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Water and energy management in an automated irrigation district

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ABSTRACT

An important modernization process providing pressurized irrigation systems to the traditional surface irrigation districts has taken place in Spain over the last 20 years However, an adverse consequence of modernization is the important increase in the energy cost in the modernized irrigation districts, which is aggravated by the current high energy prices. The Almudévar irrigation district (AID), a traditional surface irrigation district, was transformed into a pressurized sprinkler irrigation system in late 2010. The irrigation network was equipped with a high-level telemetry and remote control system that reaches the hydraulic valves of the irrigated blocks into which the plots are divided. Therefore, the telemetry system enables the centralized management of the irrigation scheduling from the district office. The district is divided into four independent networks with their own reservoirs and electric pump stations. A comparison of the land structure, crop patterns and irrigation management between the modernized AID in 2011 and the pre-modernization AID in 2006-2008 was performed. The temporal evolution of the irrigation water and energy demands in the 2011 irrigation season was analyzed with the available telemetry data from 2011. An irrigation performance index (SIPI) of the monthly and seasonal frequencies was computed for the main crops of the AID. Most irrigation events were performed during the low electricity tariff periods (P6 electric tariff) due to the centralized irrigation scheduling. Meteorological constraints had a low incidence in irrigation scheduling. Generally, a slight decrease in total irrigation deliveries was observed before and after medium-to-large precipitation events, but no changes in irrigation deliveries was observed with increases in wind speed. The exploitation of telemetry data in the AID has been an important tool to optimize the contracted electricity power in each tariff period and in decreasing the electric bill of the AID. This type of telemetry data analysis, similar to the analysis performed in the modernized AID in 2011, could be used in other water use associations as an important decision-making tool to improve water and energy management and to control the irrigation cost.

1. Introduction

In the last two decades, an important modernization process providing pressurized irrigation systems to traditional surface irrigation districts has taken place in Spanish irrigated areas. As a result of these irrigation modernization plans, sprinkler irrigation areas have increased in Spain. According to the 2011 Areas and Crop Yields Survey (ESYRCE) (M.A.A.M.A., 2012), the total irrigated area in Spain is 3,473,474 ha, of which 497,794 ha are sprinkler-irrigated.

Irrigation modernization in collective irrigation districts usually involves the replacement of open-channel gravity systems by pressurized irrigation networks with a hydrant in each farm. Each hydrant includes a filter and an hydraulic valve with an integrated flow measuring and pressure regulator unit. Additionally, modern telemetry and remote control systems are incorporated into the majority of the modernized collective irrigation networks in Spain. This type of infrastructure provides many opportunities for irrigation management improvement (Stambouli et al., 2012). New networks enable a more efficient water application with irrigation systems, such as drip and sprinkler irrigation, instead of surface irrigation (Playán and Mateos, 2006). Lecina et al. (2010) reported that a consequence of irrigation modernization could be an increase in the consumptive water use due to more intensive cropping. Another important consequence of irrigation modernization is the increase in energy consumption and, therefore, the increase in

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irrigation energy cost. However, the use of pressurized irrigation systems has drastically decreased the labor cost of irrigation. From 1970-2007, Corominas (2010) reported that the water that was used for on-farm irrigation in Spain decreased by 21%, from 8250 to 6500 m^3 ha^{-1}, but energy consumption increased by 657%, from 206 to 1560 KWh ha^{-1}.

Due to the 2008 liberalization of the electricity market in Spain and the elimination of special rates for irrigation, the average energy costs in modernized irrigation districts have sharply increased. For example, the average electric energy cost in a few irrigation districts in northern Spain increased by 82% between 2005 and 2009 (Ederra and Murugarren, 2010; Abadía et al., 2012). The high contribution of energy to the total irrigation cost has led to the publication of numerous studies and methodologies to quantify and improve energy efficiency (Carrillo-Cobo et al., 2010; Moreno et al., 2010; Rodriguez-Díaz et al., 2009; Lamaddalena and Khila, 2012). Their results indicate that collective pressurized irrigation networks should be operated with maximum energy efficiency in order to optimize the economical profit.

Many irrigation performance analyses characterizing the water irrigation efficiency in pressurized irrigation districts can be found in the literature (Faci et al., 2000; Dechmi et al., 2003; Lorite et al., 2004a,b; Stambouli et al., 2012; Salvador et al., 2011). All of these works found a high spatial variability of irrigation performance indicators and concluded that variability between farms indicates a potential for improvement. These analyses are complex, but the new telemetry and remote control systems provide the necessary data (Stambouli et al., 2012).

The on-demand delivery scheme offers the greatest potential to optimize irrigation scheduling (Lamaddalena and Sagardoy, 2000) since farmers get more flexibility to make irrigation decisions. However the significant increase in energy costs in recent years has changed the perception of this delivery scheme. The knowledge that is needed to cope with economic, technical and environmental constraints cannot be amassed by individual farmers. Authors such as Rodriguez Díaz et al. (2009), Moreno et al. (2010), and Carrillo Cobo et al. (2011) have proposed solutions based on optimizing technical issues, such as the pumping efficiency and hydraulic performance. Other authors, such as Zapata et al. (2007, 2009), have proposed solutions based on using simulation tools to drive the telecontrol systems.

This study was performed in the Almudévar Irrigation District (AID), which was recently modernized from a surface to a pressurized irrigation system. This district is one of the most innovative irrigated areas as it has incorporated new sprinkler irrigation systems, the highest technological telemetry and remote control systems that control the low-level element (valves of the hydrant's irrigated blocks). Due to its electrical dependence and high investment cost, the modernized district requires a high standard of water and energy management to be competitive. The future water and energy limitations and high prices will trigger the exploitation of new technologies to improve irrigation management standards (Evans and King, 2012). This study presents an analysis of the current water and energy management of the AID and indicates the difficulties in coping with all of the constraints in maximizing farm income. Also this study provides a tool to exploit telemetry and telecontrol data to improve irrigation cost in the district.

The specific objectives of this study were as follows: 1) to analyze the seasonal and monthly on-farm irrigation performances at the plot level by assessing the continuous irrigation performance index (SIPI) and to compare these performances with those pre-modernization; 2) to characterize the irrigation scheduling patterns that are related to meteorology and to energy cost structure; and 3) to exploit the telemetry data records to improve water management and optimize irrigation cost.

2. Material and Methods

2.1. The Almudévar Irrigation District evolution

The study area was the Almudévar Irrigation District (AID), which is located in the Ebro River Basin in northeastern Spain in the autonomous community of Aragón, which has the fourth largest irrigated area in Spain after Andalucía, Castilla La Mancha and Castilla Leon (M.A.A.M.A, 2012).

The district occupies 3,744 ha of irrigated land and is integrated into the Monegros I irrigation scheme. Until 2008, 94% of the AID area was surface-irrigated with blocked-end plots, 5% was sprinkler-irrigated and 1% was drip-irrigated. The AID irrigation system was originally designed to irrigate winter cereal, and the capacity of the irrigation ditches was very limited (Faci et al., 2000; Playán et al., 2000). Consequently, the proportion of summer crops in the district was limited, and very often the summer crops suffered some degree of water stress due to very long irrigation intervals.

The modernization process that was completed in 2010 transformed the entire irrigation system from surface to pressurized (94% of the area with solid-set, 5% with center pivots and lateral move systems and 1% with drip irrigation systems). The first phase of the AID modernization process was land consolidation. As a result, a farmer would get a single plot in the district with an area that was similar to the sum of the plots that he owned before the consolidation. The former district was characterized by a high number of part-time farmers, with only 20% of farmers being fully dedicated to agriculture. Even after the modernization process, part-time farmers are numerous (around 75%), and plot leasing is very common. The changes in land ownership and tenure structure were also analyzed.

The modernized AID was divided into four independent irrigated zones, including three independent irrigated networks (Abariés, Colladas and Matilero) and two interconnected irrigated networks (Violada and Artical) that will be referred to one irrigated zone (Violada-Artical). Each zone has its own reservoir, its own electric pumping station and its own distribution pipe network. The total storage capacity of the AID is 635,160 m^3. The total installed pumping power is 6,361 kW, enabling a maximum flow rate of 6,000 L s^{-1}. This flow is sufficient for simultaneously supplying water to 60% of AID area. From the district control center, a programmable robot remotely manages the pumping station operations and the associated electromechanical systems.

The second part of the modernization process, was the construction of shared irrigation network infrastructure. The network brings water to hydrants, which are located in each farm at an average pressure of 400 kPa (downstream the hydrant). The accomplishment of on-farm irrigation systems was also executed collectively by the water user association. This accomplishment has homogenized the on-farm irrigation system design. In the AID, solid sets (94% of the area) have a triangular arrangement of 18 m between sprinkler lines and 18 m between sprinklers. The impact sprinklers were installed 2 m aboveground and were equipped with a double nozzle with inside diameters of 4.4 mm and 2.4 mm. The on-farm systems were designed to operate at an average nozzle pressure of 300 kPa, which represents a design irrigation precipitation of 5.3 mm h^{-1}.

The new infrastructure was equipped with a high-level technological telemetry and remote control system (TM/RC) that enables the remote management of all of the hydraulic valves (290 hydrants valves and 2,200 irrigation block valves) in the irrigation networks (collective and on-farm) from the district office. The collective irrigation system operates in an organized on-demand scheme. Irrigation scheduling of all irrigation blocks was performed by the district manager, considering farmers′ preferences, hydraulic