G Model
AGWAT-4677; No. of Pages 6
ARTICLE IN PRESS
Agricultural Water Management xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Agricultural Water Management
journal homepage: www.elsevier.com/locate/agwat

# Performance indicators to assess the implementation of automation in golf courses located in Southeast Spain

A. Melián-Navarro[a,*], J.M. Molina-Martínez[b], J.A. Rodríguez-Díaz[c], A. Ruiz-Canales[d]

[a] Agro-Environmental Economics, Cartography Engineering and Graphic Expression in Engineering Department, Miguel Hernández University of Elche, Orihuela 03312, Spain
[b] Engineering and Agricultural Equipment Department, Technical University of Cartagena, Cartagena 30203, Spain
[c] Agronomy Department, University of Cordoba, Cordoba 14071, Spain
[d] Water and Energy for a Sustainable Agriculture, Engineering Department, Miguel Hernández University of Elche, Orihuela 03312, Spain

ARTICLE INFO

*Article history:*
Received 4 July 2016
Received in revised form
10 November 2016
Accepted 12 November 2016
Available online xxx

*Keywords:*
Benchmarking
Efficiency
Economical saving
Water and energy management

ABSTRACT

Generally, in most pressure irrigation systems and particularly in irrigation systems of golf courses, an efficient management of water and energy use is required. Through an efficient management of these resources the excessive consumptions are controlled and a savings in exploitation costs could be achieved. One of the tools that allow controlling and identifying the water and energy consumption is the use of management and automation indicators. With the employ of these tools, several parameters that affect in the efficiency of water and energy use of pumping systems, water network configuration, automation and the associated energy systems could be controlled. In this paper the methodology and implementation of several water, energy and automation indicators and their productivity adapted to four golf courses in south-east Spain are shown. For this purpose, some data of a developed study among 2008 and 2011 in the irrigation systems of these golf courses and their influence in the improvement of the efficiency in the water and energy use are presented. This combined methodology is particularly suitable for comparing the irrigation systems of several golf courses. Moreover, by using these indicators with automation and remote control devices for water and energy management in such irrigation systems, it is possible to reduce and control associated costs. The results demonstrate that automation is a low-cost investment (with a maximum of 2% of the total costs) compared to the large benefits and advantages. For this study, the maximum values of the automation cost per controlled water volume and energy were 0.2007 €·m$^{-3}$ and 0.2233 €·kWh$^{-1}$, respectively. The percentage of automation cost in the total cost is around 1.5 percent.



## 1. Introduction

Golf courses (GC) represent the best example of water demand for sports and other leisure purposes. Although their water consumption is relatively small, less than 0.5% of the total water diverted for agriculture in Spain (Rodriguez-Diaz et al., 2007), it is rapidly growing in many countries. However, in countries where water resources are under stress, there is a perception that irrigating golf courses represents a significant additional abstraction which causes a major impact on the environment and other abstractors, including irrigated agriculture.

Thus, water use efficiency has been a major issue in the sustainability of golf courses and National legislation increasingly requires the implementation of programs to ensure that water is used efficiently (Junta de Andalucía, 2008). Carrow (2006) highlighted the role of water conservation programmes to ensure efficient water use on golf courses. Priego de Montiano et al., 2006 and García (2008) completed the studies with the implication in environment of the golf courses. Recent publications about this matter are included in Winchell and Gibbs (2016), and Millington and Wilson (2016). This objective was to be achieved through the development and implementation of a site-specific íBest Management Practicesí (BMP) programme. These practices are not only to increase efficient use, but also to prevent quality damage in the water resources. Related to this, benchmarking and performance indicators represent useful tools to detect if water is used efficiently (Richie et al., 2002; Bastug and Buyuktas, 2003; Jordan et al., 2003; Dai et al., 2016). By comparing the performance indicators of similar organizations or systems, gaps between the most efficient and poorly

* Corresponding author.
*E-mail address:* amparo.melian@umh.es (A. Melián-Navarro).

http://dx.doi.org/10.1016/j.agwat.2016.11.017


Please cite this article in press as: Melián-Navarro, A., et al., Performance indicators to assess the implementation of automation in golf courses located in Southeast Spain. Agric. Water Manage. (2016), http://dx.doi.org/10.1016/j.agwat.2016.11.017

performing ones are highlighted and, by identifying the best practices, guidelines to improve performance can be established.

Previous research has focused on evaluating the irrigation water use by using performance indicators with benchmarking techniques in the agricultural sector (Molden et al., 1998; Burt and Styles 2000; Malano and Burton, 2001; Alexander and Potter 2004; Weatherhead et al., 2006; Rodríguez-Díaz et al., 2008; Ruiz Canales et al., 2011; Swarts et al., 2016). However, although Connellan (2004), Reyes (2007) and Rodríguez-Díaz et al. (2011a) developed methodologies for the application of benchmarking in sustainable water management in golf, there are few implementations in the golf industry. In all these studies, the evaluations were done for water consumption but not other resources that play an important role in irrigation such as energy.

However, in the agricultural sector, other research work has highlighted the necessity of improving the use of both water and energy resources simultaneously, focusing on the analysis of alternatives for reducing energy consumption and energy costs (Abadía et al., 2008b; Abadia et al., 2012; Moreno et al., 2007, 2009; Rodríguez-Díaz et al., 2011b; Jimenez-Bello et al., 2010; Shifflett et al., 2016). Also methodologies for water and energy audits using performance indicators have been developed and they have proven to be effective in the agricultural irrigation sector (Abadia et al., 2008a; Carrillo-Cobo et al., 2010; Pardo et al., 2013; Corcoles et al., 2016). Methodologies for energy audits in the golf sector have not been developed yet. However, there is a gradual growth in awareness of the fact that golf courses can save in maintenance and energy costs by making efficient use of the energy resources (Staples, 2009; FENERCORM, 2012; García-González et al., 2015). Also, improvements in energy efficiency may contribute to the overall environmental sustainability and improve public perception of the golf sector.

In this work several performance indicators are proposed to assess the implementation of automation in golf courses (GC). First, a description of the commercial technology applied for the automation of several golf courses is presented. Next, the proposed indicators and methodology for data gathering are discussed. Finally, the results of the comparison between the studied golf courses 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 four GCs located in the southeast Spain between 2008 and 2011. All of the GCs had a collective pressurized irrigation pipe network. Before the determination of the proposed indicators, different audits for the GCs were developed. The methodology described by several authors (Abadía et al., 2008b; Moreno et al., 2009) to improve water and energy management was used in all GCs. Additionally, some parts of the specific methodology for the evaluation of automation in agricultural irrigation systems, included in Fernández-Pacheco et al. (2015), was employed. This methodology allows the determination of several descriptive indicators and water and energy use indicators from the management data and measured field data (Rodríguez-Díaz et al., 2011a). These efficiency indicators are according to the international nomenclature and some are additionally included by the authors. The management data were obtained during different years (from 2008 to 2011), and the values for the annual average period were calculated. Although the period of the study comprises only four years, the relevance of the work can be increased with a wide temporary serial. There are no preliminary studies about the application of these indicators in golf courses and this is the reason because is interesting to develop this study for this period. Although there are previous works about the analysis of this problem, this study subject to evaluation presents as novelty that is located in golf course systems. Four GCs with differences among then has been choosen. The main similitude is the surface in order to stablish comparisons for applying all the efficiency indicators.

The collective irrigation networks of the GCs all consisted of a branched pipe network with diversions that supply water to numerous hydrants for sprinkler irrigation. These 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 GC, with it primarily as surface water, ground water or sewage water, in some cases.

### 2.1. Automation and communication systems

All four GCs evaluated in this study were automated in the same degree. Table 1 shows the characteristics of the GCs, indicating the type of sensors used, the type of actuators controlled, the degree of automation, the communication system and the collection of pumps that each automation system must control. Although the devices installed in the different GCs are varied, they are structured in a very similar way with a pump and control station and several hydrant heads. These hydrant heads are separated by approximately several meters from the control station, such that a wired communication system is always required. The GCs includes a higher degree of automation (see Table 1) usually incorporate novel wireless communication structures, as shown in Fig. 1. The pump and control station usually contains the following components: (a) a pump system with a variable speed drive, which is responsible for the water supply to the hydrant head and is controlled by the SCADA system; (b) a SCADA system that reads the signals from the hydrant heads of the irrigation system and activates the electrovalves; and (c) a module with a high gain antenna for wire or wireless communication with the irrigation head. The presence or absence of some of the cited elements, such as the variable speed drive, SCADA, wired or wireless communication, and the type of

**Table 1**
Characteristics of the studied Golf Courses.

| ID | Type of sensors | Type of actuators | Automation system | Communication system | Pumps to be controlled |
|---|---|---|---|---|---|
| Golf Course 1 | Level, pressure and volume sensors | Start-Stop vertical well pump, variable-frequency-drive | SCADA | Wired | 1 × 7.5 kW; 1 × 30Kw; 1 × 22 kW; 1 × 37 kW |
| Golf Course 2 | Level, pressure and volume sensors | Start-Stop vertical well pump, variable-frequency-drive | SCADA | Wired | 1 × 7.72 kW, 1 × 19.60 kW; 1 × 19.69 kW; 1 × 27.15 kW; 1 × 23.86 kW 1 × 26.26 kW; 1 × 27.70 kW |
| Golf Course 3 | Level, pressure and volume sensors | Start-Stop vertical well pump, variable-frecuency drive | SCADA | Wired | 1 × 49.36 kW; 1 × 49.46 kW; 1 × 49.86 kW |
| Golf Course 4 | Level, pressure and volume sensors | Start-Stop vertical well pump, variable-frecuency drive | SCADA | Wired | 1 × 6.58 kW; 1 × 5.86 kW; 1 × 50.40 kW; 1 × 51.10 kW; 1 × 49.30 kW |

Please cite this article in press as: Melián-Navarro, A., et al., Performance indicators to assess the implementation of automation in golf courses located in Southeast Spain. Agric. Water Manage. (2016), http://dx.doi.org/10.1016/j.agwat.2016.11.017