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Research Paper

Generalisation of supply energy efficiency in irrigation distribution networks

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Energy efficiency in irrigation distribution networks can be estimated by following the method proposed by Abadia et al (2008) [Biosystems Engineering, 101, 21–27], in which energy efficiency is quantified in terms of global energy efficiency (GEE), a parameter that is a compound of the pumping energy efficiency (PEE) and the supply energy efficiency (SEE). PEE is related to pump functioning, while SEE is related to the design and management of the distribution system. Calculation of SEE by this method is limited to irrigation networks that have a single water intake at an elevation below that of the irrigated area and a single supplied sector. Results from the method are confusing for networks with more than one water supply point or irrigation sectors supplied by intakes located at elevations higher than that of the irrigated area. This paper proposes a modification of the earlier method that is appropriate to any type of layout and configuration of the irrigation network, with one or several water intake points and supplied sectors. The new model is applied to four different types of collective pressurised irrigation network, and the results are compared with those of the previous model. The influence of different measures taken to improve the SEE and determine the variables that affect this efficiency was analysed. The results show that adequate SEE values can be obtained with the proposed model for all the situations analysed, and that it is possible to quantify the improvements in SEE with the model.

1. Introduction

Energy consumption is the main factor responsible for the emission of the greenhouse gases (GHG) which contribute to climate change, and numerous global climate change mitigation policies are based on the reduction of GHG emissions (IEA, 2015). Of the total GHG emissions, 26% are from electricity consumption (IEA, 2015) and this the main source of energy in modern irrigation systems (IDAE, 2011). Modern irrigation systems such as those used in the Mediterranean region of Spain, consist of collective pressurised irrigation networks, instead of open-channel distribution systems. They allow the use of more-efficient on-farm irrigation systems, such as trickle or sprinkler systems. This improves water conservation but it also increases energy expenditure, since pumping stations are required to supply the pressure and water discharge demanded by the on-farm irrigation systems (Abadia, Rocamora, & Vera, 2012).

Improvement of the energy efficiency of pressurised irrigation requires a systematic energy analysis to evaluate

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Nomenclature

GEE	Global energy efficiency, %
PEE	Pumping energy efficiency, %
SEE	Supply energy efficiency, %
ΔWH	Water head balance, m
WHI	Water head at the inlet point, m
WHD	Water head needed at the consumption point, m
PHI	Pumping head injected by a pumping station, m
H_k	Pumping head supplied by pump *k*, m
V_T	Total volume supplied to the system, m^3
V_k	Volume supplied by pump *k*, m^3
V_i	Volume supplied by the inlet point *i*, m^3
z_i	Geographical elevation of inlet point *i*, m
S_T	Total irrigated area supplied, ha
S_j	Irrigated area located at constant geographical elevation *j*, ha
z_j	Geographical elevation of irrigated area *j*, m
H_{dj}	Pressure head demanded by the on-farm irrigation system located in the irrigated area *j*, m
h	Pipe head losses
WDN	Water distribution network

separately the influence of the pumping stations, network and water loss; this allows inconsistencies in the design and management to be identified for both resources, water and energy (Bolognesi, Bragalli, Lenzi, & Artina, 2014). However, water losses are not usually included in energy efficiency studies of pressurised irrigation networks (Abadia, Rocamora, Ruiz, & Puerto, 2008; Abadia et al., 2012; Carrillo-Cobo, Rodriguez Díaz, & Camacho-Poyato, 2010; Moreno, Córcoles, Tarjuelo, & Ortega, 2010), since they are much smaller than the losses found in urban supply networks. This is because irrigation networks have many fewer discharge points and much higher discharge flows than urban supply networks, which makes losses easily controllable in this type of network, where conveyance efficiencies of up to 96% are possible (Carrillo-Cobo et al., 2010).

The methods developed in recent years to improve the energy efficiency of irrigation can be grouped into three types: (1) Measures based on improvements in the design and regulation of pumping stations (Córcoles, Tarjuelo, & Moreno, 2016; Fernández García, Moreno, & Rodríguez Díaz, 2014; Lamaddalena & Khila, 2012, 2013; Moreno, Planells, Córcoles, Tarjuelo, & Carrion, 2009; Planells, Carrion, Ortega, Moreno, & Tarjuelo, 2005); (2) Measures based on improvements in the design and management of the distribution network (Carrillo Cobo, Rodríguez Díaz, Montesinos, López Luque, & Camacho Poyato, 2011; Navarro Navajas, Montesinos, Camacho Poyato, & Rodríguez Díaz, 2012; Rodríguez Díaz, López Luque, Carrillo Cobo, Montesinos, & Camacho Poyato, 2009; Rodríguez Díaz, Montesinos, & Camacho Poyato, 2012); and (3) Measures that combine the design and regulation of pumping with the design and management of the distribution network (Abadia et al., 2012; Fernández García, Montesinos, Camacho Poyato, & Rodríguez Díaz, 2014; Jiménez Bello, Martínez Alzamora, Bou Soler, & Bartoli Ayala, 2010; Moreno et al., 2010).

To determine the effect of applying corrective measures to improve energy efficiency in irrigation distribution networks, it is necessary to measure both the efficiency of the pumping systems and the efficiency of the management and design of the network. One of the methods for calculating both efficiencies is that proposed by Abadia et al. (2008, 2012), which defines the global energy efficiency (GEE) of irrigation water distribution systems as being composed of two factors: the pumping energy efficiency (PEE) and the supply energy efficiency (SEE). PEE analyses pump functioning, while SEE analyses the design and management of the distribution system.

The PEE of a water distribution network is calculated by dividing the hydraulic power supplied by the power absorbed by the pumping station; usually, it is the only efficiency term that is calculated to determine the energy efficiency of a distribution system. SEE, the second component of GEE, has received less attention in the scientific literature, probably because it is more difficult to define and to quantify, even though it strongly influences the global efficiency of the distribution system.

The SEE of a water distribution network is defined as the ratio between the water head required by the on-farm irrigation systems and the pumping head supplied by the pumping stations. Water head required is directly related to the topographic characteristics of the irrigated area, the water head demanded by the on-farm irrigation systems and the water head at the inlet points. The pumping head supplied must include not only the water head required by the on-farm irrigation system but also the head losses in the pipes of the network, the elevation of reservoirs, head losses at the pumping and filtration stations and the number of sectors in the network. Ultimately, it will depend on the final design and management of the distribution system.

According to Abadia et al. (2008), SEE can be calculated as a water head ratio, using the following equation:

$$SEE = \frac{\Delta WH}{PHI} = \frac{WHD - WHI}{PHI} = \frac{\frac{\sum S_j(z_j + H_{dj})}{S_T} - \frac{\sum V_i z_i}{V_T}}{\frac{\sum V_k H_k}{V_T}} \quad (1)$$

where ΔWH is the value of the water head balance, m; *PHI* is the average pumping head injected by the pumping stations, m; *WHD* is the water head demanded in the irrigated area, m; *WHI* is the source water head at the inlet point, m; S_T is the total irrigated area, ha; S_j is the irrigation area *j*, ha, located at a geographical elevation of z_j, m; H_{dj} is the pressure head demanded by the on-farm irrigation system located in the irrigated area *j*, m; V_T is the total volume of water supplied to the system, m^3; V_i is the total volume supplied by the source *i*, m^3; z_i is the geographical elevation of the source *i*, m; V_k is the total volume supplied by the pump *k*, m^3; and H_k is the pumping head supplied by the pump *k*, m.

However, the SEE calculated by Eq. (1) is only suitable for distribution systems with one water inlet point located at a lower geographical elevation than the minimum water head demanded by the irrigated area, and with only one irrigation sector that is supplied. The method has some limitations if it is applied to other network configurations that involve one or more of the following: