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Research Article

Research Journal of Applied Sciences Engineering and Technology-Review Article Control of an Irrigation Canal

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Abstract: This study summarizes the most important developments and results found in the specialized research literature on Control of Irrigation Canals in the last ten years. The control of irrigation canals is not an easy task to carry out without solid background knowledge on the theme. Fortunately, this subject has attracted the attention of many researchers around the world in the last decades.

Keywords: Control water, nonlinear control, optimal control, pid control, predictive control, robust control

INTRODUCTION

Irrigation is the artificial application of water to the soil usually for assisting in growing crops.

In crop production, irrigation is mainly used to replace missing rainfall in periods of drought, but also to protect plants against frost.

At the global scale, approximately 2788 000 km^2 of agricultural land is equipped for irrigation in the world. 68% of this area is located in Asia, 17% in America, 9% in Europe, 5% in Africa and 1% in Oceania. Most of this vast area is gridded by irrigation canals.

Irrigation canals are artificial systems developed to transport water from main water reservoirs to several water-demanding agricultural farms during irrigational seasons.

Generally, they cover very long distances: their length can range from hundreds of meters to hundreds of kilometers. Along these canals, farms are located close to them and distributed all over the way.

It is not trivial to manage this type of systems. Water must be transported, minimizing the losses and assuring that every farm receives the stipulated amount of water at its corresponding frequency. Besides, the inherent characteristics of these systems increase the complexity of the problem. These systems present very long delays in the water transport (from minutes to hours), delay that even varies depending on the provided discharge. Moreover, there are important dynamical effects produced generally by changes in the amount of supplied water, that produce in different degrees depending on the case, interferences in the delivers of the whole system (coupling). Historically, these problems and the availability of water have motivated the creation in many countries of irrigation associations with their own irrigation statutes and rules.

Despite these measures, it is estimated that between 15 and 21% of water set aside for irrigation is lost, because of inappropriate transport management policies.

Regulation of an irrigation water delivery system generally relies on manual or open-loop techniques. The use of this type of managing strategies has the following drawbacks according to researchers around the world:

- Routing known flow changes and accounting for unknown flow disturbances and flow measurement errors using manual control is a difficult and time-consuming process (Wahlin and Clemmens, 2006)
- Low efficiency in terms of delivered water versus water taken from the resource (Litrico and Georges, 1999b)
- Large water losses (Rivas Pérez *et al.*, 2007)
- The performance is limited and the costs of operation are relatively high (Litrico and Georges, 1999b)
- Poor timing of irrigation, a consequence of manual water scheduling on the supply canals and tendency to oversupply water, as a lack of water has obviously adverse effects on the yield (Mareels *et al.*, 2005)

For these reasons, the research communities have paid attention in improving the operational management of these systems by applying control engineering tools.

Generally speaking, the goal of any irrigation canal automation is to maintain water levels as constant as possible at the offtakes by moving intermediate check gates in an automatic operation. This type of objective is requested for the following reason: either if irrigation water is taken out of the system by pumps or weirs, a constant level ensures water availability neither wasting water nor interfering other irrigations. Furthermore, there are several other benefits that can be gained. For

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instance, the erosion of the canal covering is reduced leading to lower maintenance costs, canal overflows are eliminated thereby saving water, etc..

SYSTEM CHARACTERISTICS AND THE CONTROL PROBLEM

In Malaterre *et al.*(1998) and in Ruiz *et al.* (1998) there is a survey about the different types of controllable variables in canal systems, in order to assure the availability of water for the final users. These are:

- Supplied water discharges
- Water depth levels where water is diverted for irrigation
- Stored water volumes

The truth is that what are really supplied to the farmers are always discharges, but the difficulties that has the measurement of this variable, make it less attractive. In contrast, the fact of controlling the water levels in the extraction zones, produce the same effect of water availability for the farmers, contributing additional advantages like, for example, preventing canal overflows and increasing the stability of the system. Choosing to control the storage water volumes has the advantage that this variable is less sensitive to the disturbances (unexpected water extractions), but at the cost of incrementing the response times of the system. Therefore the most used policy is considering the water levels in the extraction zones as control objective.

On the other hand, the final control action is always limited to control the gates or valves position or pumping actions. However, according to the same works and Malaterre and Baume (1999), it is also usual to solve the control problem using only discharges and afterwards use local controllers or discharge formulas inversion, in order to obtain the necessary actions over the actuators.

In the operational point of view, generally, it is more often required a regulation effect, in front of previous known demands, than a change in the operational working point (Clemmens *et al.*, 1998). However, the system has also unknown disturbances due to: inaccuracies in the measurement of the supplied discharge, filtration of the canals, non-authorized water extractions and changes in the demand.

A frequency analysis around a given working point, as the one made in Litrico and Fromion (2004c), gives valuable information about the different types of behaviors that can appear. According to the geometrical characteristics of the canal and the hydraulic conditions of the flow that circulates through it, the system can exhibit (small slope canals) or not (high slope canals) resonant modes, can have long delays (whose values depend mainly on the canal's length) that vary according to the circulating water discharge and can also have pure integrating dynamics (single pole in the origin).

IRRIGATION CANAL MODELS FOR AUTOMATIC CONTROL PURPOSES

The modeling of an irrigation canal is carried out dividing the canal into pools (section of a canal between two gates or any similar device), characterizing then the water dynamics at each reach separately and, finally, including the water regulation devices equations as boundary conditions between reaches.

As detailed in Henderson (1966) the water flow through a reach can be well characterized by the Saint-Venant equations, a nonlinear hyperbolic Partial Differential Equation (PDE) system.

On the other hand, the governing equations of the devices that are usually found in an irrigation canal (gates, weirs, etc.) are of nonlinear nature. In this manner, the solution of a complete irrigation canal model does not exist analytically and can only be done by means of advanced numerical methods (finite volume, finite differences, method of characteristics, etc.).

Clearly these models are not adequate for their use in automatic control design and implementation. For this reason, a series of authors have proposed different and diverse simplified types of models for control.

In Malaterre and Baume (1998) there is a survey about all types of models that had been used, until that date, in the canal control literature. They cover a large spectrum that includes:

Saint-Venant model linearization, infinite order linear transfer functions, finite order nonlinear models, finite order linear models (state-space models), finite order linear models (transfer functions), neural networks based models, fuzzy logic based models and petri nets based models.

In all these alternatives, Single-Input Single-Output (SISO) approaches that model each reach separately and Multiple-Input Multiple-Output (MIMO) approaches that model a whole canal, have been used. In both cases, some models include the actuators dynamics and models that do not.

In the last years, the literature shows the inclusion of new models and improvements to the already existing ones. First of all, we will refer to models that use some physical knowledge about the canal for its formulation. Second, we will review some black-box models along with identification techniques.

In Schuurmans *et al*. (1999a, b) a model, proposed by the same authors in 1995, is evaluated.

This one approximates each canal's reach as a pure integrator plus a delay, the reason why it is called Integrator Delay (ID) Model. The input variables of the model are the reach's inflow and outflow discharges and what is obtained is the water level at the end of it. In this model, the delay is obtained in an algebraic manner as a function of the physical parameters of each reach and the storage area (integrative part) is obtained by means of the canal's backwater curve. In order to include the actuators, linearized models of them were used. The model's validation in the time domain, with experimental data, showed an acceptable performance when the system was operated with small movements around a working point. In the frequency domain, the model showed a good fit in the low frequencies, but a bad fit in the high frequencies. In other words, there exists some evidence that the model does not perform well in the short-term period.

For this reason, the model manifested incapability to approximate resonant modes when they exist. They put emphasis on remarking, however, that the modeling of these modes is not so important, because they are generally filtered in control applications. This model has been also used to generate state-space MIMO models and in Clemmens and Schuurmans (2004a, b); Wahlin (2004); Montazar *et al*. (2005) and Van Overloop *et al*. (2005).

Few years ago, improvements to the ID model have been also proposed in Litrico and Fromion (2004a, b). There, the inclusion of a transfer function to approximate better the high frequency range was proposed. The model was called Integrator Delay Zero (IDZ) Model and this additional transfer function was considered for the influences of the inflow and outflow discharges. In that study, the algebraic expressions that describe the model parameters were also modified.

Another model in the same line as the preceding ones was the one presented in Rodellar *et al*. (1993) and Gómez *et al*. (2002), where the Muskingum model was used to model the water transport and, also, an integrator was used to characterize the water level variations upstream a gate (extraction zone).

Another approach was the one used in Litrico and Georges (1999a, b), where a simplification of the Saint-Venant equations was used to model a reach by means of the Hayami model. Due to the similarities that the authors observed between this model and a standard second-order plus delay one, they used the Method of Moments to obtain the parameters of this last one as a function of the Hayami parameters.

For the particular modeling case where rivers are used for irrigation purposes, in Litrico (2001a, b) system identification techniques were used to obtain the parameters of a Diffusive Wave model (another simplification of the Saint-Venant model) with the aid of experimental data.

For canals, in Litrico and From ion (2004c) and in Litrico *et al*. (2005) they developed and used a methodology for obtaining numerically the frequency response of a reach, including the gates, by means of the linearization of the Saint-Venant equations around an operation point and the knowledge of the hydraulic and geometric parameters of the canal.

A different approach was used, for example, in Malaterre and Rodellar (1997) and in Malaterre (1998). In that study, a state-space MIMO model was generated, using the linear zed Preissmann method in order to solve the Saint-Venant equations directly and construct, in that manner, a state observer. A linearized version of all gates equations were also included in order to generate a model that, by knowing the gate's openings, can calculate all water levels in the irrigation water extraction zones. This approach includes all system coupling effects and in general generates very large matrices.

In the same line of thought, Reddy and Jacquot (1999) used a linearization of the Saint- Venant equations using the Taylor series and a finite difference approximation to develop state-space MIMO model. A Kalman filter was also designed to estimate values for the state variables that were not measured.

In Durdu (2005), they developed a state-space MIMO model using another finite difference method. The difference was that in that study they developed a state estimator based on fuzzy logic rules.

Another state-space MIMO model was used in Seatzu (1999, 2000) and Seatzu and Usai (2002). In that case the modeling was performed around a particular hydraulic regime, called uniform regime that is the only one that has an algebraic solution by linear zing the Saint- Venant equations. Additionally, the model used as inputs, gate openings and as outputs, not the water depth levels, but rather, the storaged water volumes in each reach. A nonlinear irrigation canal model for control has also been developed. In Dulhoste *et al*. (2004), a model was developed by means of a nonlinear approximation with Lagrange polynomials of the Saint-Venant equations. In De Halleux *et al*. (2003) they went one step ahead and used the Saint-Venant model, but only for a zero-slope rectangular canal without friction. In Sanders and Katopodes (1999) the canal was modeled solving numerically the original Saint-Venant equations as an adjoint problem discredited with the Leap-Frog scheme. In Soler *et al*. (2004) a numerical scheme solving the Saint Venant equations using the method of the characteristics has been developed to calculate desired trajectories for control gates.

The modeling problem has also been faced from the Black-box model and Grey-box model identification point of view.

In Akouz *et al*. (1998), Ruiz and Ramírez (1998), Sawadogo *et al*. (1998, 2000), Rivas *et al*.(2002) and Rodellar *et al*. (2003) Auto-Regressive Integrated with exogenous input (ARIX) and Auto-Regressive Integrated Moving Average with exogenous Input (ARIMAX) Black-box models were used without getting too deep into the analysis or validation issues. The majority of these models used or the discharge or the gate opening at the beginning of the reach as model input and, the water level at its end, as output. In some cases the reach's outflow discharge and the water delivered for irrigation (when it was initially known) were used as known disturbances.

All of them used data obtained by computational simulation of the Saint-Venant equations.

In Weyer (2001) a deeper study was performed for model identification of the Haughton Main Channel reaches in Australia. Three gray-box models were used, based on elementary mass balances and gate equations. Because, in this case, the canal has overflow gates, the inputs to the model were water levels over the gates and its outputs, water levels in the extraction zones. Linear and nonlinear first order, second order and second order plus integrator (third order) models were proven. All of them included explicitly the delay. The obtained results, by means of model validation against real data, showed that the only model that could reproduce the effect of the waves was the nonlinear third order model. However, the first and second order ones could follow the tendencies in most of the cases. In the final conclusions they emphasized the need to study more the cases with gates in submerged regime and the use of closed loop identification, in order to estimate models using smaller variations and shorter experimentation times. The results of this study were extended in Eurén and Weyer (2007) in several aspects:

- The irrigation channel was equipped with both overshot and undershot gates.
- The overshot gates operated in both submerged and free flow
- There were several gates at each regulator structure and they had different positions
- The flows and pools were larger

TYPES OF CONTROL ALGORITHMS DEVELOPED FOR IRRIGATION CANALS

Malaterre *et al*. (1998), Malaterre and Baume (1998) and Ruiz *et al*. (1998) gave a survey of the control algorithms that had been developed until 1998 for canal irrigation control. They cover a large spectrum of approaches and techniques, among which can be mentioned: monovariable heuristically methods, Proportional Integral Derivative (PID) Control, Smith Predictor scheme, Pole Placement Control, Predictive Control, Fuzzy Logic Control, Model Inversion methods, Optimization methods, Robust Control, Adaptive Control and Nonlinear Control. Due to the diversity of proposed methods and distinct performance criteria used, the American Society of Civil Engineers (ASCE) Task Committee on Canal Automation Algorithms developed in Clemmens *et al*. (1998) two standard cases (Test Canal 1 and Test Canal 2) to test and evaluate automatic control algorithms. These cases are based on real canals and normal operation conditions as, for example, scheduled and unscheduled water discharge offtakes and correct and incorrect knowledge of the canal physical parameters. In that study , a series of evaluation criteria are likewise given in order to standardize the evaluation of control algorithm performance.

In spite of the important amount of studies that have been done about the subject (the majority of them in computational simulation), as denoted by Rogers and Goussard (1998) and Burt and Piao (2004) until now the few real canals that are managed in an automatic form use, in their majority, at the most PID control based techniques. It has been used, aside from several heuristic techniques, in the form of Proportional Integral (PI) control in many cases, PI plus filter (PIF) in cases with resonance problems and occasionally PID. These developments can be found in North America, Asia and Europe, but mostly in the USA.

Going back to the academicals knowledge developed, it is also important to mention that some of the cited methods have used only feedback strategies and others only feed forward strategies, while others have made use of combinations of both (Malaterre *et al*., 1998). Feedback produces a corrective control action in order to return the controlled variable to its nominal value, inclusively in presence of unknown disturbances, whereas feed forward can compensate the inherent delays of the system by anticipating the needs of the canal users.

In Bautista and Clemmens (1999) they tested a classical open-loop method, called Gate Stroking. The conclusion was that an adequate irrigation canal controller should be implemented, when possible, with feedback and feed forward capabilities. That is especially true for canals that need large water volume variations, to arrive to another steady state condition and for those characterized by a low Froude number.

PID control: From 1998 on, the works based on PID control have focused in improving the tuning of these types of controllers. To achieve this goal, two common practices have been identified from the literature: the use of simplified mathematical models and the employment of strategies that lead to decoupling the influences, produced by the control action of a reach over all the adjacent ones.

Schuurmans *et al*. (1999b) proposed a control where every reach was controlled by its upstream gate. In order to achieve this, a supervisory control was used. It calculated which should be the input discharge and then a local controller moved the gate so as to obtain the required discharge. The reach's outflow discharge and the water demands were also included as known disturbances, so as to decouple, in a better way, the interaction between reaches. The philosophy was, thus, to include the local controller in order to minimize the nonlinear effects that a gate induces on the canal operation. The tuning of these controllers was based on the ID Model and a filter was also used, so as to filter the canal inherent resonance.

In Malaterre and Baume (1999) optimum PI controller tunings were calculated in conjunction with their corresponding performances for different cases. In that study, different manipulated variable choices and decoupling strategies were tested. They arrived at the conclusion that the best results are obtained with a supervisory control that calculates for each reach their optimum inflow discharge and a series of local slave controllers that calculate the gate openings taking into account the water level variations induced by the gate movements. Better result was also obtained when the local controllers ran at a sampling time 5 times faster than the supervisory controller, but with a considerable increase in the control effort.

Other work that treated the decentralized Proportional (P) and PI controller tuning was Seatzu (1999). They proposed the use of a state feedback diagonal matrix and a H_2 norm minimization, so as to obtain an optimal tuning.

Seatzu (2000) proposed the same scheme, now seeking to place the eigenvalues and eigenvectors of the controlled MIMO system to some optimal values, obtained previously with the Linear Quadratic Regulator (LQR) method. Besides, in a later work (Seatzu and Usai, 2002), a research was made in order to know when this controller plus an observer was robust against modeling errors.

In Wahlin and Clemmens (2002) three classical controllers were tested on the ASCE Test Canal 1: PI Control, PI Control with upstream and downstream decouplers as proposed by Schuurmans (1992) (they were tested separately and together) and a heuristic control called Canal Automation for Rapid Demand Deliveries (CARDD). In all cases the control variables were the gate openings and feed forward control was implemented by means of a volume compensation method. The results showed that the best option was the control with both decouplers and that feed forward strategy was indispensable for all the cases. A control deterioration was also observed when the canal parameters were not accurate and when the gate movement restrictions were included.

Afterwards, in Clemmens and Schuurmans (2004a, b), a methodology was developed and tested in which, using a modified PI structure in order to compensate the delay of each reach, they structured a state feedback matrix with some non-zero elements. Then, formulating a LQR objective function and solving the Ricatti equation, they found the parameters of this feedback. They identified that using the trick of making zero some elements of the feedback matrix was equivalent to use different decoupling logics and that the use of the whole matrix was equal to implement a completely centralized controller.

They also made a performance study for all possible controllers, going from the complete centralization to the total decentralization. The conclusions was that, the centralized controller and the PI that sends information to all upstream reaches and to the closest downstream one, were the best options in the performance point of view. Another thing worth to mention is that they observed a possible control system destabilization when there exist a minimum gate movement restriction.

Other similar PI scheme working together with a centralized controller was used in Montazar *et al*. (2005). Van Overloop *et al*. (2005) also performed a decentralized PI tuning solving an optimization problem, but using, instead of one model for each flow condition, a set of models.

The idea behind was the abstention of a more stable controller.

Litrico *et al*. (2005) used each reach's frequency response to tune PI controllers. Making use of the gain margin obtained for different discharge conditions, a series of robust controllers were calculated. In this manner, they achieved robustness against operation condition changes. The test performed in a laboratory canal showed also a great correspondence between the observed and the expected performances.

A more detailed robustness analysis was performed in Litrico and Fromion (2006) and in Litrico *et al*. (2006). They proposed a new method to tune robust distant downstream Proportional Integral (PI) controllers for an irrigation canal pool. These tuning rules are appropriate to obtain specific robust margins and error characteristics. Implementation issues are also addressed.

Finally, in Litrico *et al*. (2007) a classical closed loop PI tuning method, called ATV method, was adapted for irrigation canal decentralized level controllers. The method needs to induce sustained level oscillations to characterize the stability margins of the controlled system.

Robust control: In addition to the robust PI controllers previously mentioned, other robust control techniques have also been employed. Litrico and Georges (1999b) suggested two irrigation canal controllers design methodologies: the a priori computation of a robust Smith Predictor and the trial and error tuning of a robust Pole Placement controller. Both of them used a nominal linear model and multiplicative uncertainty. These schemes were compared with the performance given by a PID tuned with the Haalman method, suitable for time delay dominant systems. The research concluded that a PID without a filter was faster, but also oscillating. In this context, the robust controllers fulfilled the established performance and robust requirements without major problems. Litrico (2001b) developed another methodology for robust controllers based on internal models, in this case, for the Gimone River in France. This river, in particular, has two water irrigation offtakes. They used the Hayami model and a multiplicative model uncertainty representation. The formulation was the following: they parameterized the filter value in order to obtain it, subsequently, assuring the closed loop robust stability.

Optimal control: In spite of the use of this technique for tuning other types of controllers, there are few recent studies about it. In Malaterre (1998) they used a MIMO Linear Quadratic (LQ)-optimal control for irrigation canals. This control was developed together with a previously mentioned state observer. It could handle unexpected and beforehand scheduled demands. Additionally, the MIMO structure of the controller exhibited big advantages to counteract canal coupling and transport delay effects.

Among the disadvantages of the method, they mentioned the large dimension of vectors and matrices, that the model validity is assured only for subcritical flows and the difficulty of LQ- optimal control to include gates restrictions.

In Reddy and Jacquot (1999) a proportional-plus-integral controller was developed for an irrigation canal with five pools using the linear optimal control theory. Different strategies were tested and it was found that the performance of regional constant-volume control algorithms was as good as the performance of a global control algorithm, whereas the performance of regional constant-level control algorithms was marginally acceptable.

More recently Durdu (2005) used a Linear Quadratic Gaussian (LQG) control strategy for irrigation canals in order to test different state observers.

Predictive control: Similarly as occurs with optimal control, there are few recent works that address the canal control with Predictive control techniques and the ones that do, use in general classical techniques in this area.

Malaterre and Rodellar (1997) performed a multivariable predictive control of a two reaches canal using a state space model. They observed that the increase of the prediction horizon produced a change in the controller behavior, varying the control perspective from a local to a global problem.

Following the research line of Rodellar *et al*. (1989, 1993) and Gómez *et al*. (2002) presented a decentralized predictive irrigation canal control. They used the Muskingum model plus a storage model in order to perform the water dynamic predictions in each reach.

In order to decouple the system, the controller used an estimation of the future discharges and the hypothesis of being linearly approaching the reference, to finally reach it, at the end of the prediction horizon. Because the control law solution was given in terms of reach's inflow discharge, they used a local controller to adjust the gate opening to the required discharge.

Akouz *et al*. (1998) used decentralized predictive controllers to manage three reaches of the ASCE Test Canal 2, acting on each reach's inflow discharge. They didn't include in the control, feed forward compensation for known scheduled demands or reach's outflow discharges. The same technique was used in Ruiz and Ramírez (1998); including the reach's outflow discharge as a known disturbance. In Sawadogo *et al*. (1998) and later in Sawadogo *et al*. (2000), they presented a similar decentralized adaptive predictive control, but that used the reach's head gate opening as controllable variable and the reach's tail gate opening and the irrigation offtakes discharge as known disturbances.

A decentralized adaptive predictive controller was also presented in Rivas *et al*. (2002). Here the manipulated variable was the inflow discharge and they did not include the known disturbances. In order to achieve some kind of robustness they used dead bands and normalization in the adaptation of the model.

Sometimes it is convenient to take into account actuator and process constraints when controlling a particular system. In this respect, a constrained predictive control scheme was developed in Rodellar *et al*. (2003) to manage irrigation canals. It was based on a linear model that used gate openings and water levels as input and output variables respectively and one of the novelties of the method was that it takes into account explicitly in the control problem that gates should not come out of water. Constraints on the movement velocity of the gates were also considered and the results exhibited an improvement in the control performance in comparison with the predictive unconstrained case.

More recently, Wahlin (2004) tested a MIMO Constrained Predictive controller using a state space model based on Schuurmans ID model. They performed tests where the controller either knew or did not know the canal parameters and with and without the minimum gate movement restriction. While many gate operation restrictions could be included in the control law, the minimum gate movement restriction could only be applied as a dead band in the control action once calculated. The reason for this is that this type of constrains are very difficult to implement in a controller. The results showed that it was possible to control the canal in question, but with a performance not superior than a centralized PI. Nevertheless, they conjectured that the problem was attributable to the modeling errors of the ID Model. In that case, a better model would be required in order to implement the predictive control. Additionally, they observed that the minimum gate movement restriction worsened, in a high degree, the control performance.

There are also some real implementations of predictive control in laboratory canals. In Begovich *et al*. (2004) a multivariable predictive controller with constraints was implemented in real-time to regulate the downstream levels of a four-pool irrigation canal prototype. In Silva *et al*. (2007) a predictive controller, based on a linearization of the Saint Venant equations, has been also implemented on an experimental water canal.

Nonlinear control: Because of the complexity of the original nonlinear model, there are not many research works that had faced the nonlinear control for these types of systems. In Sanders and Katopodes (1999), they used a nonlinear optimization method for controlling one canal reach adjusting its gate openings. The computation times were near the three minutes with Pentium processors.

Dulhoste *et al*. (2004) made a controller based on the dynamic state feedback linearization. The control was tested for set-point changes, infiltration and water extraction cases. There were good results on computational simulation for different length rectangular canals.

In De Halleux *et al*. (2003), they described and analyzed a general stability condition for water velocities and levels in open channels. With the aid of it, they proposed and applied a controller to a two-reach no-friction horizontal computer-simulated canal. In Soler *et al*. (2004), the nonlinear numerical scheme has been combined with a typical predictive control performance criterion to compute gate trajectories in an open-loop operation.

CONCLUSION

In brief, this study reviews the conceptual/ theoretical dimension and the methodological dimension of the literature in irrigation canal control.

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