Agricultural Water Management 151 (2015) 87–92

Contents lists available at ScienceDirect

Agricultural Water Management

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

# Performance indicators to assess the implementation of automation in water user associations: A case study in southeast Spain

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ARTICLE INFO

*Article history:*
Available online 26 November 2014

*Keywords:*
Collective pressurized irrigation network
Water and energy management
Economical saving

ABSTRACT

Water and energy in the agricultural sector must be used efficiently to obtain sustainable agriculture, which also leads to economical savings. This also has a positive influence on the conservation of fossil resources and the reduction of contamination. Automation in irrigation systems permits the control of water and energy resources. Therefore, several parameters related to water and energy efficiency, both in the pump station and in the collective irrigation network, can be controlled. In this study, several performance indicators are proposed to assess the implementation of automation in water user associations. Both the indicators and the methodology used for data gathering are detailed in the study, and the results of a case study in southeast Spain are presented. The results demonstrate that automation is a low-cost investment (1.24–6.72% of the total costs) compared to the large benefits and advantages (2.05–8.21% energy saving and 0.71–6.46% water saving). Moreover, the amortization periods are very short and are less than 1.5 years in the majority of cases.



## 1. Introduction

In irrigation systems, particularly in collective irrigation networks, efficient water management is required for water user associations (WUAs). The purpose of WUAs is to control excessive water and energy consumption and to achieve cost savings (Abadia et al., 2008; Moreno et al., 2007, 2009; Jiménez-Bello et al., 2010; Rodríguez Díaz et al., 2011; Bagirov et al., 2013). Therefore, tools related to decision support systems (Khan et al., 2010), management of pump stations (Lamaddalena and Khila, 2013) and energy management (Reca et al., 2014) are used. Tools that permit the control and analysis of water and energy consumption in a WUA include performance indicators (Córcoles et al., 2012).

In 2001, the consulting group of the IPTRID (International Programme for Technology and Research in Irrigation and Drainage) published a document with guidelines for developing a methodology to improve the management and efficiency of irrigation systems. The proposed methodology was based on comparison with a reference pattern or "benchmarking" (Malano and Burton, 2001) and was applied worldwide. Guidelines were established in several zones, such as Spain (Rodríguez Díaz et al., 2004) and Australia (Alexander and Potter, 2004). Using the periodical control of these performance indicators, the water and energy consumption of an irrigation system were determined, and later, correcting measures to reduce water, energy and money were proposed (González Perea et al., 2014).

Among the existing technologies for the adequate management of water and energy resources, automation and remote control tools for irrigation systems are notable (Sweigard, 2003). To implement an automation project for the management of a collective pressurized irrigation network in a WUA, adequate information about the crop characteristics must be gathered, including the climate conditions, availability, precedence, demand of water resources, hydraulic and energy conditions of the irrigation network. Based on this information, different scenarios are then suggested (Avlonitis et al., 2003) and the establishment costs are evaluated to address the design and establishment phase. Several examples of the implementation of automation systems in the agricultural field are found in the literature, such as intelligent systems for opening and closing valves (Sweigard, 2003) and remote control systems for the maintenance of irrigation systems (Abderrahman et al., 2001).

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http://dx.doi.org/10.1016/j.agwat.2014.11.005
0378-3774/

**Table 1**
Characteristics of the WUAs.

| ID | Type of sensors | Type of actuators | Automation degree | Communication system | Pumps to be controlled |
|---|---|---|---|---|---|
| WUA 1 | Level sensors | Start–stop vertical well pump, start–stop horizontal pump | 1 | Wired | 1 × 150 kW, 1 × 100 kW |
| WUA 2 | Level sensors | Start–stop vertical well pump, variable-frequency-drive | 2 | Wired | 3 × 150 kW |
| WUA 3 | Level sensors | Start–stop horizontal pumps, start–stop vertical well pump, variable-frecuency drive | 4 | Wireless | 2 × 150 kW, 1 × 60 kW, 1 × 10 kW |
| WUA 4 | Level and pressure sensors | Start–stop horizontal pumps, start–stop vertical well pump, variable-frecuency drive | 5 | Wireless | 1 × 140 kW, 2 × 180 kW, 1 × 160 kW, 1 × 215 kW, 1 × 190 kW, 1 × 100 kW |
| WUA 5 | Level sensors | Start–stop horizontal pumps, start–stop vertical well pump, variable-frecuency drive | 1 | Wired | 1 × 22 kW, 1 × 90 kW, 1 × 15 kW, 1 × 105 kW |
| WUA 6 | Level sensors | Start–stop horizontal pumps | 2 | Wired | 1 × 180 kW, 2 × 120 kW, 2 × 60 kW |
| WUA 7 | Level sensors | Start–stop horizontal pumps, start–stop vertical pump | 2 | Wired | 1 × 60 kW, 2 × 170 kW |
| WUA 8 | Level sensors | Start–stop horizontal pumps, start–stop vertical pump | 3 | Wired | 1 × 15 kW, 2 × 30 kW, 2 × 60 kW, 2 × 150 kW, 1 × 1 kW, 2 × 50 kW |
| WUA 9 | Level sensors | Start–stop horizontal pumps | 3 | Wired | 4 × 60 kW, 1 × 200 kW, 2 × 40 kW |

*Automation degree:* (1) low level of automation: automatic control of the start & stop of pumps. (2) Soft level of automation: automatic control of the start & stop of pumps and automation of the open/close of hydrants. (3) Middle level of automation: automatic control of the start & stop of pumps, automation of the open/close of hydrants, data register for the hydrants of the network (volume and pressure). (4) Advanced level of automation: automatic control of the start & stop of pumps, automation of the open/close of hydrants, data register for the hydrants of the network (volume and pressure) and SCADA. (5) High level of automation: automatic control of the start & stop of pumps, automation of the open/close of hydrants, data register for the hydrants of the network (flow, volume and pressure), automatic control of the level of reservoirs and SCADA.

One possibility to control these automation and remote control devices is with the implementation of a supervisory control and data acquisition (SCADA) system. These type of systems have been used as valid solutions in the agriculture sector for the management of irrigation companies (Aquije et al., 2009), irrigation scheduling (Molina-Martínez and Ruiz-Canales, 2010; Molina et al., 2014), controlling pumping systems (Dobriceanu et al., 2008), canal management (Figueiredo et al., 2013; Rijo and Arranja, 2010), decision making (Almiñana et al., 2010), optimal management in water resources (Sweigard, 2003; Gensler et al., 2009) and deficit irrigation (Fernández-Pacheco et al., 2014).

In some WUAs, the communication system is wired because the distances between the base station and sensors and electrovalves to be controlled are short. However, in the majority of WUAs, SCADA systems usually monitor sensors that are far from the base station; therefore, a direct cable connection is not feasible. To address this issue, wireless sensor networks (WSNs) are used instead (Hedley and Yule, 2009; Wang et al., 2006). The most popular wireless technologies currently available and used in the agriculture and food industry sectors are the following: wireless local area network (WLAN), Bluetooth, ZigBee, and GSM/GPRS (global system for mobile communications/global packet radio service). Concretely, ZigBee is an open and global standard for WSN with a low rate, low cost, low power consumption and self-forming wireless communication, which make it ideal for the development of applications focused on sensor and automatic control. Several current applications using ZigBee technology are found in the literature, such as soil moisture monitoring (Morais et al., 2008; Sulaiman et al., 2009), microclimate real-time monitoring (Watthanawisuth et al., 2009), temperature monitoring in all phases of wine production (Boquete et al., 2010), and soil water monitoring for decision making in a sprinkler irrigation system (Kim et al., 2009).

In this study several performance indicators are proposed to assess the implementation of automation in water user associations. First, a description of the commercial technology applied for the automation of several WUAs is presented. Next, the proposed indicators and methodology for data gathering are discussed. Finally, the results of the comparison between the studied WUAs are reported to demonstrate the suitability of using these indicators to establish the strengths and weaknesses of the installation and propose corrective actions.

## 2. Materials and methods

The performance indicators proposed for the automation systems were applied in nine WUAs located in southeast Spain during 2011 and 2012. All of the WUAs had a collective pressurized irrigation network.

Before the determination of the proposed indicators, different audits for the WUAs were developed. The methodology described by several authors (Abadia et al., 2008; Moreno et al., 2009) to improve water and energy management was used in all WUAs. This methodology permitted the determination of several descriptive indicators and water and energy use indicators from the management data and measured field data. The management data were obtained from the 2011 and 2012 seasons, and the values for the annual average period were calculated. The collective irrigation networks of the WUAs all consisted of a branched network with diversions that supply water to numerous hydrants for drip irrigation. These collective irrigation systems also count with water storage systems, which are taken into account for this study. The water source can vary in the function of the WUA, with it primarily as surface water, ground water or sewage water, in some cases.

### 2.1. Automation and communication systems

All nine WUAs evaluated in this study were automated to different degrees. Table 1 shows the characteristics of the WUAs, indicating the type of sensors used, the type of actuators