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NIREUS: A new software for the analysis of on-demand pressurized collective irrigation networks

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ABSTRACT

On-demand collective irrigation networks are hydraulic systems designed to deliver and distribute irrigation water from the water source to the irrigation perimeter, while providing users with the flexibility to decide on the time, the duration and the frequency with which they intend to use their hydrant. This paper presents the newly developed software NIREUS, which is developed for implementing the performance analysis of such networks. The performance analysis with NIREUS gives an overview of the operational status of the network under study by implementing the model of the indexed characteristic curves, while on the other hand, NIREUS determines the pipes/hydrants of the network that present, or are most likely to present, operational problems by implementing the performance analysis at hydrant level. This information is particularly useful for the management of existing networks as well as for the planning of future interventions and rehabilitation activities. The paper also describes the main functions of NIREUS and the characteristics that differentiate it from other existing software. Moreover, a new indicator which is incorporated in NIREUS is presented, in which the whole magnitude of the operational efficiency of a hydrant is depicted. The validation of the new software is made through a comparative application of NIREUS and COPAM to an existing on-demand pressurized collective irrigation network. Results proved the usefulness of NIREUS in highlighting both the weak and the strong parts of the network. The validation procedure gave a very close approximation of the respective values calculated with COPAM with the relative error ranging between 0.0% to 0.36% for the indexed characteristic curve of C50 and 0.01% to 0.22% for the indexed characteristic curves of C70.

1. Introduction

On-demand pressurized irrigation networks, are pipeline systems, usually without loops, designed to deliver and distribute irrigation water from the water source to the irrigation perimeter. On-demand networks, provide users with the flexibility to decide on the time, the duration and the frequency with which they use their hydrant. Nevertheless, these networks require frequent evaluation of their performance in order to ensure good operational status and efficient water use. The freedom of the farmers to use their hydrants on-demand, leads to a significant pattern variation of the open hydrants, both in time and space, depending on the decision of the farmers to irrigate or not, at a particular point of time. The total number of the hydrants operating simultaneously and their exact position in the network are impossible to guess a priori (Khadra et al., 2013). According to Zaccaria and Neale (2014), irrigation modernization and service oriented management present a lack of analytical frameworks for the assessment of these systems' performance (Small and Svendsen, 1992; Burt and Styles, 2004; FAO, 2007).

For the calculation of the discharges in on-demand irrigation networks, probabilistic approaches are usually adopted (Clément, 1966; Clément and Galand, 1979; Calejo et al., 2008) which attempt to forecast and model the consumption behaviour. Thus, the spatio-temporal distribution of open hydrants may vary significantly depending on various parameters such as the meteorological conditions, the cropping pattern, the irrigation system and the crop growth stage. The water demand pattern may alter significantly from what was initially foreseen during the design stage of the collective network. Over time, many pressurized irrigation networks have been arbitrarily changed by users (Kanakis et al., 2014). The variety of flow regimes cause variability in hydrant pressure and consequently, an adequate analysis of the hydraulic performance of the system is needed for better operation and adequate management (Khadra and Lamaddalena, 2010). Therefore, it

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is important to assess frequently the operation quality of such networks.

Performance analysis of on-demand distribution networks is assessed up to now with two basic approaches. The first one uses the indexed characteristic curves of the network (Labye et al., 1975) in order to provide analysis at network level, while the second one implements the performance analysis at hydrant level. At present, the most common software implementing such analysis are ICARE and COPAM. ICARE (CEMAGREF, 1983) is a commercial program developed by CEMAGREF in MS-DOS environment. COPAM (Combined Optimization and Performance Analysis Model) is a free distributed software, developed by FAO and CHIEAM-Bari Institute in Windows environment (Lamaddalena and Sagardoy, 2000). ICARE and COPAM implement both network and hydrant level analysis. More lately, Daccache et al. (2010) suggested a methodology simulating the interaction between on-demand water distribution systems and on-farm networks and applied it on a case study to assess the implication of pressure change on the irrigation performance. Lorite et al. (2013) used a wireless telemetry system for data collection which was applied to an on-demand collective network in Spain. The proposed technology determined the daily irrigation performance at field scale, for the whole irrigation district. More lately, Zaccaria and Neale (2014) proposed a methodology which entails simulating the peak-demand flow configurations in the pipe network through a deterministic-stochastic combined agro-hydrological model, and forecasting the delivery performance by means of a hydraulic simulation model and of some specific performance indicators.

Although COPAM is the most common software for the analysis of on-demand pressurized networks, still it is not compatible with Windows (64-bit) environment. COPAM allows only one hydrant per water intake but in the majority of on-demand irrigation networks there are more than one hydrants per water intake. This results in an incorrect introduction of the examined network in the software, with the use of hypothetical pipes that introduce additional friction losses but mainly change the topology of the examined network. Both ICARE and COPAM do not use the widely used tested and accepted Darcy–Weisbach equation for the calculation of the friction losses. Within this context, an alternative software, NIREUS, was developed which implements performance analysis both at network and at hydrant level. The developed software enables easy introduction of the topology of the examined network and a variety of friction loss equations to choose.

This paper, presents the newly developed software NIREUS including the key aspects that differentiate it from the existent relevant software for the performance analysis of on-demand networks. Firstly, an overview of the newly developed simulation model is presented, followed by the description of the main simulation processes supported by NIREUS. Finally, in order to validate our approach, both NIREUS and COPAM are used in a comparative application on a Greek on-demand irrigation network.

2. Software description

NIREUS is a software compatible with 64-bit versions of Windows that performs performance analysis of pressurized collective irrigation networks. The output information of NIREUS software can significantly contribute to the management of these networks and to the planning of interventions required to modernize or rehabilitate their operation. In addition, the developed software was created as a tool which allows intervention at any point of the analysis and can be extended with new capabilities to meet future needs.

The model permits the operation analysis of on-demand collective irrigation networks, at network level with the use of the indexed characteristic curves and the operation analysis at hydrant level. The model offers the choice of the friction loss formula and of the random number generator for the implementation of the analysis.

The NIREUS software has been developed with object-oriented programming in Visual Basic using .Net Framework (VB.NET). Visual Basic.net was chosen due to the intuitive and user friendly interface which provides in Windows environment. The software interface has been designed firstly to provide generic answers on the general operational condition of the particular networks. At a second level, the software gives also specific information on parts of the network that present malfunctions or which are bound to present problems in the near future.

2.1. Operation analysis at network level

For the analysis of on-demand collective irrigation networks several models have been developed, which assess their performance at network level.

At network level, the analysis is implemented with the indexed characteristic curves (Labye et al., 1975; Bethery et al., 1981; Bethery, 1990; CEMAGREF, 1983; Lamaddalena and Sagardoy, 2000). The flow chart of the developed simulation model for the analysis at network level is presented at Fig. 1.

For the implementation of the model, the user enters data through forms, concerning the geometry of the network (uphill and downhill node of each pipe, pipe length, ground elevation of downhill node, hydrants at the downhill node), the hydraulic characteristics of the network (diameters, roughness coefficients –depending on the chosen friction loss formula, nominal discharge of the hydrants, minimum pressure head at hydrant, special continuous discharge) and chooses the formula for the calculation of the friction losses that will be used in the analysis as well as the number of the simulations that will be implemented.

Initially, a random configuration of open hydrants is created with the use of a random number generator. The random number generator creates a new random number for each hydrant in each simulation, which is then used for the determination of the hydrant's operation as follows. A hydrant j is considered open if $p_j > k$ (where p_j is the operation probability of hydrant j and k is the random number ranging between 0 and 1). In order to create a configuration of open-closed hydrants of a network with R hydrants, R random numbers are produced. The default random number generator was Mersenne Twister (Matsumoto and Nishimura, 1998). Three of the most common random number generators were incorporated into the software, namely Mersenne Twister, Fast Random (Marsaglia, 2003) and System.random. An initial examination showed that the random number generator does not affect the analysis of such networks. Thus, Mersenne Twister was chosen as the default generator, since it is excessively tested (L'Ecuyer and Simard, 2007; Cornejo Díaz et al., 2010; Gentle et al., 2004).

The calculation of the friction losses for the particular configuration is followed by the determination of the required pressure head at each node. Finally, the required piezometric head at the head of the network for the particular configuration is estimated. The above procedure is implemented for a high number of simulations (determined by the user) and for all the examined discharges at the head of the network. The discharges at the head of the network that will be examined should range between 0 and the maximum theoretical discharge (cumulative discharge) which corresponds to the discharge at the head of the network when all hydrants are open and offer their nominal discharge. The required piezometric heads estimated from all simulations and for all examined discharges at the head of the network are statistically processed in order to design the indexed characteristic curves.