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Research Paper

Methodology to improve pumping station management of on-demand irrigation networks

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The energy efficiency of pumping stations in irrigation networks was examined using a methodology to determine the optimum pumping station regulation. The methodology was developed in the MATLAB® environment using the EPANET® toolkit and developed using three on-demand irrigation networks located in the Castilla—La Mancha region of Spain. In each irrigation network, the energy efficiency and energy consumption were obtained for three cases: a fixed pumping head, a pumping head that guaranteed minimum pressure head required at the open hydrant and a pumping head that minimised the absorbed power at the pumping station. With the three networks average energy savings of 3%, 7% and 30% were obtained by using the optimum pressure head compared with the current management based on fixed pressure regulation. This methodology is intended to be useful in irrigable areas to improve the management of pumping systems where the use of fixed pressure regulation is extensive. It is important to measure electrical and hydraulic parameters of pumps which make it possible to determine the energy efficiency of a pumping station for each combination of discharge and pressure head as well as the pressure head which minimises the energy consumed for the pumping station to guarantee a specific pressure at open hydrants. These results were related to the fact that with fixed pressures, and mainly low and medium discharges, the energy efficiency of pumping systems can drop.

1. Introduction

Currently, in the context of climate change and the increasing trend in energy prices, it is necessary to develop tools to optimise the use of energy resources to provide environmental and economic benefits. In irrigated areas, energy is a relevant factor to consider because it has a high impact on the total management, operation and maintenance costs. Therefore, in these areas not only water but also energy should be

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Nomenclature

C	Hazen–Williams roughness coefficients
IRN	Irrigation network
IRN A	Irrigation network A
IRN B	Irrigation network B
IRN C	Irrigation network C
MAEEB	Model for energy analysis of pumping stations
OT	Operating time
PVC	Polyvinylchloride
RDDC	Random daily demand curve

considered as a resource for guaranteeing sustainable development (Rodríguez Díaz, Camacho Poyato, & López Luque, 2007).

Pressurised irrigation networks (IRN) help improve the use of water resources compared with other distribution systems, such as open channels. However, in pressurised systems, energy consumption is relatively high owing to the need for pumping stations to pressurise the system (Fernández García, Rodríguez Díaz, Camacho Poyato, Montesinos, & Berbel, 2014; Fernández García, Rodríguez Díaz, Camacho Poyato, & Montesinos, 2013). This fact, along with increasing energy costs, makes it necessary to develop tools to optimise the efficiency of this type of infrastructure.

Several studies aiming to reduce the energy consumption of pressurised irrigation networks have been carried out. In on-demand irrigation networks (Lamaddalena, Khadra, & Fouial, 2015), some studies are based on sectoring methodologies. Rodríguez Díaz, López Luque, Carrillo Cobo, Montesinos, and Camacho (2009) developed a model in which hydrants were enabled to irrigate in homogeneous groups. Carrillo Cobo, Rodríguez Díaz, Montesinos, López Luque, and Camacho Poyato (2011) developed a methodology focused on grouping hydrants to irrigate depending on their energy demand, obtaining energy savings ranged from 9% to 27%. Other studies have been based on analysing the location of hydrants with special energy requirements, defined as critical control points, to reduce energy consumption and improve network sectoring (Fernández García, Montesinos, Camacho Poyato, & Rodríguez Díaz, 2014; González Perea, Camacho Poyato, Montesinos, & Rodríguez Díaz, 2014; Rodriguez Diaz, Montesinos, & Camacho, 2012).

Most of these studies assume a fixed level of efficiency in the pumping system without considering its variability, which depends on the combination of discharge and pressure head for each scenario. When designing pumping stations, only high discharges are considered to determine the design flow, but in most of cases, low and medium discharges are generated. This can cause pumping stations to operate at lower efficiency (Moreno, Córcoles, Tarjuelo, & Ortega, 2010; Pérez Urrestarazu & Burt, 2012). It is therefore necessary to improve the efficiency of systems at low and medium discharges. This fact is important with on-demand irrigation networks and is related to the high variability of discharges and the required pumping head changes that occur during the irrigation season (Lamaddalena & Sagardoy, 2000).

Therefore, it is necessary to consider the efficiency of pumping systems for each combination of discharge and pressure, once the optimum regulation strategy is known and can be implemented. This fact has been considered in some studies. Jiménez-Bello, Martínez Alzamora, Bou Soler, and Ayala (2010) proposed grouping pressurised irrigation network intakes into sectors using a genetic algorithm, which was validated for optimising energy use (Jiménez-Bello, Alzamora, Castel, & Intrigliolo, 2011). Other studies analysed the benefits of installing frequency speed drives to optimise the sectoring operation (Fernández García, Moreno, & Rodríguez Díaz, 2014).

The most common type of regulation for pumping stations in pressurised irrigation networks is fixed pressure regulation, but variable pressure regulation can be used to guarantee a minimum pressure at the open hydrant. The main aspect is to analyse whether the minimum pressure head can be considered as the most efficient depending on the combination of discharge and pressure. Therefore, for each discharge scenario, the pressure at the pumping station that guarantees a specified hydrant pressure value and minimises the power consumption at the pumping system can be determined.

The aim of this paper was to develop a methodology to determine the optimum pressure head that minimises the power needed at the pumping station and guarantees a specified minimum pressure at all the open hydrants in the network. This tool was developed in the MATLAB® environment using the EPANET® toolkit (Rossman, 2000). Using this tool, the efficiency of pumping stations for each combination of discharge and pressure head was considered.

2. Methodology

2.1. *Irrigation network characteristics*

To demonstrate the utility of the developed methodology three on-demand pressurised irrigation networks (designated IRN A, IRN B and IRN C) were analysed (Fig. 1). Each irrigation network had different designs, crops and management regimes, to enable general conclusions to be made from the results of their analysis. One of the irrigation networks was located in the province of Albacete (Spain), but the other two were in the province of Cuenca (Spain). All analysed IRNs used groundwater, which was pumped to a reservoir and then pumped to the irrigation network.

IRN A covered approximately 95% of the total irrigated area (550 ha) with sprinkler irrigation and was cropped with maize and onion representing 85% of the irrigable area (Table 1). This IRN had 323 hydrants and a pumping station composed of 10 pumps (104 kW each), one of which has a frequency speed drive, and soft starters are in the remainder. IRN A had a fixed pressure regulation system, with 55 m as the fixed pressure head, to guarantee a pressure head of 35 m at all the open hydrants in the network.

IRN B covered an irrigable area of 170 ha and had 149 hydrants (Table 1). Vineyards and olive trees were the prevalent crops and drip irrigation systems were used. This IRN had a pumping station composed of four pumps (38 kW each), one of which had a variable frequency drive and fixed pressure regulation with a 50 m pressure head to guarantee 30 m head at each open hydrants.