Agricultural Water Management 210 (2018) 49–58

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Model for management of an on-demand irrigation network based on irrigation scheduling of crops to minimize energy use (Part I): Model Development

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ARTICLE INFO

Keywords:
Irrigation network
Restricted arranged operation
Irrigation scheduling
Pumping station
Energy costss

ABSTRACT

A tool implemented in MATLAB®, called GREDRIP, has been developed to simulate the behavior of an on-demand irrigation network, taking into account crop distributions in an irrigable area. It was applied during two complete irrigation seasons (2015 and 2016) for weekly irrigation scheduling. This tool portends to be useful as a decision support system tool to manage on-demand collective irrigable areas with minimum energy costs at the pumping station and by performing an irrigation schedule to guarantee crop water requirements. Hence, it is possible to go from an on-demand irrigation management system to a restricted arranged operation, carried out with centralized management, where the manager of the irrigation network satisfies the demand of farmers within a short period of time. The main novelty of this paper is to show a simulation tool which integrate the energy efficiency of the pumping station taking into account irrigation events distribution according to the crop irrigation scheduling at each plot. In this regard, this tool respects the irrigation scheduling of farmers, and it controls the starting time for each hydrant to minimize the energy cost. It was applied considering two types of pressure regulations, i.e., fixed and variable pressure heads. The distribution of open hydrants and the starting times of the irrigation events at each case performed by this tool led to optimization of the flow discharge distribution in the irrigation network, guaranteeing adequate flow discharge and pressure to all hydrants, which affected the uniformity of irrigation in the plot. Although the regulation using fixed pressure management represented energy costs 10% higher than the regulation using the variable pressure head, this difference would not compensate for the implementation of variable pressure management given the complexity of managing a variable pressure head in a pumping station. The actual irrigation network management, which does not consider the energy efficiency at the pumping station, showed higher energy consumed and energy costs at the pumping system in comparison with the results using GREDRIP. This fact suggest that it is necessary to improve the technical advisory system for irrigation scheduling at the plot scale and irrigation network management.

1. Introduction

In recent years, the modernization of irrigation systems, from gravity systems to pressurized systems, has led to increased water and land productivity but also to an increase in energy consumption (Fernández García et al., 2014a; Tarjuelo et al., 2015). In irrigation societies, increased energy costs, along with investment costs linked to modernization, may put the economic viability of some modernized farms at risk.

The lack of knowledge on the relationship between water and energy use can lead to increases in energy costs. This fact is especially relevant to on-demand irrigation networks, where inefficient water use as well as significant increases in energy consumption can result, even when farmers do not schedule irrigation adequately. In these types of irrigation networks, typically, farmers irrigate whenever they want, and this is characterized by irrigation management flexibility (Lamaddalena and Sagardoy, 2000). This management is subjected to high variability of flow regimes because it depends on the number of hydrants simultaneously opened, which can contribute to low energy efficiency in some of these irrigation networks because the pumping station is not working in designed conditions (Lamaddalena and Pereira, 2007; Rodríguez Díaz et al., 2009). According to this, it is necessary to use

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https://doi.org/10.1016/j.agwat.2018.07.046
Received 27 April 2018; Received in revised form 27 July 2018; Accepted 31 July 2018

tools to improve the efficiency of these types of pressurized irrigation networks.

Several strategies have been developed to improve water and energy use efficiency in on-demand pressurized irrigation networks. One of them consists of sectoring and grouping hydrants with similar energy demands (Jiménez Bello et al., 2011; Carrillo Cobo et al., 2011; Navarro Navajas et al., 2012). Other methodologies are based on detecting and controlling critical points (Rodríguez Díaz et al., 2009, 2012), which are defined as hydrants with special energy requirements depending on their distance to the pump station or their difference in elevation. Daccache et al. (2010) developed a methodology combining network design and performance analysis of a sprinkler network, simulating the interaction between on-demand water distribution systems and on-farm networks.

The variation in pumping station efficiency at each combination of flow discharge and pressure head is an important factor to consider in irrigation networks, which was not always considered in previous operational studies. In those cases, a fixed efficiency was considered, which might not be representative when the pumping station is working during an irrigation season. It is related to the fact that when pumping stations are designed, only high discharges are considered to determine the design flow, but in most of the cases, low and medium discharges are generated (Moreno et al., 2010), and the required pumping head changes occur during the irrigation season (Pérez Urrestarazu and Burt, 2012).

In this regard, Moreno et al. (2007b) developed the MAEEB model, with the aim of analysing the energy efficiency of the pumping stations. Fernández García et al., 2014a developed a pumping station model to analyse the performance of pumps for several activation sequences that were applied to study optimum pumping station management for irrigation network sectoring in Spain. Córcoles et al. (2016a) considered the energy efficiency at each combination of flow discharge and pressure head to develop a methodology to determine the optimum pressure head that minimizes the power needed at the pumping station.

The aforementioned studies did not consider electricity tariffs, and they used an average fixed cost for the energy consumed. Hence, Fernández García et al. (2016) developed a decision-making support system to analyse several network operation scenarios considering different energy prices according to the electricity tariff. They applied this methodology in sectoring and critical points control in previous studies developed by the same authors (Fernández García et al., 2013, Fernández García et al., 2014b). Córcoles et al. (2015) took into account the energy costs for several energy rate periods when developing a methodology to minimize the energy cost of the pumping stations in on-demand irrigation networks with the organization of the starting irrigation times for each hydrant. Khadra et al. (2016) analysed energy and hydraulic performance-based management of large–scale pressurized irrigation systems, which analysed the interaction between the irrigation system use and the energy consumption, based on to generate demand scenarios according to a random selection of open hydrants.

Few studies have considered the influence of irrigation scheduling at the plot scale on irrigation networks. In this regard, González Perea et al. (2016) developed a tool based on optimizing irrigation scheduling using the soil water balance and a genetic algorithm. They used a model that establishes the optimal sectoring operation during the irrigation season and focused on the simultaneous optimization of irrigation scheduling at the plot scale, considering water demand at a hydrant level and energy consumption at the pumping station in Southern Spain. They determined daily irrigation needs during the peak demand period.

Most of these studies focused on analysing the performance of irrigation networks in a peak period, with maximum crop water requirements. Likewise, other studies are based on creating demand scenarios using methodologies to define the probability of open hydrants (Moreno et al., 2007a), and considering a random selection of open hydrants. None of the above-mentioned methodologies considered crop water requirements over a complete irrigation season.

The aim of this paper is to present a MATLAB® tool, called GREDRIP. This tool can be useful to compare irrigation network behavior under several irrigation strategies, which is analysed in the part II of this work, focused on the economic impact of regulated deficit irrigation in irrigation networks.

The main novelty of GREDRIP is that it considers several aspects in one tool. It combines the hydraulic and energy behavior of the irrigation network, considering the well-known variability of the energy efficiency in a pumping station and the electricity tariffs depending on the period, along with irrigation scheduling and crop water requirements in the plots during the whole irrigation season (low and peak water demand). This tool is not based on a probability of open hydrants, and simulates the behavior of an on-demand irrigation network, taking into account the actual crop distribution in the irrigable area and the actual irrigation scheduling in the plots. Likewise, GREDRIP respects the irrigation scheduling of farmers, and it controls the starting time combinations at each plot, which minimizes energy costs.

The main contribution of this research is to set up a model that enables a centralized management of the irrigation network, minimizing the energy costs while considering the irrigation scheduling at farm level. In this regard, it is possible to go from an on-demand irrigation management system to a restricted arranged operation.

2. Material and methods

2.1. Irrigation network

The GREDRIP model was applied to the irrigation network named SORETA in the province of Albacete in the Castilla – La Mancha region (Spain) (Fig. 1) during two complete irrigation seasons (2015 and 2016), for weekly irrigation scheduling, which is the common management of irrigation used by farmers. This was an on-demand irrigation network that covered an irrigable area of 550 ha with 323 hydrants. It used ground water resources pumped from four boreholes to a reservoir (23,000 m^3), using submerged pumps installed at 150 m in depth with absorbed power from 139 kW to 330 kW depending on the extracted flow discharge. A pumping station, composed of 9 pumps (140 HP), one of them with variable frequency speed drive and the rest with soft starters, delivered water to the irrigation network. The pumping station was managed with a fixed pressure head of 52 m, to guarantee 35 m at each open hydrant, for a sprinkler and drip irrigation system at a plot scale, which represented 65% and 35% of the irrigated area, respectively. The most common are permanent sprinkler irrigation systems, with 17 m × 17 m spacing, two nozzles of 4.4 + 2.8 mm or one nozzle of 5.2 mm, and a drip irrigation system, with self-

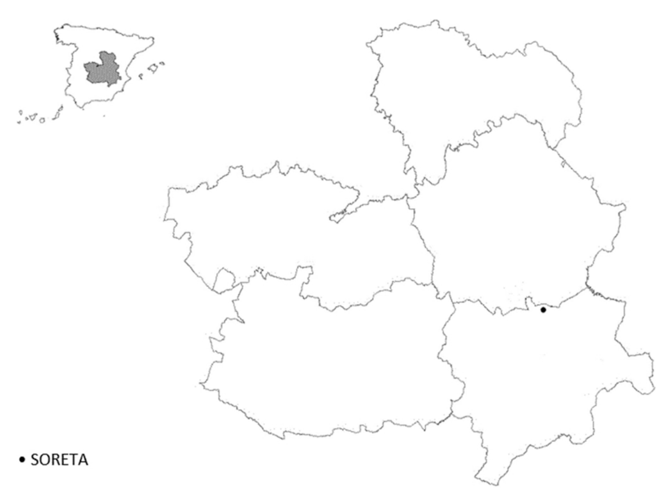

Fig. 1. Location of the irrigation network.