

AN OPEN CHANNEL NETWORK MODERNIZATION WITH AUTOMATED STRUCTURES

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ABSTRACT

In Mexico, most irrigation delivery systems consist of a network of open-channels with manually-operated control structures. Efficiencies of these systems typically are low. To improve water management in these systems, the Mexican government has attempted to modernize many irrigation projects (Reynosa, Apatzingan, Valle del Mezquital, and Santiago among others) using automatic self-leveling check structures. However, problems have emerged with the operation of these structures, causing dissatisfaction among water users.

The Santiago Irrigation System (SIS) began operating in 1998. Its main distribution system consists of open channels regulated by self-leveling gates and constant flow modules. Low-pressure pipelines deliver water to individual plots. During the first three years of operation, inadequate water level regulation with the automated gates caused water distribution problems that ultimately affected crop productivity. This negative situation encouraged users to take control over the irrigation system and to revert to the traditional manual operation.

To help address the technical issues, an experimental channel was built at the University of Zacatecas. The channel was expected to help researchers develop a better understanding of the hydraulic theory and operation of this type of structures and to help solve practical installation and operational problems. This paper describes our experience rehabilitating and calibrating AVIS and AVIO self-leveling gates; it also describes the sequence of operations that must be followed for the adequate management of the automated structures in the SIS main network.

Keywords: Self-leveling gates; Modernization; Operation efficiency

INTRODUCTION

Water application for agricultural purposes in adequate time and amount plays a fundamental role in crop yield. On the other hand, water availability for irrigation has been reduced in past years due to severe and extended droughts (Rosano-Méndez et al. 2001). About 70% of the

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current worldwide water withdrawal is used for irrigation (FAO 2003). Global efficiency in irrigation projects in Mexico is less than 50% (CNA, 2006). A factor contributing to low efficiencies is the distribution of water through irrigation networks. In Mexico, most irrigation conveyance and distribution systems consist of a network of open channels controlled by manually operated control structures. Operation of these systems is typically based on empirical concepts and operator experience. Water deliveries to farms frequently do not match irrigation requirements as the volume delivered depends on the operator's judgment.

In countries such as France, Spain, and Italy one alternative that has been used to improve canal operation and water delivery service is the use of automated control with self-leveling gates (Guillén et al. 2000). In theory, these structures enable more predictable and equitable water distribution since they do not require continuous manual adjustments. The Mexican government has modernized several irrigation projects using this technology (Reynosa, Apatzingan, Valle del Mezquital, and Santiago). Performance of some of these systems has been disappointing as a result of design and installation problems and the lack of experience by operators and water users with the use of self-leveling gates. A better understanding of the technology is needed in order to get the most benefits and overcome its limitations.

The objective of this article is to summarize our experience with the development and implementation of an integrated operational plan for the irrigation project of Santiago, Zacatecas. This irrigation project began operating in 1998 and currently services about 600 hectares. During the initial years, operation of the conveyance and distribution network faced numerous technical and organizational challenges that ultimately led to conflicts among users and low global project efficiency.

BACKGROUND

The Santiago Irrigation System (SIS)

The study area is located within the Ejido (communal land) "Miguel Auza," in the northwest of the State of Zacatecas, Mexico (Figure 1). Geographic coordinates are latitude of 23° 17' 52''N and longitude 103° 27' 36''W, and the elevation is 1,898 m AMSL.

Average annual rainfall in northwest Zacatecas is less than the water requirements for crops that can be grown in the region; therefore, the SIS was built to provide supplementary irrigation. The National Water Commission (CNA, from its Spanish acronym) conducted hydrologic, engineering, and feasibility studies in the area in 1990 and began building the system in 1991. When the delivery system was completed in 1998, it irrigated 100 ha; today it services an average of 600 ha per year. Predominant crops are corn, chili, beans, and alfalfa. The system supplies 306 users with an average farm size of 2 ha. Agriculture is a secondary economic activity for most users, as most work in construction, commerce and services. Production is mostly self-consumed or used as feed, but occasional surpluses are sold in regional markets.

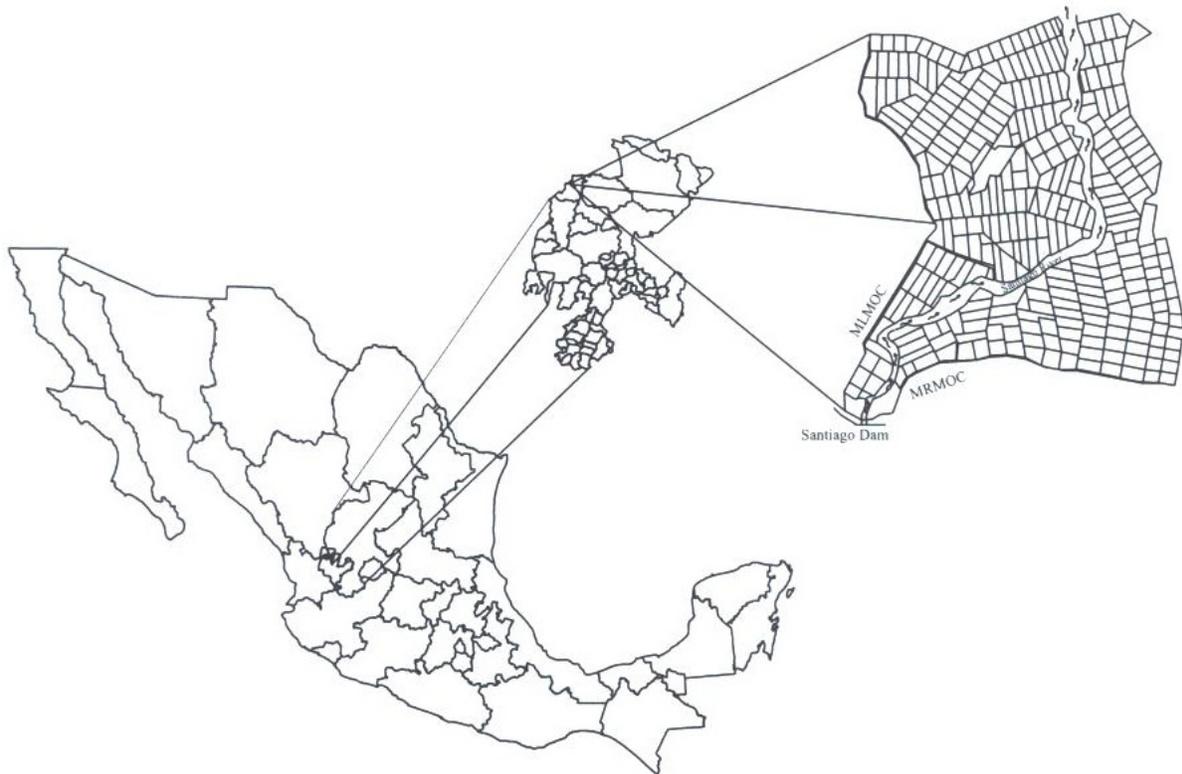


Figure 1. Location of the Santiago Irrigation System

The users are legally organized in a Water User Association (WUA). A six-member Board of Directors (BOD) represents their interests before the federal government (represented by the CNA), state government, and the private sector. The WUA elects the Board every three years and all Board members are registered users. The SIS administrative and operational staff consists of an accountant, a technical manager, and two CNA-certified ditch-riders.

The SIS Technical Manager and the BOD together develop the operational plan for the water year October 1-September 30, which must be approved by the CNA. The plan includes forecasts of the yearly cropping pattern and monthly delivery volumes needed to meet crop water demands. CNA delivers water to the SIS headgate based on this plan, and SIS distributes of this water to users through its network. The CNA is responsible for monitoring reservoir storage and for making adjustments on bimonthly basis based on actual storage levels and deliveries.

The delivery system has two main channels, the Right and Left Margin Channels, with a capacity of 0.798 and 0.771 m³/s, respectively. Unlike most Mexican irrigation projects, which were built for upstream control with manually operated cross-regulators, the SIS was built for downstream water level control with self-leveling gates. Water is delivered through offtakes equipped with constant-flow modules which are also used for flow measurement. Each offtake is designed to supply water to 10 ha, and thus they service between 4 and 5 users.

The original plan was for the SIS to operate as a constrained arranged delivery system, with a fixed delivery flow rate at each turnout, 30 l/s (the design Unit Irrigation Flow Rate). Users were expected to submit their water orders to ditch-riders either Monday through Wednesday for deliveries on Thursday and Friday, or Thursday through Saturday for Monday through Wednesday deliveries. From these orders, the technical manager was then expected to develop the daily schedule of deliveries, including the starting and stopping time for delivery to a turnout, and the schedule of canal operations to be followed by the ditch-riders.

Upon completion, the CNA turned over the canal system to the user association in 1998, assuming that the users would only encounter minor problems in operating the system with the self-leveling gates and that they would be able to easily solve those problems on their own. Lack of experience in the operation of these hydraulic networks, and in particular a lack of understanding of the installation and operation of self-leveling gates created immediate difficulties. Because of the resulting inequitable and untimely deliveries, crop yields were affected in the initial year of operation and conflicts emerged among users.

Evaluation of the Santiago Irrigation System

The Autonomous University of Zacatecas (UAZ), through its Hydraulic Resources Planning program, built an experimental channel in the year 2000 for the purpose of demonstrating and researching canal control concepts with self-leveling gates and to provide training on those concepts to irrigation system operators. The channel was built with technical and economic support of the Mexican Institute of Water Technology (IMTA) and the Spanish Agency for International Cooperation (AECI). This channel is 70 meters long, with a 1.00 X 0.85 meter rectangular cross section, and is equipped with self-leveling structures for upstream and downstream water regulation. With the channel, UAZ researchers have been able to establish criteria for the installation, calibration and operation of AVIS, AVIO and AMIL gates. Given the problems experienced at the SIS and the expertise available at the UAZ, the CNA entered into a collaborative agreement in 2001 with IMTA and UAZ to conduct a systematic assessment of the Santiago Irrigation System and develop a plan to improve its operation. CNA agreed to fund the project while IMTA and the UAZ agreed to define the research methodology and provide the needed technical resources. The WUA agreed to adopt the resulting recommendations.

The assessment was carried out in three stages: diagnosis, development of solution alternatives, and dissemination of results. The Rapid Appraisal Process (RAP) (Burt, 2001) was selected as the diagnostic methodology. Part of this process consists of a detailed field inspection to characterize the design, construction, and physical condition of the infrastructure. Another part of the process examines water allocation and delivery policies, operational procedures, and administrative procedures based on interviews with users and irrigation system staff.

Diagnostic Results

The following paragraphs summarize the key findings from the RAP:

- The capacity of the main network was found to be adequate for downstream water regulation. This capacity has to be greater than the maximum crop water demands. These demands were calculated using the Unitary Irrigation Coefficient (UIC) methodology (SARH, 1973). The UIC is calculated for different reaches of the network, based on their service area and predominant crops. The analysis confirmed that capacity exceeds peak demands, even though the system operates only for 11 hours of every day.
- Cross-regulators and offtakes were found to be in poor physical condition. The field inspection revealed damaged or worn-out structures (as is shown in Figure 2), and thus incapable of operating as designed. As a result, structures were being operated manually, and based on the criteria of individual ditch-riders. Installed self-leveling gates were evaluated and compared with AVIS and AVIO gates manufactured by Nerpyc GEC Alstom. The gates satisfied minimum hydraulic design criteria, but problems were observed with installation and calibration. Hence, those structures were not performing as they were supposed to.
- Deficient operation of the network. Data collected during field visits and office interviews revealed that SIS operators lacked general training in downstream regulation and specific training in the operation of self-leveling structures. At the same time, CNA did not have technicians capable of calibrating the self-leveling structures. Clearly, technical support was needed to improve the system's operation but CNA was unable to provide that support.
- User dissatisfaction. Inadequacies of the delivery rules and in the implementation of those rules generated user dissatisfaction with the delivery service. First, the delivery constraints (with different users receiving water on different days) generated conflicts among users, as the needs of some of the users were not being satisfied; in addition, the ditch-riders were not following the daily plan, but were assigning instead irrigation turns and volumes arbitrarily. As a result, deliveries were inequitable.
- Lack of mechanisms to enforce user rights and responsibilities. The system started operating without written administrative procedures needed to enforce delivery and maintenance rules. Because of the lax enforcement, the SIS was having a difficult time collecting irrigation service fees and users were tampering with the control structures and taking water out-of-turn.
- A significant volume of water was being lost due to the discontinuous operation of the system. The system only delivers water during the daylight hours. Because control structures are not water-tight, water left in the canals at the end of the day leaks out. Table 1 shows an average in the occurred volume changes between the initial and final Margin Right Main Open Channel (MRMOC) operation for several consecutive days. In addition to the water loss, this mode of operation further reduces the delivery window, due to the time needed to refill the channel.



Figure 2. Damage and hydraulic instability of Self-Leveling Gates

Table 1. Volume Changes without MRMOC Operation During Consecutive Days

	Reach 1	Reach 2	Reach 3	Reach 4	Total
Reach Length (m)	320.00	1,000.00	1,100.00	320.00	
Side Slope	1.50	1.50	1.50	1.50	
Width Bed (m)	0.65	0.65	0.65	0.65	
Head (m)	0.93	0.93	0.73	0.58	
Longitudinal Slope (m/m)	0.0005	0.0004	0.0001	0.001	
Reach Volume (m ³)	611.66	1,950.45	1,394.94	300.49	4,257.54
Storage Volume (m ³)	0.00	53.20	347.08	300.49	700.76
Recover Volume (m ³)	611.66	1,897.25	1,047.86	0.00	3,556.78
Time for Volume Recovering Considering a 400 lps flowrate (min)	25.00	79.00	44.00	0.00	148.00

Integrated Operational Plan for Santiago Irrigation System

Irrigation projects modernization has been defined as a process of administrative and technical improvements of the irrigation system in combination with institutional reforms with the goal of

improving the water delivery service to users and, ultimately, the use of resources (labor, water, economy and environment among others) and agricultural productivity (Burt, 1999). In the SIS case, initial efforts to calibrate and improve the operation of self-leveling gates led to the development of an integrated operation plan for the system. Based on the RAP results, administrative and technical proposals were formulated aimed at modernizing the system's operation. The proposals were analyzed by the CNA, the IMTA and the UAZ experts, as well as the SIS users. Proposed physical improvements included:

- Rehabilitation or replacement of damaged control structures, depending on their condition.
- Installation of control structures (AVIS or AVIO floodgates) where technically necessary.
- Preventing main channel water losses to reduce delays in water distribution.
- Measuring flows at the main channel headgates and at offtakes.

On the technology transfer side, the following actions were proposed:

- Training of operators in the calibration and operation of the self-leveling gates.
- Development of a practical guide for main channel operation, to be provided to both staff and users.
- Establishment of an educational program for users on the capabilities and limitations of the canal control systems and procedures.
- Evaluation of the operation system during its primary function months to correct deficiencies presented by the administration of the SIS.

RESULTS

The results of the physical improvements by implementing an integrated operational plan in the SIS were:

- Rehabilitation of eight control structures; damaged gate leaf, floaters, and support structures were replaced and the structures were repainted.
- Replacement of an installed self-leveling gate with a locally manufactured AVIO-type self-leveling gate. The replaced structure did not meet the design criteria of Nerpyc Gec Alsthom and was experiencing instability problems.
- Structures were calibrated by IMTA and UAZ experts to enable proper water level regulation following the methodology proposed by Nerpyc Gec Alsthom.

- To maintain water volumes in the open-channels network during all irrigation season, sliding gates were installed immediately upstream of every self-leveling gate as shown in Figure 3.
- To quantify offtake deliveries, a calibrated weir and sliding gates are used. Water flows to lateral off-takes are measured through constant flow modules.



Figure 3. Regulation and Control Structures before the Implementation of the Integrated Operational Plan

The integrated operation plan also produced changes in the delivery procedures, namely the users now present their water orders to the canal manager and the orders need to be submitted only one day in advance.

There has been a positive response by the water users to the integrated operational plan. Users are now more convinced about the ability of the system to provide the promised delivery service. Conveyance efficiency in has improved considerably partly due to elimination of canal water losses overnight, which created delays for the early deliveries, as shown in Table 2.

Table 2. Volumes Recovered in the MRMOC with the Integrated Operational Plan

	Reach 1	Reach 2	Reach 3	Reach 4	Total
Reach Length (m)	320.00	1,000.00	1,100.00	320.00	
Side Slope	1.50	1.50	1.50	1.50	
Width Bed (m)	0.65	0.65	0.65	0.65	
Head (m)	0.93	0.93	0.73	0.58	
Longitudinal Slope (m/m)	0.0005	0.0004	0.0001	0.001	
Reach Volume (m ³)	611.66	1,950.45	1,394.94	300.49	4,257.54
Storage Volume (m ³)	576.63	1,848.29	1,311.54	274.35	4,010.81
Recover Volume (m ³)	35.03	102.16	83.40	26.14	246.73
Time for Volume Recovering Considering a 400 lps flowrate (min)	1.50	4.25	3.50	1.1	10.35

Operations have improved also due to the practical operational guide, which outlines the different operational steps, including instructions for filling channels, initiating and stopping deliveries, procedures for correcting flows and levels. The guide also provides instructions for calibration of the self-leveling gates and of flow measuring weirs and sliding gates.

CONCLUSIONS

University of Zacatecas researchers developed significant experience in the design, installation, calibration and operation of self-leveling gates with the help of the experimental channel built in their hydraulics laboratory. With this experience, researchers were able to assist SIS staff and develop specific criteria for the installation and operation of these structures. Thanks to the operational plan, SIS users and staff now have a better understanding of the system's capabilities and operation and have simplified their operational procedures. Flexibility of deliveries has improved, as orders need now to be submitted only one day in advance and users now can get service any day of week. The implementation of the integrated operational plan has reduced operational water losses and improved service, and as a result, users are making more productive uses of the available water.

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