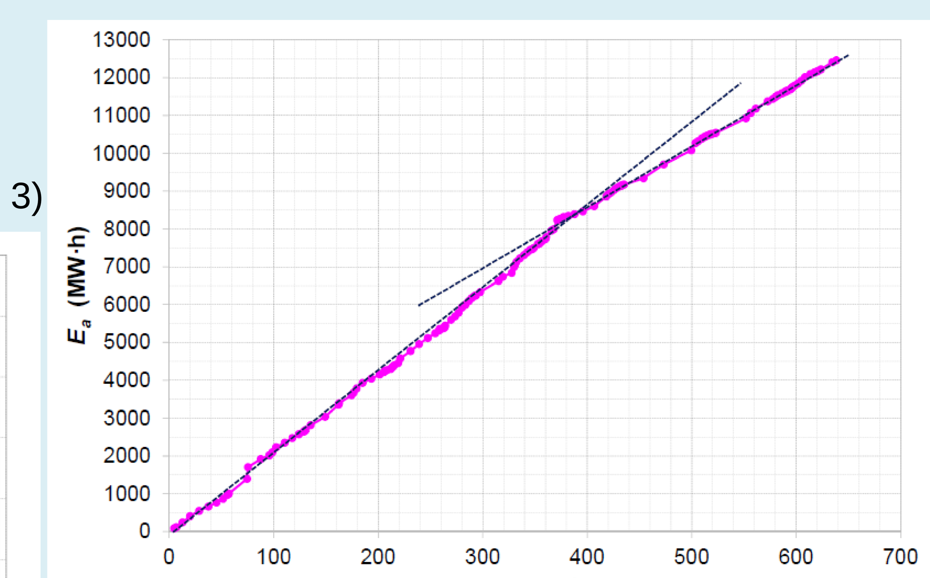

Figure 4

- Accumulated energy data (E_a) versus accumulated drainage (D_a) considering Reference 0[1]. Two differentiated trends (Fig. 4).

[1] Reference 0 (initially considered model parametric vector).

4 Results

4.3 Model calibration

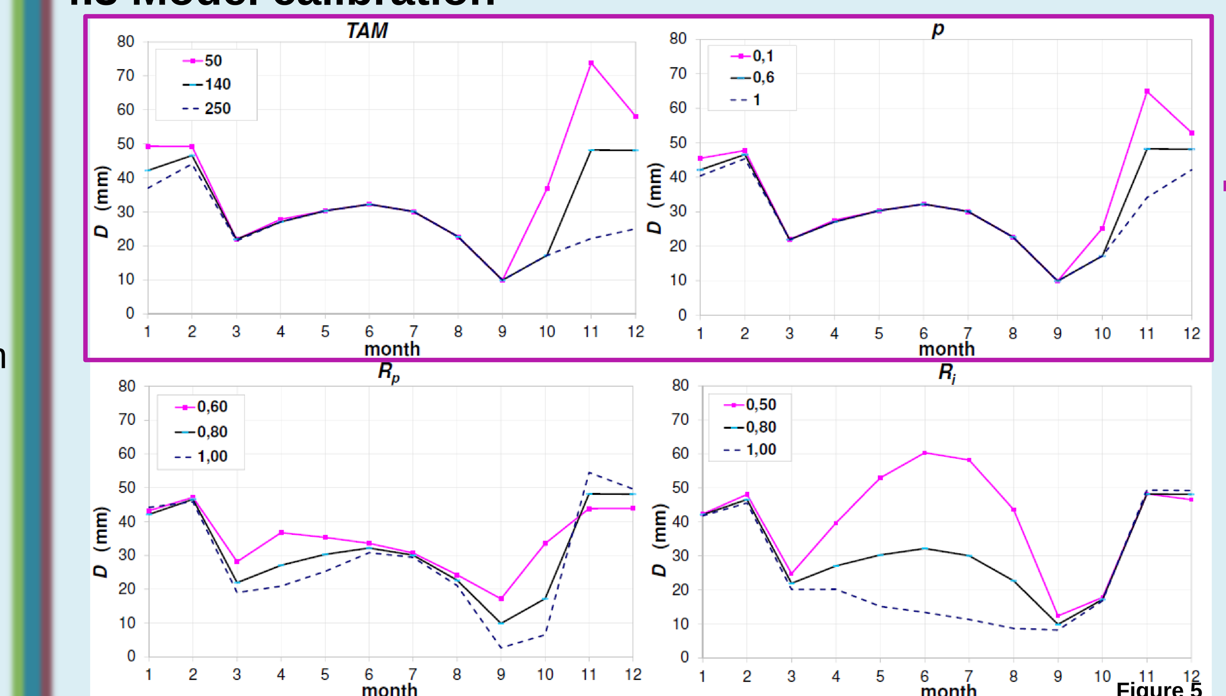

Figure 5

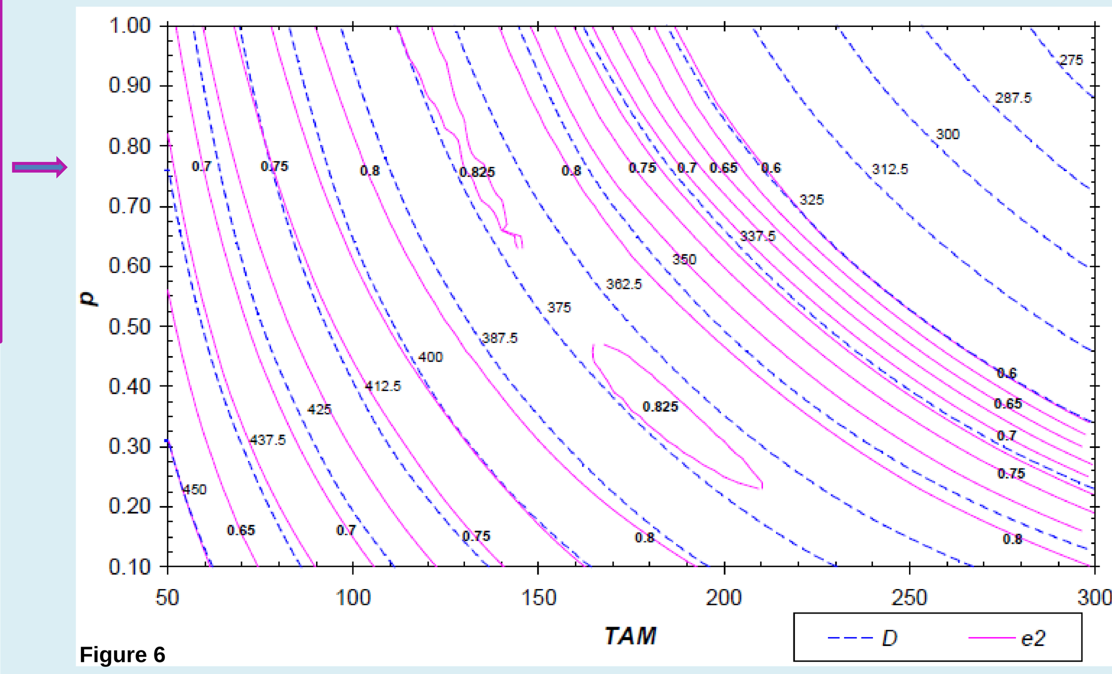

Figure 6

- **One-way sensitivity analysis** (Fig. 5): *TAM* and *p* have an effect over winter model results, R_I has an effect on summer months; R_P showed interrelation with all the studied parameters.
- **Two-way sensitivity analysis:** *TAM-p* correlation. Fig. 6 shows model results for the objective function coefficient of efficiency (e_2) for different *TAM-p* combinations.

4.4 Model results discriminating per crops

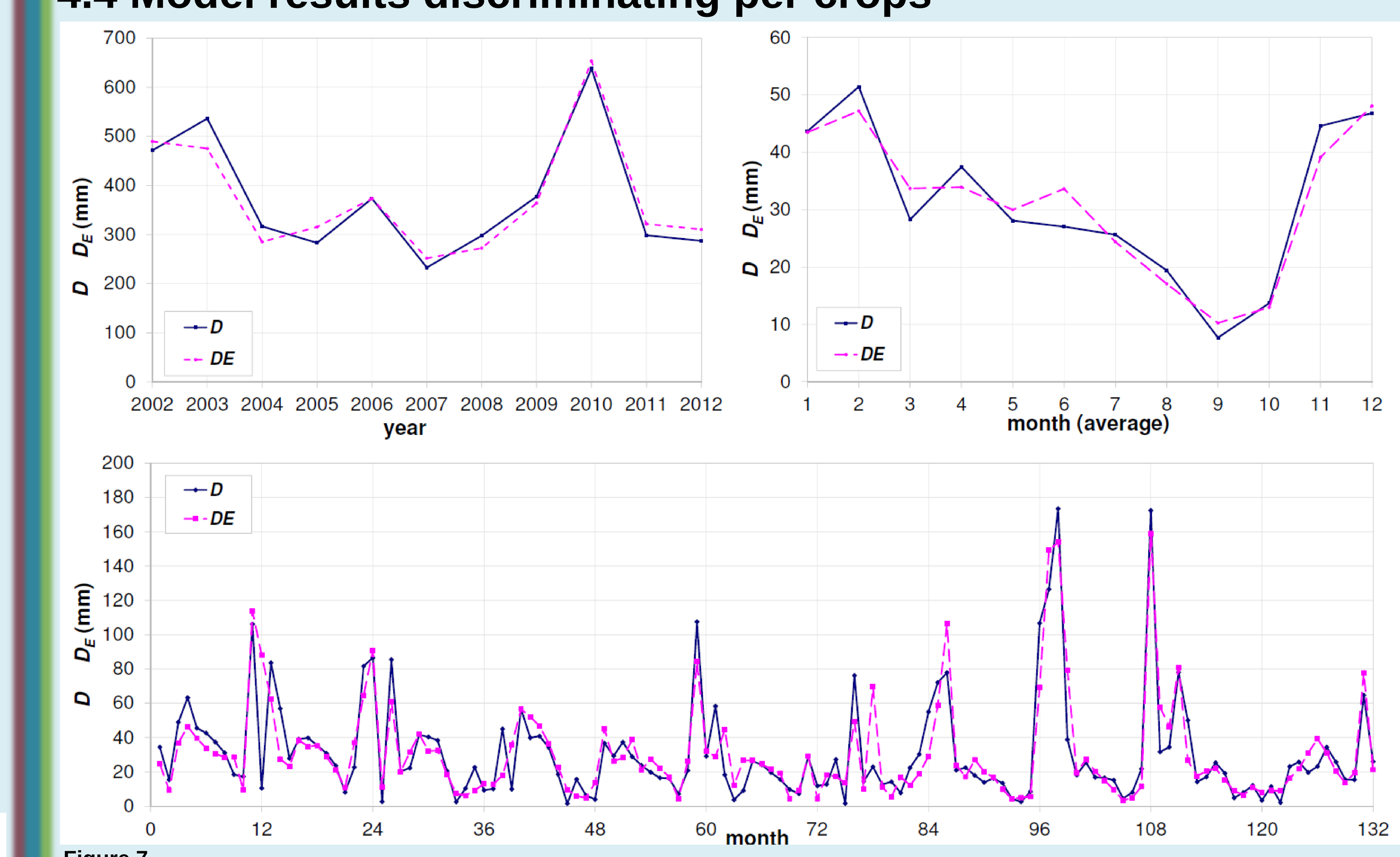

Figure 7

- Finally, a water balance for each individual crop based on Eq. (2), (3) and (4) was performed (Fig. 7).
- The new solution resulted on better model performance. The average coefficient of efficiency e_2 improved from 0.87 to 0.90.
- Calibration through MCS process was driven in the direction of better model performance.

5 Conclusions

- The proposed lumped model WATEN attained an average Nash-Sutcliffe coefficient $e_2 \cong 0.90$ between observed and estimated drainage discharge. Energy consumption for drainage discharge was used for model calibration.
- A significant crop evapotranspiration reduction was detected over the studied period. Average water discharge was close to 3740 m³/ha/year, probably sufficient for leaching irrigation water salts.
- Defined as a nitrate vulnerable zone, flow rate discharge and drainage chemical monitoring would allow improving water balance and energy savings, and to assess the long-term effect on the Guadalquivir River.
- This study is intended as a basis for analogous scarce-data 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.

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