CEMAGREF-IIMI International Workshop on
The application of Mathematical Modelling for the Improvement of Irrigation Canal Operation
October 26-30 1992, Montpellier, FRANCE

USE OF THE SIC SIMULATION MODEL TO IMPROVE THE MANAGEMENT OF AN IRRIGATION CANAL IN LA BEGOÑA, GUANAJUATO, MEXICO

Benjamín DE LEON MOJARRO[1] , Pascal KOSUTH[2] , Jorge ARGUETA[3]

Abstract
La Begonia Irrigation District consists in a total irrigated area of 11 000 hectares. 8 000 hectares receive water from a 20 km long main canal and 3 000 hectares use underground water by mean of electrical pumping stations. The main canal is controlled with 29 manual check gates, used to distribute water to 83 extraction points. The management of the main canal is traditional and is representative of most of the Mexican irrigation canals which have a weekly rotational water delivery schedule and a manual upstream control.

The energy costs of pumping underground water and its effect on the watertable level, the seemingly low efficiency of water distribution to secondary canals as well as the need for a more flexible use of water by farmers, induced the managers of La Begonia Irrigation District to look for improved management strategies. This lead to a three steps approach.

The first step was a detailed analysis of the present management of the distribution and operation of the main canal, with a quantified diagnosis of the efficiency. This was done through physical measurement, data analysis and use of a simulation model.

The second step was the study of possible improvements adapted to the hydraulic characteristics of the canal, the organization of the water distribution, the management process and the investment possibilities. This was done by elaboration, simulation and test of improved operational strategies.

The third step was the study of automatic control methods and their applicability to the canal. Due to investment possibilities and present organization, this approach focused on the existing operational organisation of the canal in four sections, each section including various control structures and extraction points.

Most of this study was realized using SIC (Simulation of Irrigation Canals) mathematical simulation model to represent the hydraulic behavior of the canal as well as the manual operational rules used by the ditchriders (canaleros) at the check gates, or the automatic control procedures. Results confirm the accuracy of the mathematical modelling and the benefits it can bring to the study and improvement of irrigation canals operation.

[1] Professor in Colegio de Postgraduados de Montecillo, MEXICO
[2] Head of Irrigation Division, CEMAGREF Montpellier, FRANCE
[3] Head Manager of La Begoña Irrigation Perimeter, Celaya, Guanajuato, MEXICO

1 INTRODUCTION

In Mexico there are 21 million hectares of agricultural area of which 6 million hectares are irrigated. Nearly 50 percent of the total agricultural production comes from this irrigated area, and it is expected to increase to 65 percent by the turn of the century. In order to increase the yield of irrigated agriculture it is required to modernize the management and water distribution in the irrigation districts, in a way that allows a better operation of the conveyance systems and improves the distribution of water which in Mexico is a limiting factor of irrigated agriculture.

A better operation of the conveyance and distribution infrastructure must permit to reduce the water losses and to improve the irrigation service to the users. Water delivery at the farm turnout has to be in the right amount, at the right time and for the right duration.

For many years, in Mexico, strategies for improving the overall performance of irrigation districts have been concentrated on on-farm water management assuming that the main systems management was satisfying. However evaluations realised in some irrigation districts where rotational irrigation is widely practised demonstrated that the average efficiency was less than 40 percent. All main systems consist of open channels and control structures such as gates and weirs. The fundamental objective of the operation of main channels is to maintain stable flow conditions and to deliver water according to crop needs.

In la Begoña Irrigation District the management of the canals is traditional and representative of most of the Mexican irrigation canals with a weekly rotation delivery schedule and a manual upstream control. This district was conceived 30 years ago and its modernization means to increase conveyance and distribution efficiencies, to improve flexibility of the delivery system, to make it adequate to modern requirements of farm irrigation, to adapt deliveries to irrigation scheduling needs.

To do so many improved management strategies are being tested. This work presents the application of a mathematical simulation model in order to analyze the present management and operation of the main canal, to improve the manual operation, and to study the automatic control methods and their applicability to the canal.

2 LA BEGOÑA IRRIGATION DISTRICT

The La Begoña Irrigation District, covering about 11 000 ha, supplies water to 2 800 farms, some as small as 1.5 ha, through a network of open channels. The water is taken from the Ignacio Allende Reservoir as well as from 127 existing wells.

The district is divided into 10 operational divisions (sections). 7 divisions receive water from a 20 km long primary canal. This main canal is operated by manual upstream control; see Figure 1. The 3 remaining sections take water straight from the river.

2.1 Farmers' organisation and requirements

La Begoña district was designed to practice a rotational schedule system where the users request the rate and duration of water delivery one week in advance. Farmers use traditional surface irrigation techniques. The main canal is operated using manual upstream control rules.

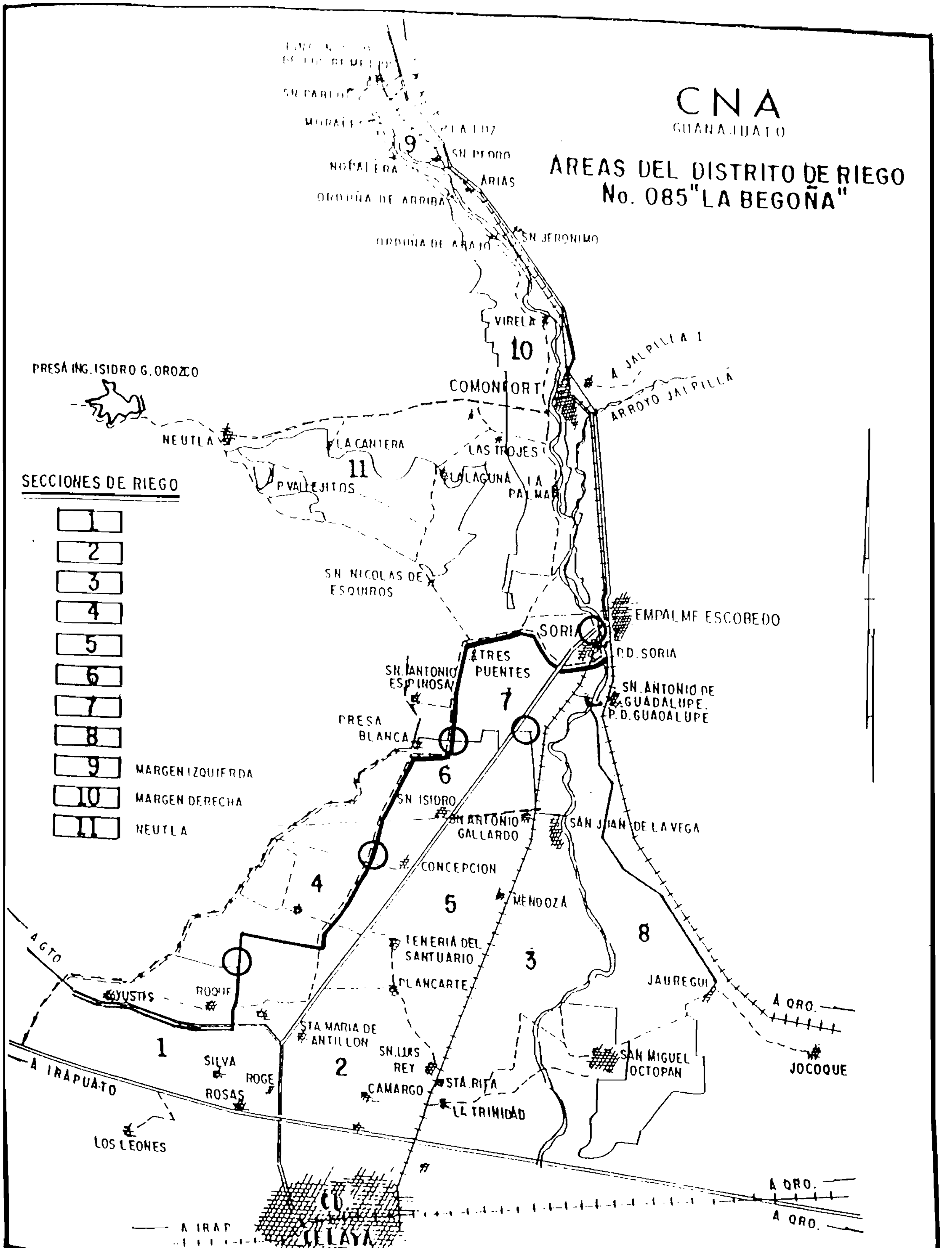


Figure 1: La Begonia Irrigation district

The main crops of this district are wheat, sorghum, maize, alfalfa and others. There are two main farming systems. One is based on rotations between alfalfa and cereals (wheat, sorghum, maïze) while the other alternates vegetables, alfalfa and cereals. Both are very intensive systems and allow high yields.

Water price only represents 10% of production costs for cereals and alfalfa, and even less for vegetables. Nevertheless water is a constraint for farms which do not own any well. These farmers do not have sufficient flexibility in water use, due to the water distribution system. In some cases they would have to wait two weeks for water and growing vegetables is these conditions is too hazardous. Moreover, during droughts, irrigation district managers have to limit the irrigated area per farm taking water from the canal

The weekly water delivery schedule has limited the evolution of the cropping pattern because of unreliable water delivery and water losses in the conveyance system. Farmers are unwilling to invest in on-farm irrigation equipment.

Therefore, improving water distribution implies reaching better distribution flexibility as well as sparing water.

2.2 Hydraulic system

The conveyance system consists of a main canal which is 20 km long with a slope of 20 cm/km. It has a trapezoidal cross-section shape and the bottom width is variable. The maximum design capacity is 10 m^3/s. It is entirely lined with concrete.

Cross regulators consist of several vertical manual gates (from 1 to 3 at the same location), with lateral weirs.

Turnouts are generally located directly upstream of the regulators. They consist in a manual gate with a flow regulator ("module a masque"), or in some cases in a Constant Head Orifice (CHO) gate.

Table 1 presents information on the location of the gates and turnouts.

Distance from head (m)	Cross-regulator n°	Number of gates	Offtakes		Irrigated surface (ha)
			Secondary canal	Turnouts	
1580	2	2	2	0	626
3200	3	3	1	6	85
4585	4	3	0	6	151
5520	5	1	2	3	3563
6830	6	2	2	8	117
8360	7	2	1	5	77
8655	8	2	1	1	85
9200	9	2	1	2	309
9555	10	2	0	2	23
10100	11	2	0	1	52
10775	12	2	1	2	96
11390	13	2	1	1	140
12030	14	2	1	3	253
13150	15	2	0	2	13
13400	16	2	0	0	0
13890	17	2	1	1	134
14680	18	2	1	1	153
15760	19	2	1	4	186
16170	20	2	2	1	259
16503	21	2	1	1	134
16907	22	2	0	1	16
17323	23	2	0	1	35
17605	24	2	0	1	16
17920	25	1	0	1	21
18247	26	1	1	1	98
18640	27	1	1	1	211
19320	28	1	0	2	35
19920	29	1	0	3	28
19970	30	1	0	1	0
TOTAL	30	53	21	62	6916

TABLE 1. Location of regulating structures in the main canal.

3 PRESENT MANAGEMENT OF THE DISTRIBUTION AND OPERATION OF THE MAIN CANAL

3.1 Delivery organisation

The main canal is divided in four sections which consist of a total of 29 pools (Cf. table 2). These pools are defined by check gates which function is to maintain a constant upstream water level to supply the 83 extraction points (secondary canals and turnouts) located within each pool.

The water level upstream of each gate is controlled by an operator who, based on his practical experience, handles the check structure and adjusts its setting.

The four sections are operated by four ditchriders. Table 2, shows the section, cross-regulator and the off-takes handled by each ditchrider several times per day.

As it was explained, the water delivery is by arranged rotational schedule on a weekly basis. Although the travel time between Ignacio Allende Reservoir and the farm turnouts is only 20 hours, this lead time is mainly due to the canal control method used. In fact, the managers' objective for the main canal operation is to minimize the manual adjustment of control structures. The 8-days basis is established in order to get a constant total off-take on every operational section during this period (Cf. table 3).

The standard irrigation delivery rate is 100 l/s, but a farmer can request and receive flow rate up to about 150 l/s, depending on his skill to operate this flow. Water delivery is changed daily in the morning throughout the main canal and operators travel periodically along the canal to make adjustments when necessary.

During the week users go to the Central Office to request water to irrigate their crops for the next week. They pay for water and get a receipt. Water orders are centralized and total flow for the next week is computed, taking into account an efficiency coefficient. Each ditchrider, responsible for the operation of a section, receives information on the flow rate he can deliver to turnouts. Farmers get in contact with the ditchrider (with their receipt in hand) who organizes the attribution of flow rate, duration and date of irrigation.

Ditch-rider	Reach	Irrigation section	Number of users	Irrigated surface (ha)	Number of cross-regulators	Offtakes	
						Secondary canal	Turnout
1	0+000 to 5+520	7	222	862	4	3	12
2	5+520 to 8+660	6 (2,3,5)	1094	3842	4	6	17
3	8+660 to 15+650	4	229	1173	10	6	15
4	15+650 to 19+920	1	278	1039	12	6	18
total	19+920	7	1823	6916	30	21	62

Table 2. Reaches, cross-regulators and off-takes handled by ditchrider.

3.2 Efficiency calculation and evaluation

The arranged schedule at farm turnouts or secondary canals is not always respected. This is due to many factors: variations of derived flows because of water level fluctuations in the main canal, delay due to some farmers being late in their irrigation,...

This leads to a distribution organisation where times of delivery are not well defined: a sequence of users is established, the next one receiving water once the previous "has finished" irrigating.

These factors cause a lower operation efficiency. The efficiency of water distribution is calculated by means of statistical data analysis, through physical measurement and using a simulation model.

Its expression is:

$$Eo_i = \frac{Qdem_i}{Qdel_i}$$

where:

$Qdem_i$ = demanded flow rate in the off-take i
$Qdel_i$ = delivered flow rate in the off-take i

A first evaluation of this efficiency (De Leon 1991), based on field data, indicates a 60% efficiency. This result will have to be confirmed, as field data have not been checked and no systematic measurement process is used on the District.

Great efforts should be devoted in the future to improve the data acquisition process.

4 IMPROVEMENT OF THE PRESENT MANAGEMENT

In this district, the traditional main canal operation has been identified as restrictive in terms of timing, flow rate and reliability of water deliveries to the users. This results from a conjunction of technical and sociological elements.

Farmers' behaviours can change with improvement of the delivery reliability.

Technical improvement can only be achieved by a better knowledge of the complex behaviour of the hydraulic system, which means a better information (through measurements) and a better understanding (through simulation model) of the system dynamic.

4.1 Use of the SIC Model (Simulation of Irrigation Canals) to improve la Begonia main canal operation

In 1987, the Irrigation and Drainage Division of ASCE (American Society of Civil Engineering) presented a symposium on "Planing, Operation and Rehabilitation of Irrigation Water Delivery Systems". This symposium concentrated its attention on canal system management and on regulation of canal strategies. The conclusions establish the need for better computer programs for modeling the non-uniform unsteady flow in irrigation canal networks that could be used to test different water control systems (Zimbelman, 1987).

In 1990, the ASCE task committee on "Irrigation Canal System Hydraulic Modeling" examined a number of programs to determine their general applicability in modeling unsteady flow in irrigation canals. The evaluation criteria were: computational accuracy, numerical solution criteria, robustness, initial conditions, internal and external boundary condition analysis, special hydraulic conditions, system configuration, frictional resistance, turnouts, automatic control, user interface and documentation and support.

The task committee determined that the current models available for simulating in irrigation canal networks have many limitations and concluded that models for the prediction of unsteady flow in irrigation canal network are in development.

A model not examined by the ASCE task committee which has a very good performance of evaluation criterias mentioned above is the SIC model (Simulation of Irrigation Canals). This model was developed in 1989 at the CEMAGREF, in France. The model permits to represent overall physical and hydraulic characteristics in a network irrigation canal systems having any cross-section.

The following paragraphs describe the applications of SIC model to simulate canal hydraulics and generate control structure and turnouts opening values based on given water allocation schedules in the main canal of La Begoña District.

The SIC model consists of three software units: topography, steady flow and unsteady flow units. Topography unit enables input of the geometrical and topcgraphic canal data. The steady flow unit enables the input of hydraulic characteristics of the canal, cross-regulators and off-takes. This unit generates the initial hydraulic conditions for the transient flow. It also allows to calculate steady flow water levels in different conditions (cross structures, off-takes,...).The unsteady flow unit allows the simulation of transient flow conditions, including cross structures operation.

4.2 Model Calibration

The overall topographic and geometrical characteristics of the main canal and the location and description of the hydraulic structures and off-takes were obtained by field measurements (Cf. figure 1).

In collaboration with the Irrigation Department of La Begoña District three measurements campaigns to calibrate the model have been carried out since 1991 during a period when the flow in the main canal was supposed to be steady. The discharges in the reaches of the main canal were estimated using current meter and at each cross-regulator the opening and the water level upstream and downstream were measured.

The calibration was realised using an empirical method. Starting from the downstream end reach, appropriate roughness coefficients for each reach and discharge coefficients for the cross-regulators are computed in order to explain measured upstream and downstream levels. Figure 3 presents the results of the current calibration of the main canal. The set of roughness and discharge coefficients are in an acceptable range.

After this calibration phase, the model was validated with a different data set measured under unsteady flow conditions in a reach of the canal.

During 1992 concrete lining has been realised on the canal. New hydraulic measurement campaigns will be analysed using the automatic calibration module newly developed in the SIC software.

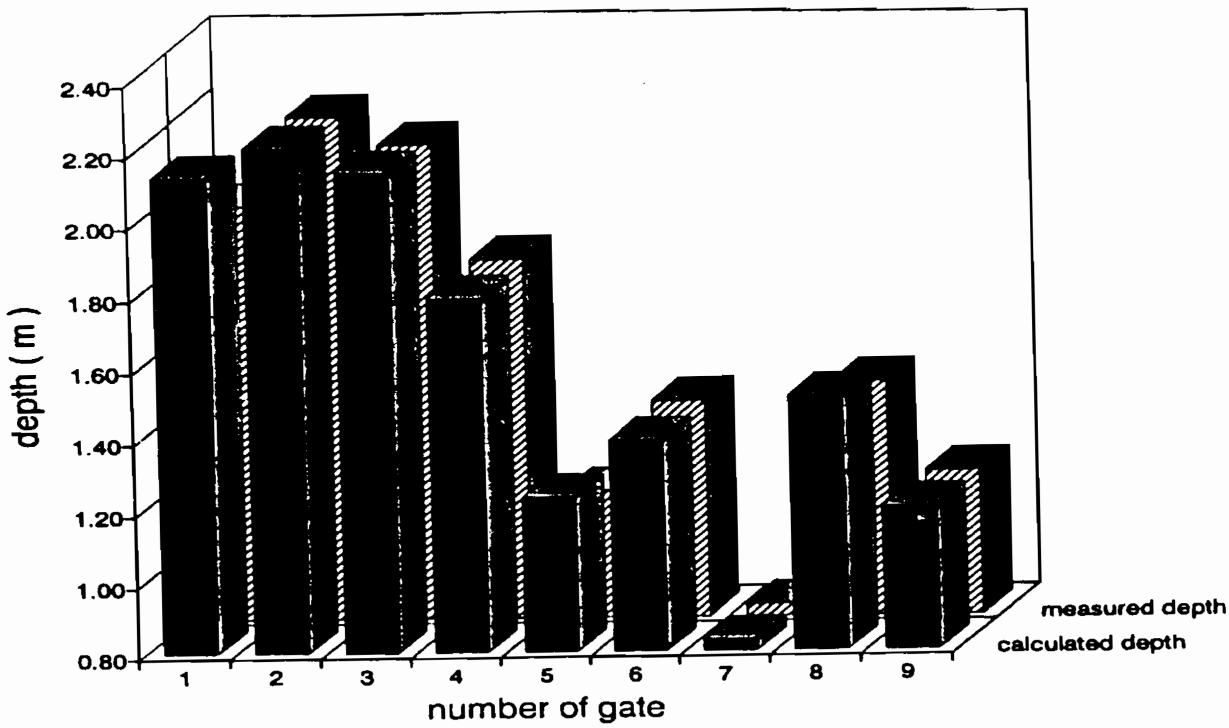


Figure 3. Calibration results on the upstream part of the canal: calculated and measured water profiles.

4.3 Application of the model to analyse and improve the present canal operation

The SIC model offers many application possibilities. Several applications will be described: the analysis of the present operation and the test of automatic control methods to improve the present operation (Cf. part 5.).

The main canal is divided in four operational sections (Table 2) and each one is operated by a ditchrider who receives the set of irrigation farm requests and elaborates a weekly schedule deliveries. This schedule defines the flow rate, the duration and the irrigation sequence for each farm; beside, at each off take and cross-regulator the schedule defines the discharge and the setting as function of time. Table 3 gives an example of the weekly schedule for the cross-regulators within the first operation section.

This type of schedule is elaborated in all reaches and within their reach the ditchriders move the setting of gates in such a way that only the water assigned (0.7 m3/s in section 1) is delivered, and does not affect the supplying of downstream reaches.

By means of the SIC model (Simulation of Irrigation Canals), the hydraulic behaviour of La Begonia canal was simulated under different water supply demand assumptions corresponding to the realized delivery schedule during the agricultural seasons 1990 to 1992. The overall operation of the main canal was represented (De Leon 1991).

Day	Cross-Regulator	Number of irrigations	Discharge (m3/s)
Monday	1	4	0.40
	2	3	0.30
Tuesday	1	3	0.30
	2	4	0.40
Wednesday	1	1	0.10
	2	3	0.30
	3	2	0.20
	4	1	0.10
Thursday	1	2	0.20
	2	3	0.30
	3	1	0.10
	4	1	0.10
Friday	1	2	0.20
	2	2	0.20
	3	1	0.10
	4	2	0.20
Saturday	1	2	0.20
	2	3	0.30
	4	2	0.20
Sunday	1	2	0.20
	2	2	0.20
	3	2	0.20
	4	1	0.10

Table 3. Weekly Schedule for the cross-regulator in first reach.

The first simulations enlightened the fact that downstream reaches are more sensitive than upstream reaches to the present operation method. Delivery discharges in the first reaches are very small compared to total conveyed discharge, whereas in the last reaches the changes in water discharges between different off-takes must be done very carefully, since the capacity of the canal is reduced and the water stored volume in each pool is limited.

Efforts will be devoted to give a better representation of the ditchriders' actual decision rules and operation process. This should give a better understanding of all the factors that cause changes in the original irrigation schedule.

Further applications of the model will aim at testing improved operation rules that could give more flexibility in the water delivery schedule.

5 APPLICATION OF AUTOMATIC CONTROL METHODS

Due to the political and economic conditions of La Begoña District, the government wishes to encourage the transfer of the canal operation responsibility to a farmers' association. This association should assume a dominant role in the control and management of water supply to the irrigation district.

The availability of personnel (four), their means of transportation (motorcycle), the amount of gates to manoeuvre and the dynamic of the hydraulic phenomena illustrate the present difficulties. Improvements can be made through continuous evaluation of the hydraulic state of the canals, more efficient techniques of information transmission and finally change of the current main canal control technique.

On the other hand, users want to improve the operation of the hydraulic infrastructure in order to reduce water losses and increase flexibility of water supply to the field at the right time.

To achieve these two objectives it is necessary to reduce the time step of irrigation scheduling and improve the main canal regulation technique.

This can be done through the improvement of the present manual operation or through introduction of new techniques like automatic control, the strategy of automatic control having to be compatible with the physical, economic, technical and organization constraints of this irrigation district.

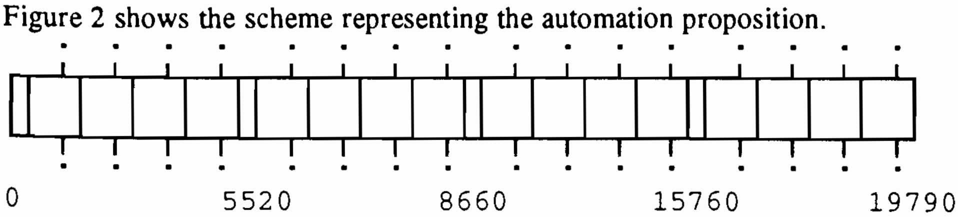
5.1 Selected Control Architecture

As it is not economically possible to invest to automate all structures in the main canal, several alternatives and degrees of automation have been analysed.

The selected proposition takes into account only five points which, according to the canal managers, are keys to control water distribution. These points are the limits of the present operational sections: the gate of the Ignacio Allende Reservoir, the cross-regulator at the head of main canal and the check structures located at 5,520, 8,660 and 15,760 meters along the main canal.

At these points only one gate per check-structure will be automated and the remaining will operate by manual control. This permits to save costs and moreover can provide a good control able to handle fluctuations of +/- 30% of the total flow in the canal. While these cross-structures separating the different sections will be under automatic control, intermediate cross-structures will still be under manual control. New operation rules, compatible with the selected automatic control, will have to be determined by and for the ditchriders.

Figure 2 shows the scheme representing the automation proposition.



Distance from the head (m).

□ gate under automatic control

| gate under manual control

· extraction point

Figure 2. Schematic representation of the automation proposition

5.2 Test of automatic control methods

An hybrid control algorithm (manual and automatic control) was tested and applied to each operational section of the main canal; see Figure 4.

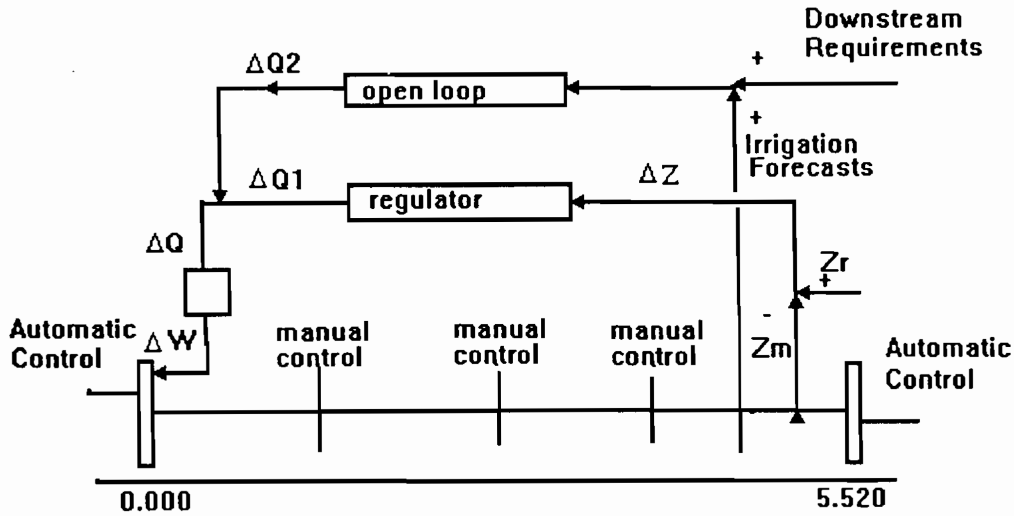
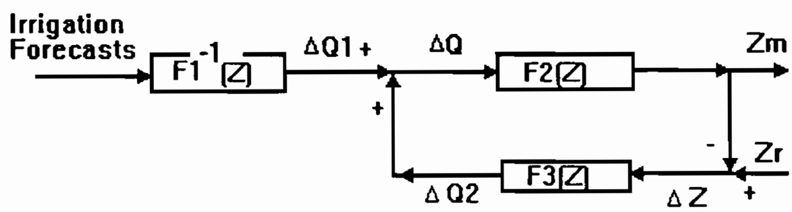


Figure 4. Water profile calculated and measured

The correspondent block diagram of this operation reach is shown in Figure 5



Zm = measured water level
Zr = reference water level
q = temporal variable
W = Automated gate opening

Figure 5. Block diagram of the first operation reach

The transfer functions F1(q) and F2(q) were identified in each operational section by means of tabular functions between input / upstream and output / downstream discharge (F1) and input / upstream discharge and output / downstream water level (F2), the data being obtained with the simulation model.

The regulator characteristics [F3(q)] were defined with a proportional-integral control algorithm which keeps the water depth downstream of each operational section close to a reference water level, modifying the flow rate upstream of the reach. The control algorithm has been tested by means of simulation in the control of La Begoña main canal.

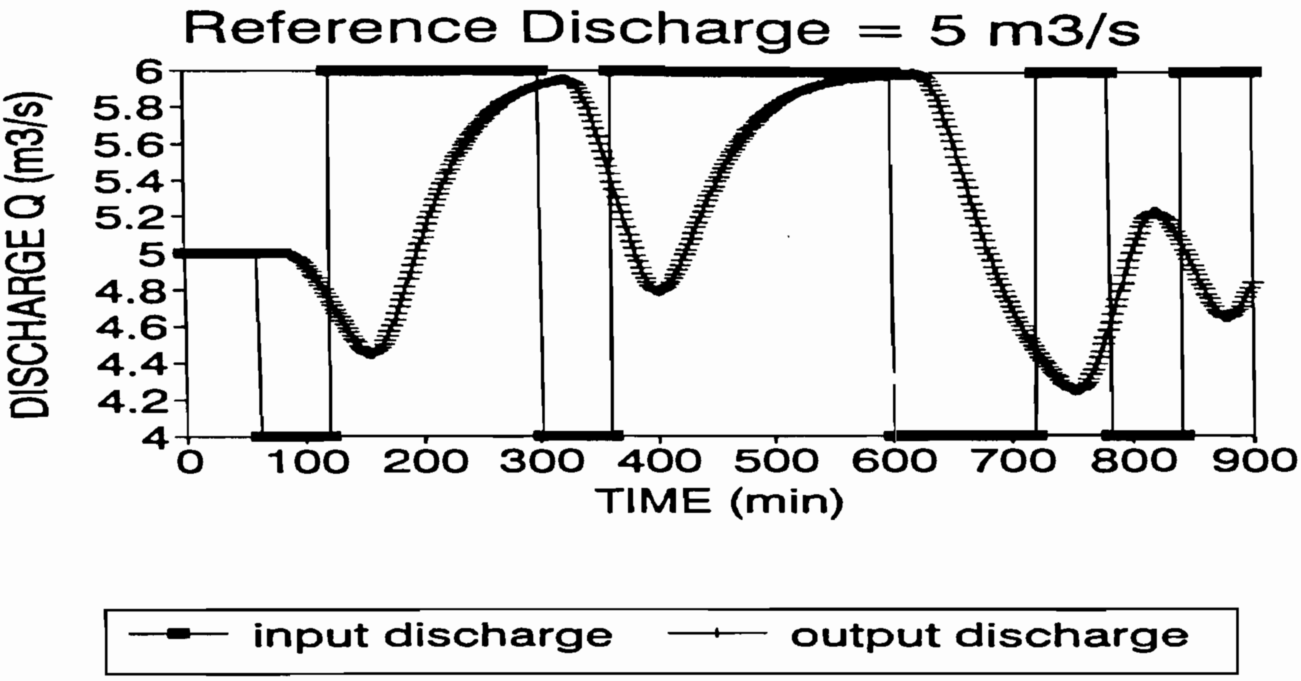


Figure 6. Input and output discharge in the first operation reach

Figure 7 shows the variations of control variables (discharge and water level) downstream of the first operational section and the control response upstream of the reach for an unpredicted perturbation.

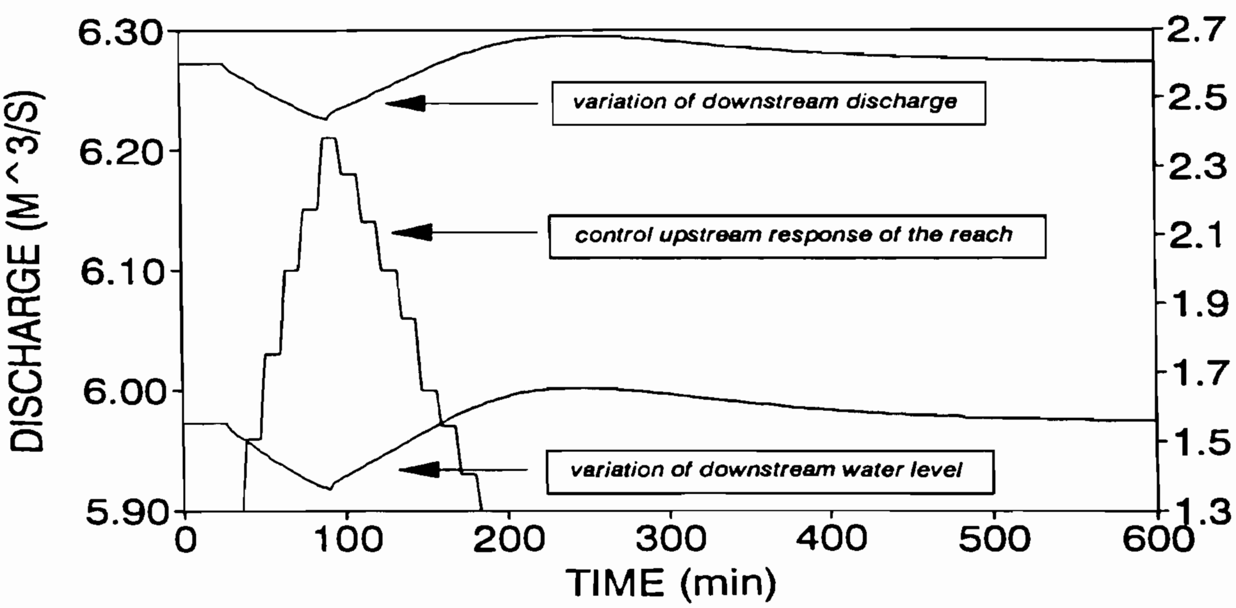


Figure 7. Control response to a non foreseen perturbation (0.3 m3/s increase in the offtake at 5+520 from 30 to 90 minutes). Kp=1.5, Ki=0.05

Further studies will analyse interactions between sections and calibration of the control algorithms.

6 CONCLUSIONS

With respect to the use of the SIC model to analyze the present management, to improve the traditional operation and to test automatic control methods in La Begoña main canal, some general conclusions can be established.

1. SIC is an accurate model to simulate the water conveyance and distribution in canal network for a wide range of physical and hydraulic features.

2. Within the scope of this study the limitations of the present management of La Begoña main canal were identified as a lack of data acquisition, data analysis facilities and efficient transmission of information.

3. The improvement of the present management of the main canal could hardly have been studied without using a simulation model.

4. Finally, the SIC model was used as a research tool to evaluate different adapted canal regulation technologies to scope La Begoña District.

5. Further studies will focus on better representation of manual operation and its effect on the canal dynamic, and on automatic control algorithm parameters calibration.

7 REFERENCES

Burt 1983	Burt, Charles M., Regulation of sloping canals by automatic downstream control, presentation at the 1983 winter Meeting American Society of Agricultural Engineers, 1983.
Burt 1989	Burt, Charles M., Canal automatization providing on-demand water deliveries for efficient irrigation, Department of Agricultural Engineering, California Polytechnic state University (Cal Poly), San Luis Obispo, CA 93407, USA, 1989.
Burt 1991	Burt, Charles M., Canal models and You, ASCE National Conference on Irrigation and Drainage Engineering, Honolulu, Hawaii, 1991.
Clemmens 1991	Clemmens A.J., Walker W.R. and Cooch R.S., Irrigation Canal System Unsteady Flow Modelling, ASCE National Conference on Irrigation and Drainage Engineering, Honolulu, Hawaï, 1991
CEMAGREF 1990	CEMAGREF, SIC Model: Simulation Model of Irrigation Canals, Institute of Agricultural and Environmental Engineering Research, Montpellier , France, 1990
De Leon 1991	Informacion del canal Principal Margen Derecha del Distrito de riego N° 085, La Begonia, GUANAHUATO, MEXICO
Gonzalez 1992	Sistema de regulacion de la red de conduccion y distribucion del Distrito de Riego N° 085, La Begonia, Guanahuato, Mexico
IIMI 1989	IIMI, Managing irrigation in the 1990's, International Irrigation Management Institute, Colombo, Sri Lanka, 1989.
Loof 1991	Loof, R., Paudyal, G.N. and Manguerra, H.B., Mathematical modeling of irrigation canal systems, State of the Art. Agricultural Land and Water Development Program, Asian Institute of Technology, Bangkok, Thailand, 1991.
Merkley 1987	Merkley, G.P., Walker, W.R. and Gichuki, F.N., Hydraulic modeling applications in canal main systems, Irrigation systems for the 21st century, ASCE, New York, 1987.
Plusquellec 1988	Plusquellec H., Improving the operation of irrigation systems, an audiovisual production of the Economic Development Institute of the world bank, Washington D.C. 20433, USA, 1988.
Rogers 1991	Rogers, D.C., Schuurmans, W. and Keith, J., Canal model evaluation and comparison criteria, ASCE National Conference on Irrigation and Drainage Engineering, Honolulu, Hawaii, 1991.
Schuurmans 1991	Schuurmans Wytze, A model to study the hydraulic performance of controlled irrigation canals, Center for Operational water Management, Delft University of technology, 1991.
Zimbelman 1987	Zimbelman D.D.,(ed.), Planning, operation, rehabilitation and automation of irrigation systems, ASCE Symposium proceedings, Portland, 1987.