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Simulation of automatic control of an irrigation canal

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ABSTRACT

Improved water management and efficient investment in the modernization of irrigation schemes are essential measures in many countries to satisfy the increasing demand for water. Automatic control of the main canals is one method for increasing the efficiency and flexibility of irrigation systems. In 2005, one canal in the irrigation scheme 'Sector B-XII del Bajo Guadalquivir' was monitored. This canal is representative of irrigation schemes in Southern Spain; it is divided into four pools and supplies an area of 5154 ha. Ultrasonic sensors and pressure transducers were used to record the gate opening and water levels at the upstream and downstream ends of each canal pool. Using the recorded data and the SIC (Simulation of Irrigation Canals) hydraulic model, two canal control options (local upstream control and distant downstream control) were evaluated using a PI (Proportional-Integral) control algorithm. First, the SIC model was calibrated and validated under steady-state conditions. Then the proportional and integral gains of the PI algorithm were calibrated. The controllers were tested using theoretical demand changes (constant outflow followed by a sudden demand increase or decrease) and real demand changes generated on the basis of a spatially distributed crop water balance that included a number of sources of variability (random and not random) in the determination of field irrigation timing and depth. The results obtained show that only the distant downstream controller was able to adjust quickly and automatically the canal dynamics to the varying water demands; it achieved this efficiently and with few spills at the canal tail, even when there were sudden and significant flow variations.

1. Introduction

Competition for water between the irrigation sector and the industrial, urban, recreational, and environmental sectors, and the need for increasing agricultural water productivity (Comprehensive Assessment of Water Management in Agriculture, 2007) are challenging irrigation engineers to save water and to provide more flexible water delivery services (Merriam et al., 2007).

In Spain, investment in the modernization of irrigation systems is significant (Anonymous, 1998). However, interventions tend to be focused mainly on the farm irrigation systems and on the transformation of open channel distribution systems into on-demand pressurized-pipe networks. In most cases, the modernization of conveyance canals has been neglected or received little technical attention, so these canals remain unchanged since they were constructed decades ago. Therefore, the bottleneck for a flexible, on-demand service is often at the level of the conveyance or primary distribution system.

Irrigation canal automation may contribute to introduce flexible water delivery and to save water. Early canal automation (before the 1950s) was characterized by the use of self-controlled hydraulic gates. In the 1960s and 1970s, electromechanical controllers were developed and installed in the US. Thereafter, local control with programmable logic controllers was implemented (Burt and Piao, 2004). With the advent of personal computers, unsteady open channel flow simulation models were applied in combination with control algorithms (Burt and Piao, 2004; Clemmens et al., 2005). This approach has allowed significant advances in the engineering of canal control and automation.

Canal control algorithms can be heuristic, classical, predictive, or optimal (Malaterre et al., 1998; Ruiz-Carmona et al., 1998). The most recent studies have returned to classical algorithms of the Proportional-Integral (PI) type, using new techniques for tuning the gains of the algorithm (Clemmens and Whalin, 2004; Overloop et al., 2005; Piao and Burt, 2005; Litrico and Fromion, 2006; Litrico et al., 2007). Their robustness, accuracy and ease of implementation in the field have favoured this new trend (Bautista et al., 2006). However, there is no single solution or recipe applicable to all problems (Burt and Piao, 2004; Rijo and Arranja, 2005).

The goals of this study were: (1) to calibrate and validate a hydraulic model that allows the simulation of the actual operation

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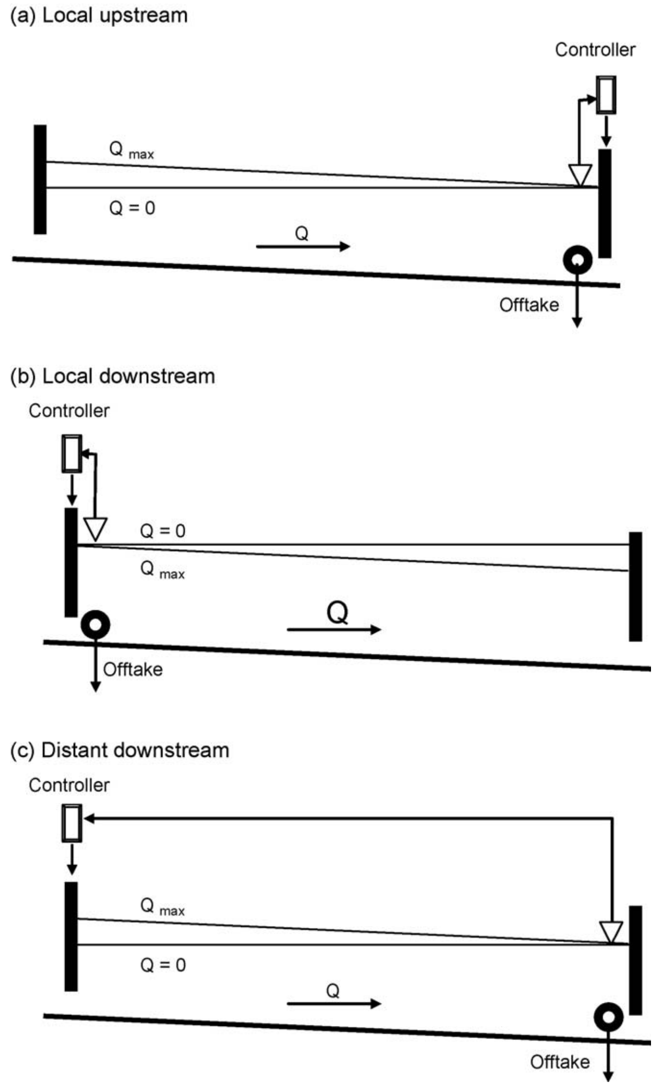

Fig. 1. Canal control logics.

and resulting water flow regime in a real canal; and (2) the simulation and evaluation of alternative automatic control methods that may help to shift the operation of irrigation canals from supply-oriented to demand-oriented operation. For this study, the hydraulic model Simulation Irrigation Canal (SIC) (Malaterre and Baume, 1997) was selected, and a study case canal that is representative of the irrigation schemes in Southern Spain was selected.

2. Control logics

There are two canal control logics (Burt, 1987; Buyalski et al., 1991): upstream control (Fig. 1a) and downstream control (Fig. 1b and c), each referring to the location from which information is needed by the control logic in relation to the check structure.

Under upstream control, the check structure adjustments are based on information from upstream (Fig. 1a); thus, the upstream control is appropriate for canal systems that are supply-oriented.

Under downstream control, the check structure adjustments are based on information from downstream (Fig. 1b and c). This control transfers the offtake demands to the upstream water supply source, thus, it is appropriate for demand-oriented delivery systems.

Under downstream control, the measured/controlled water depth may be located at different locations along the pool. If it is located at the downstream end of the canal pool (Fig. 1c), it will be called distant downstream control, using the terminology adopted in Litrico and Fromion (2006). Analogously, if the measured/controlled water depth is located at the head of the pool, i.e., close to the controller/check structure (Fig. 1b), it will be called local downstream control.

Usually, for the three control methods presented above, the target water depth is the normal depth for the design flow of the canal pool.

Under upstream control, canals can be sized to convey the maximum steady flow because the water depth in steady flow conditions never exceeds the depth for the design flow. The free surface profiles (for varying steady flows) pivot around the prescribed constant water depth just upstream of the check structure. A storage wedge between consecutive steady-state flow profiles is created (Fig. 1a represents the free surface profiles for maximum and null steady flows, and therefore the maximum storage wedge). When flow changes, the water storage volume must also change in the same sense (increasing or decreasing). That is why upstream control is particularly effective when associated with supply-oriented delivery schedules, like rotations (Clemmens, 1987). However, this method presents disadvantages when combined with demand-driven-operation because pool water storage must change opposite to the natural tendency (Buyalski et al., 1991) and, for this reason, operational water losses may be significant.

Local downstream control was the first control method developed for demand-oriented-operation. Under this control method, flow changes originated at the downstream end of the pool make the storage volume within the pool change in the opposite sense. The storage wedge responds to the outflows variations rapidly and efficiently (Buyalski et al., 1991; Goussard, 1993). However, the canal bench has to be horizontal to accommodate the null flow surface profile, and canal building becomes much more expensive and difficult.

Under distant downstream control (as under local upstream control), when there is a change in pool outflow, the tendency for pool water storage is to change in the opposite sense. To pivot the water surface on the downstream end, however, pool storage should change in the same sense (Buyalski et al., 1991). Therefore, to achieve the required volume changes with distant downstream control (as with local downstream control), inflow must be changed by a greater amount than outflow, until the new steady-state profile is reached.

If changes in water demand can be predicted, the inflow can be changed in advance and the operation becomes more effective and efficient. As changes in water depth at the end of the pool can be detected, distant downstream control allows anticipating the response. For this reason, distant downstream control often is an option for upgrading traditional upstream control in modernization projects (Rijo and Arranja, 2005).

3. Materials and methods

3.1. Description of the study canal

The canal selected for this study was canal B in the irrigation scheme "Sector B-XII del Bajo Guadalquivir", Lebrija, Spain. It consists of four pools separate by check sluice gates (named G1, G2, G3 and G4) (Fig. 2). Pumping stations located just upstream of the check gates (labelled PS I to PS III in Fig. 2) and at the canal tail (PS IV in Fig. 2) deliver the water to the farms through pressurized-pipe networks. The canal, entirely concrete lined, is 7.8 km long. The lengths of the four pools are 1.320, 2.155, 2.170, and 2.144 km,