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Research paper

Optimal operation of pressurised irrigation distribution systems operating by gravity

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ABSTRACT

On-demand pressurized irrigation distribution networks (IDN) operating by gravity may face pressure failures especially during the peak period. Several methods have been developed for irrigation sectoring where farmers are organized in turns. In general, the optimization methods used for pressurized systems consider, in the formulation of the problem, energy saving as objective function, which is not suitable for gravity-fed networks. In this study, an optimization model for pressurized IDN fed by gravity was developed to provide an optimal operating strategy based on irrigation periods. The model uses genetic algorithm to assign an irrigation period to each hydrant taking into account the minimization of pressure deficit at the most unfavorable hydrant of the network. The method is applied to a large scale irrigation distribution network in Italy. It shows to significantly improve the hydraulic performance of the network by insuring a satisfactory pressure at all hydrants, under the actual peak demand as well as higher water demands.

1. Introduction

In on-demand irrigation networks, farmers are provided with high level of flexibility, because they have the freedom to decide when and how much water to withdraw from an irrigation distribution network to meet their crop water needs (Lamaddalena and Sagardoy, 2000). On the other hand, in irrigation distribution networks operating on-rotation delivery schedule, the operating time is divided into periods or turns. Farmers are then organized in groups where they are enabled a few hours every day to irrigate. These types of networks have a lower investment cost compared to on-demand ones, but they limit the flexibility of irrigation for farmers.

Pressurized irrigation distribution networks are designed so that the pressure at the most unfavorable hydrant is equal or higher than the established minimum pressure required to properly operate the on-farm irrigation systems. However, the actual operating conditions of these systems can be different from those assumed at the design stage. Indeed, the selected on-farm irrigation systems, management decisions and changes in farmers practices and behavior, may alter the required pressure at each hydrant (Kanakis et al., 2014). In addition, on-farm irrigation scheduling highly affects the simultaneity of hydrants' operation and hence the hydraulic performance of the irrigation distribution network (Salvador et al., 2011).

A major challenge in managing irrigation networks operating on-demand is to know beforehand the flows into the networks' pipes, which are random and depend on the number and location of hydrants operating simultaneously (Daccache et al., 2010b). As a result, large spatial and temporal variability of flow regimes occurs, which may produce failures related to the design options. In fact, even when the design flows are not exceeded (meet the design simultaneity), very low hydraulic performance can occur in these networks during their operation (Lamaddalena and Pereira, 2007).

To cope with the abovementioned problems, irrigation district managers tend to switch to restricted schedule during the peak period. This action can improve the hydraulic performance of the irrigation system and reduce energy consumption (Jiménez-Bello et al., 2015). Indeed, the replacement of open channel distribution systems with pressurized irrigation networks has significantly improved conveyance efficiency, but resulted in high energy consumption (Rodríguez Díaz et al., 2011). With the significant increase in energy costs in recent years, many authors have focused their research on energy savings in irrigation distribution

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systems (Fernández García et al., 2016b; Jiménez-Bello et al., 2011; Khadra et al., 2016; Moreno et al., 2010; Rodríguez Díaz et al., 2009). They concluded that grouping hydrants into sectors (considering their homogeneous energy use and organizing farmers in irrigation turns) is one of the most efficient strategies for decreasing energy consumption, especially during the peak period.

However, the absence of available management tools to select the configurations of open hydrants makes irrigation networks operating on-rotation or restricted schedule more prone to inefficient management (Moreno et al., 2010). To this end, different methods have been developed to optimize the grouping of hydrants into sectors, using energy saving as objective function (Carrillo Cobo et al., 2011; García-Prats et al., 2012). Conversely, there is a lack of attention concerning studies focusing of the optimal management of on-demand systems operating by gravity to improve their hydraulic performance. Lamaddalena et al. (2015) proposed the use of localized loops for the rehabilitation of an existing on-demand network operating by gravity in Italy. The method has shown to improve the performance of the network (Fouial et al., 2016). However, it does not consider the approach of restricted schedule as a solution.

The problem of finding the optimal operating strategy of irrigation distribution networks can be complex. For this reason, heuristic approaches such as genetic algorithm, GA (Goldberg, 1989) are used when solving this sort of problems. GAs have been successfully used in irrigation distribution networks' design and rehabilitation (Fernández García et al., 2016a; Murphy et al., 1998; Reca and Martínez, 2006), as well as operation and management (Fernández García et al., 2013; González Perea et al., 2016).

The aim of this paper is to propose an optimal management model for proper operation of gravity-fed pressurized irrigation networks designed for on-demand delivery schedule. A genetic algorithm has been developed and used to minimize the pressure deficit at the most unfavorable hydrant, during the peak period. The model has been tested on a real gravity-fed network operating on-demand, located in Southern Italy.

2. Methodology

The methodology developed in this work was integrated in a DSS called DESIDS (Decision Support for Irrigation Distribution Systems) (Fouial et al., 2016). The DSS encompasses two modules so far: Module 1 is used for the estimation of crop water requirements and gross irrigation requirements, using available climatic, soil and crops data. Additionally, this module can be used for irrigation schemes planning, irrigation scheduling as well as determination of peak periods. Module 2 is used for the hydraulic analysis of both branched and looped systems. This module combines the capabilities of two widely used programs, COPAM (Lamaddalena and Sagardoy, 2000) and EPANET (Rossman, 2000) by integrating EPANET Toolkit in the DSS. In this study, a third module (Module 3) has been developed and incorporated in the DSS. This module is used for the optimization of irrigation time and periods, using GA, to improve the hydraulic performance of the distribution network. Finally, the behaviour of the hydraulic network, according to the new management, has been evaluated using performance indicators. The developed modules as well as the results obtained from the optimization process are described in the upcoming sections.

Fig. 1 shows the general structure of DESIDS including the optimization algorithm.

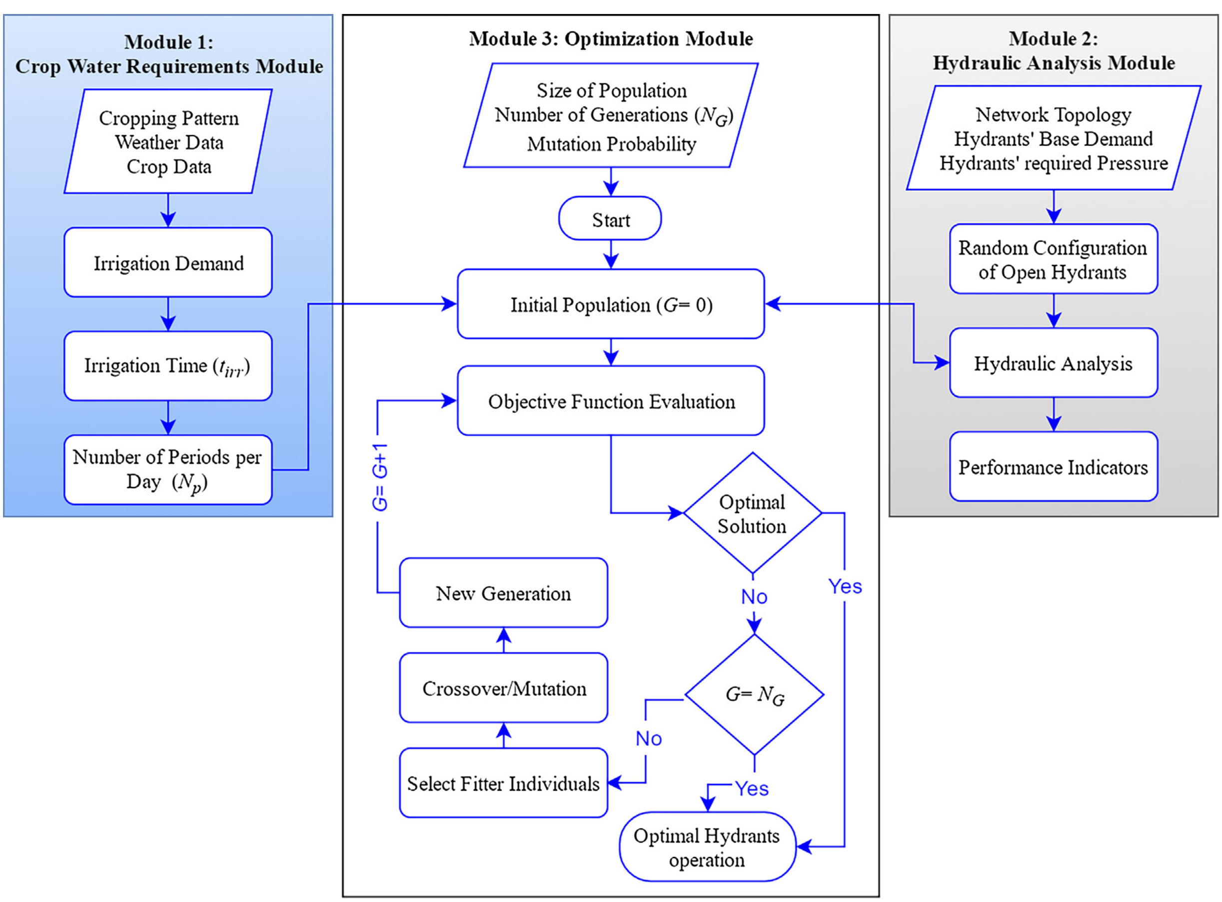

Fig. 1. DESIDS framework.