DESIGN AND IMPLEMENTATION OF AN IRRIGATION CANAL SCADA

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ABSTRACT

In Portugal all of the upstream controlled canal systems work with flexible water delivery schedules and therefore canal operational losses can be significant. Real-time technologies can allow the canal managers to continuously compare the real operation with its optimal or target value and to take appropriate corrective steps as required and minimize the water operational losses. The paper presents the design, field solutions and tuning of an implemented SCADA system on a Portuguese upstream controlled canal. Remote monitoring allows the data acquisition of water levels, gate positions and inflow and outflow computations. Remote control allows the operator to send control orders to gates. Two networks, including their remote terminal units and the needed communication and control software are parts of the presented SCADA system. This system controls the inflows to the main canal and main laterals, as well as the main outlets to the drainage system with gate controlled orifices. All the discharge equations are tuned in the field. The outflows through weirs or Neyrpic automatic siphons from the main laterals are also monitorized and their discharge equations are also tuned in the field.

INTRODUCTION

In Portugal, all the open-channel irrigation perimeters have upstream controlled systems and were designed for a rotation water delivery method. In practice, this delivery schedule was never implemented. Irrigation systems work on an arranged delivery schedule basis (Clemmens, 1987). Delivery gained flexibility, but the daily operation of the conveyance system itself is more complex, difficult and inefficient in the water use. Operational water losses in the conveyance and distribution systems are significant. Most of these systems are still empirically operated and according to personal judgments. In the particular case of the Sorraia Irrigation Project, here presented, the system manager cannot measure the inflow rates and, in order to be sure that deliveries match demands in all delivery points, he operates the system, most of the time, at full capacity. So, spills are common.

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For the sub-system under modernization (main and lateral canals, all of them concrete lined canals), Rijo & Almeida (1993) presented an estimation of the conveyance efficiency (ratio between delivered and inflow water volumes) of 40%, considering the entire irrigation seasons of the years 1987 and 1988.

The main canal systems of these projects are now the focus of a new rehabilitation and modernization policy, with the main purposes of saving water and installing more flexible water delivery rules, like on-demand schedules (Clemmens, 1987). The final objectives are to make possible new irrigation methods and give some degrees of freedom for irrigation water management to farmers. The proposed field implementation of this policy was to maintain the system architecture, to install supervisory control and data acquisition systems (SCADA) and, when possible, to install buffer and control in the form of off-channel reservoirs (Rijo & Paulo, 1998).

The SCADA systems allow the water manager to continuously compare the actual hydraulic state of the delivery system with its optimal hydraulic state, and to take appropriate corrective steps as required. These systems allow the manager to react rapidly and effectively to the changing conditions, thereby accommodating both high and low flow conditions and reducing canal spillage and seepage.

The preliminary study of the SCADA of the Sorraia Irrigation Project was already presented by Rijo (1999). This paper describes implemented solutions (control and equipments) and the correspondent tuning.

BRIEF DESCRIPTION OF THE SORRAIA IRRIGATION PROJECT

The Sorraia Irrigation Project (Figure 1) is located along the narrow alluvial valley of the Sorraia River, a tributary of the Tejo River, near Lisbon (Portugal).

Water sources are two large dam reservoirs (Figure 1 and Table 1). The main irrigation system is an open lined canal network (main and secondary canals or laterals). AMIL radial gates (Kraatz & Mahajan, 1975) provide potentially good operation conditions for the Neyrpic orifice module intakes (Kraatz & Mahajan, 1975) to tertiary systems (canals or buried low pressure pipes) and to the fields. Irrigation areas and main crops are also presented in Table 1.

REAL-TIME SUPERVISORY CONTROL OF THE MAIN SYSTEM

General Presentation

The central control of the conveyance and water delivery network is only appropriate and efficient when reliable information exists about the real-time hydraulic state of the system. As already mentioned by Rijo (1999), therefore, a central control of an open-channel system must involve:

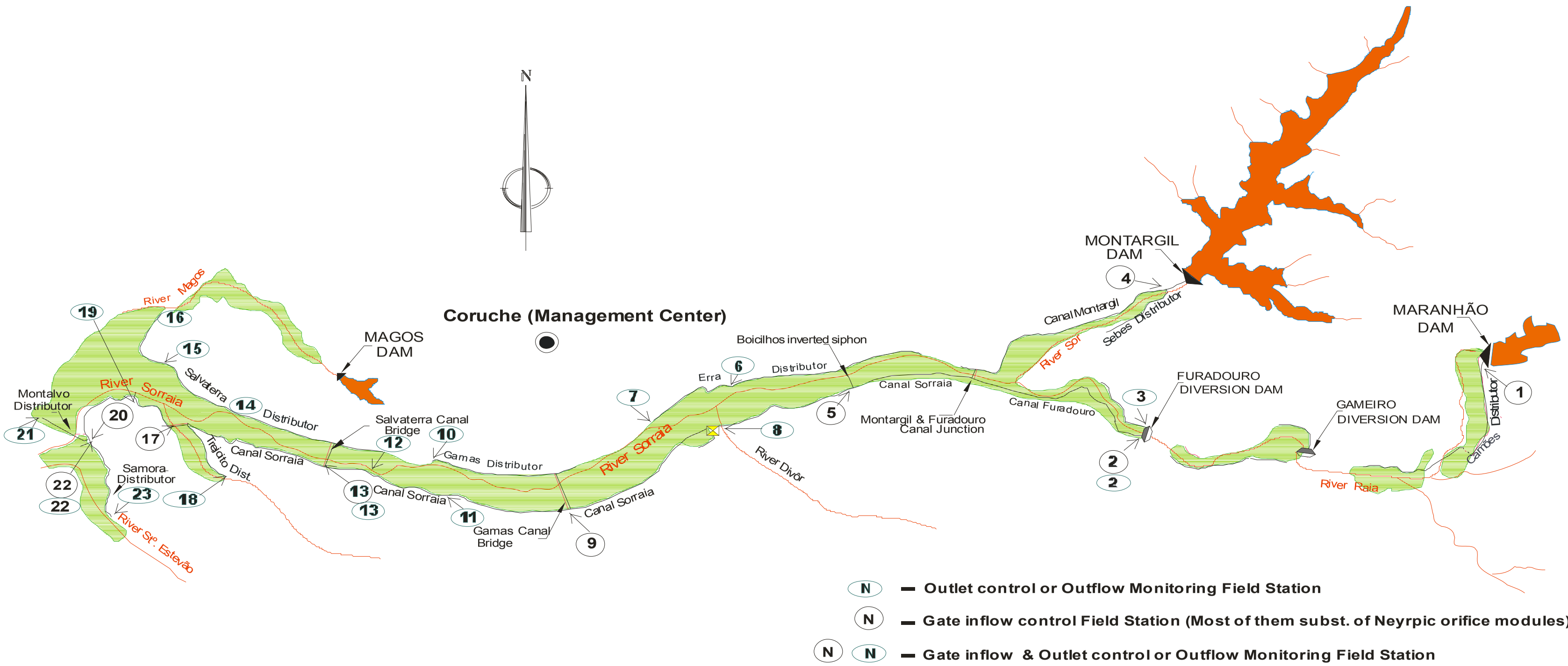


Figure1. Sorraia Irrigation Project Scheme. Field Stations of the SCADA

- a real-time remote monitoring action in order to keep abreast of the hydraulic system conditions or in order to obtain its actual state; this action is guaranteed by the SCADA;
- a remote control action in order to lead the system to the desired state, an action also guaranteed by the SCADA; the correction of the system (the closed loop control action) is taken care by the actuators in the control devices, namely gates;
- a management action to support operational decisions, ensuring the desired service performance, regarding the real and expected demands, the available storage volumes, and economic factors.

The SCADA system involves: remote terminal units (RTU), to collect local data (water levels, flow rates, gate positions) and command local equipment (gates); a command center, to supervise/manage all the RTU; a communication system, to link the RTUs to the command center.

Table 1. Main characteristics of the Sorraia Irrigation Project

Water storage volumes:	
Maranhão dam reservoir	180.9×10^6 m^3
Montargil dam reservoir	142.7×10^6 m^3
Conveyance and distribution system:	
Conveyance canals	112.9 km
Distribution canals	98.5 km
Buried low pressure pipes	171.6 km
Maximum design flow	17.0 m^3/s
Control devices	
AMIL gates	303
AVIS gates	85
Modules	567
Turnouts to farms	2026
Farmers	2000
Operational and maintenance staff	90
Irrigated areas (means of 1990-2000)	
Corn	4135 ha
Rice	3979 ha
Tomato	1281 ha
Other crops	2395 ha
TOTAL	11790 ha

RTU units are the interfaces between SCADA and the hydraulic system. For safety, they are located inside field stations (Sta.). The RTU units main purposes are: controlling inputs and outputs of field devices (intakes, offtakes and gates); monitoring field devices such as water level and gate position sensors and log alarms; reporting to the master station and carrying out the commands set they receive from these stations. The field stations can be of three types: control unit (RTUc), control and monitoring units (RTUcm) and monitoring unit (RTUm).The Sorraia Irrigation Project SCADA has 23 Field Stations with RTUcm or RTUm.

<u>Field Stations with Control and Monitoring Units (RTUcm).</u>There are 13 Field Stations with RTUcm. All of them include remote monitoring of water levels (upstream and downstream) and gate positions (Figure 1 and Table 2).

- to control inflows to main canals – from Maranhão and Montargil dam reservoirs (respectively, Sta1and Sta4), Furadouro diversion dam (Sta2);
- to control inflows to main laterals – Camões (Sta1); Sebes (Sta4); Erra (Sta5); Gamas (Sta9); Salvaterra (Sta13, Sta15); Trejoito (Sta17); Montalvo (Sta20); Samora (Sta22);
- to control wasted outflows at main outlets to the drainage system – Sorraia Canal (Sta8, Sta12); Salvaterra Lateral (Sta14).

<u>Field Stations with Monitoring Units (RTUm).</u> There are 13 Field Stations with RTUm. All of them include remote monitoring of the hydraulic device upstream water levels (*Su*) and the correspondent flows (*Q1*) (Figure 1 and Table 2).

- to monitor inflows to laterals – Entre-Águas (Sta3); Sebes (Sta4);
- to monitor wasted outflows through Neyrpic automatic siphons – Erra Lateral (Sta6); Montalvo Lateral (Sta21); Samora Lateral (Sta23);
- to monitor wasted outflow through downstream terminal canal weirs – Erra Lateral (Sta7); Gamas Lateral (Sta10); Salvaterra Lateral (Sta16); Trejoito Lateral (Sta18);
- to monitor wasted outflow through side weirs – Sorraia canal (Sta11, Sta13, Sta22); Salvaterra Lateral (Sta15).

<u>Master Station</u>. At the present development of the SCADA, there is only the Master Station at the central office of the Irrigation Project Association (Coruche, Figure 1).

All the controllers (see next chapter) are already installed in each Field Station and tuned, including the pre-definition of the daily operation schedules for the gates. For the developed SCADA application, only the pre-definition (daily, weekly and monthly) operation schedules are being developed. The communications with each RTU are also installed and used successfully.

Table 2. Summary of the equipments and control of the SCADA Field Stations (*)

Sta	Controller	Monitoring	Gate Nº	Weir	Bottom orifice	Siphon	Commu nication	Power	Description
1	*D, P, Q*	*Su*	2	no	not	not	PSTN	EDP	Camões Lateral Intake
2	*D, P, Q*	*Su*	1	yes	no	not	GSM	EDP	Furad. canal Intake; Div. Dam weir
3		*Su, Q1*	8	not	not	not	GSM	solar	Entre-Águas Lateral Intake
4	*D, P, Q*	*Su, Q1*	1	not	not	not	PSTN	EDP	Sebes Lateral Intake
5	*D, P, Q*	*Su, Sd*	1	not	not	not	GSM	EDP	Erra Lateral Intake
6		*Su, Q1*	--	not	not	yes	GSM	solar	Erra Lateral Neyrpic siphon
7		*Su, Q1*	--	yes	not	not	GSM	solar	Erra Lateral end
8	*D,P,Q, WL*	*Su*	--	not	yes	not	GSM	EDP	Sorraia canal gate controlled orifice
9	*D, P, Q*	*Su,Sd*	1	not	not	not	GSM	EDP	Gamas Lateral Intake
10		*Su, Q1*	--	yes	not	not	GSM	solar	Gamas Lateral end
11		*Su, Q1*	--	yes	not	not	GSM	solar	Sorraia Canal weir
12	*D,P,Q, WL*	*Su*	--	not	yes	not	GSM	EDP	Sorraia Canal gate controlled orifice
13	-- *D, P, Q* *D, P, Q*	*Su, Q1* *Su* *Su*	-- 2 1	yes not not	not not not	not not not	GSM	EDP	Sorraia Canal weir Salvaterra Lateral Intake Sorraia Canal gate
14	*D,P,Q, WL*	*Su*	--	not	yes	not	GSM	EDP	Salvaterra Lateral gate controlled
15	-- *D,P,Q WL*	*Su, Q1* *Su, Sd*	-- --	yes not	not not	not yes	GSM	EDP	Salvaterra Lateral weir Gate controlled Inverted siphon
16		*Su, Q1*	--	yes	not	not	GSM	solar	Salvaterra Lateral end
17	*D, P, Q*	*Su*	1	not	not	not	GSM	EDP	Trejoito Lateral Intake
18		*Su, Q1*	--	yes	not	not	GSM	solar	Trejoito Lateral weir
19		*Su*	--	not	yes	not	GSM	solar	Sorraia Canal gate controlled orifice
20	*D, P, Q*	*Su*	2	not	not	not	GSM	EDP	Montalvo Lateral Intake
21		*Su, Q1*	--	not	not	yes	GSM	solar	Mont. Lateral Neyrpic siphon
22	*D,P,Q*	*Su* *Su, Q1*	2 --	not yes	not not	not not	GSM	EDP	Samora Lateral Intake Sorraia Canal weir
23		*Su, Q1*	--	not	not	yes	GSM	solar	Sam. Lateral Neyrpic Siphon

(*) Used notation presented in the text.

The Master Station is equipped with a computer where runs the SCADA application, a synoptic panel, a master controller, communication equipment and receives the relevant data from all Field Stations, treat all the received data and shows it to the manager for control decisions (manually centralized control) and permits also the visualization of the installed local automatic water level controllers (*WL*, Table 2):

Communications. Guaranteed by public switched telephone network (PSTN, Table 2) or by GSM network (GSM, Table 2).

Power supply - The RTU are supplied by the national electrical power network (EDP) or by solar panels (Table 2).

IMPLEMENTED SCADA SOLUTIONS AND TUNING

Direct controller (*D*, Table 2). The Direct controller is responsible for the control orders sent to the actuators of the different controlled gates. For the example of the Figure 2, one of three installed controllers decides if it is necessary to adjust a certain gate and *D* sends the order to the actuator of this gate (Table 2 presents the number of gates for each station.). Sta 3 has 8 gates, but it is the only case that maintains the original baffle modules. For the other controlled intakes, the modules were replaced by larger and motorized sluice gates installed over the Neyrpic weir (Kraatz & Mahajan, 1975) associated with the modules (see Table 3).

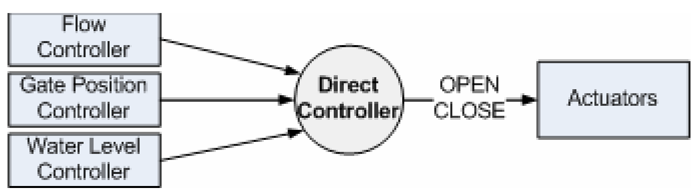
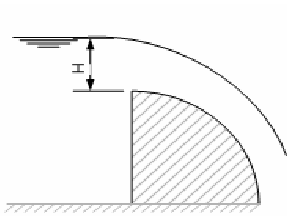


Figure 2. Direct controller connected with other controllers.

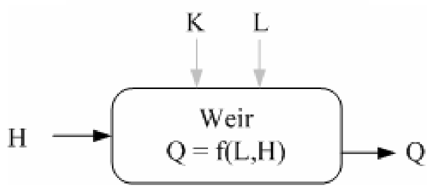
Gate position controller (*P*, Table 2). The gate positions of the main controlled intakes and gate controlled bottom orifices (Table 2 and Table 3) are controlled by a *Bang-Off-Bang* controller with a deadband (Figure 3) (Ogata, 1997). With this controller, if the error (difference between the gate position set point and the measured gate position, $ey = yset - ymed$) is grater than the defined deadband (Δy), the actuator must to open the gate and close the gate if ey is less than Δy (the defined values for all the gates is 5 *mm*).

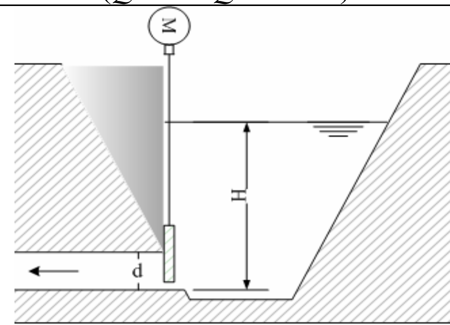
Flow controllers (*Q*, Table 2). Flow controllers were installed for the gates located at the controlled main lateral intakes and for the gate controlled bottom orifice outlets (Table 3).

Table 3. Flow algorithms computation (*Q1* and *Qnominal*)

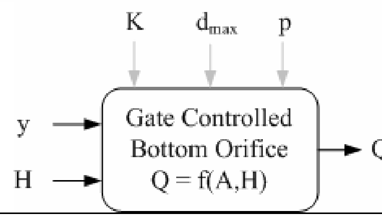


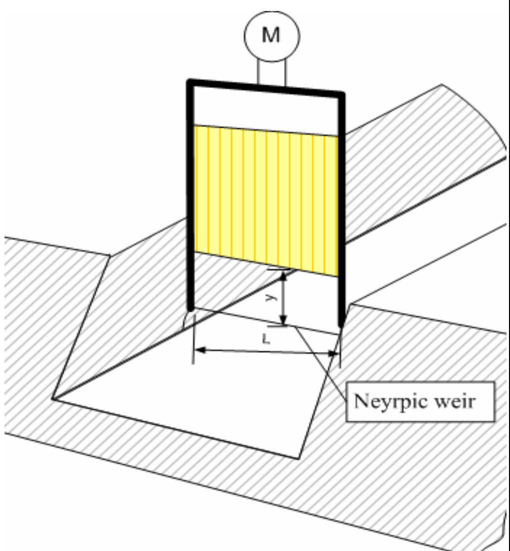
$$Q = K\,L\sqrt{2\,g}\,H^{3/2}$$



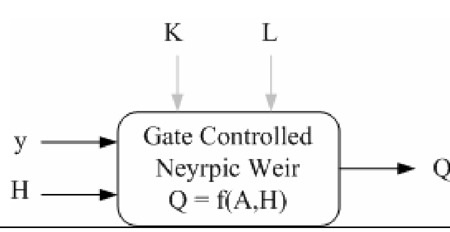


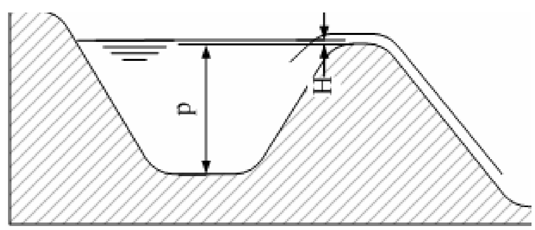
$$Q = K\,A\sqrt{2\,g\,H}$$



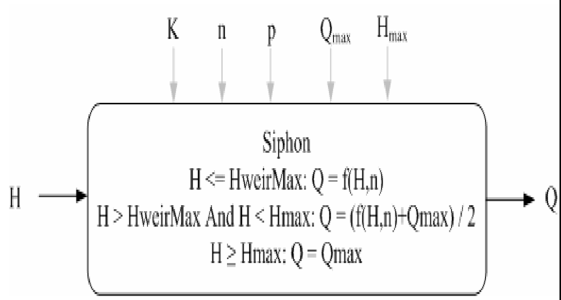


$$Q = K\,A\sqrt{2\,g}\,H^{3/2}$$





$$Q = K\;H^{n}$$



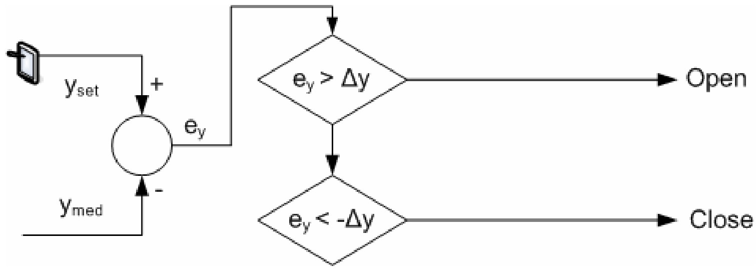


Figure 3. Gate position controller.

The Figure 4 shows the algorithm for a single gate. As shown, the algorithm is similar to the gate position controller. *Qset* is the flow set point and *Qnominal* is the estimated flow for the tuned flow equation of the installation. The flow equation was tuned in the field for each installation, using a flow meter and considering different flow situations and gate positions. In the figure, C1 is the single gate considered (there are field installations with two gates installed in parallel, Table 2). The value considered for the deadband ΔQ is 5 *l/s*, independently of the maximum flow of the installation, which can vary between 0.2 m^3/s and 4.0 m^3/s.

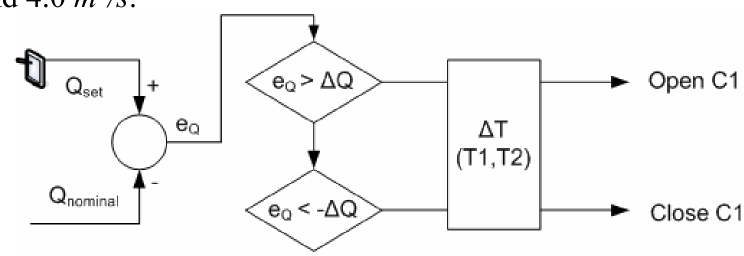


Figure 4. Gate flow controller.

Table 3 shows the most common situations: schemes, standard equations and flow computation algorithms. In the table, *A* is the orifice area, *d* is the pipe diameter, *K* is the coefficient of discharge (a calibration parameters), *L* is the length of the crest, *n* is also another calibration parameter, *Q* is the flow (*Q1* or *Qnominal*) and *y* is the gate opening. Table 3 also shows two typical installations used to monitor the main outflows (*Q1*, Table 2) – the canal side weir and the automatic siphon.

<u>Water level controllers (*WL*, Table 2).</u> For the gate controlled bottom orifices of the Sta8, Sta12, Sta14 and Sta15, an automatic local WL controller was also installed in order to keep the water level inside the canal under a pre-defined set point.

<u>Other installed softwares</u>.The developed SCADA application also has alarms, considering pre-defined conditions, messages and recipients (for the alarms messages) and also permits the computation of a few operational statistics (minimal and maximal flow, daily water volumes,…).

FINAL CONSIDERATIONS

Today, real-time monitoring and control systems are within the cost range of almost all water user groups, including irrigators, canal companies and water districts. For the present project, the total cost of the project was 1.08 million US dollars, 0.18 for software and field tuning and 0.90 for the equipment and installation.

The installed SCADA application will permit to reduce conveyance losses and waste, to increase ability of meeting real-time demands by the water users and to reduce operation and labor costs. The authors think that the SCADA will contribute for: the conservation of the actual irrigation area and inclusion of new irrigation areas outside of the gravity dominated perimeter; the installation of medium pressure pipe distributors prepared for water delivery on demand basis; the definition of a monitoring and automation system for new pressure pipe distributors; the reduction of the exploitation costs – workmanship, power and maintenance; the evolution, after some field experience, to a central automatic control for the main network – conveyor, main laterals.

ACKNOWLEDGEMENTS

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