CANAL AUTOMATION FOR IRRIGATION SYSTEMS: AMERICAN SOCIETY OF CIVIL ENGIENERS MANUAL OF PRACTICE 131

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ABSTRACT

Recently, the Task Committee on Recent Advances in Canal Automation, which is part of the Irrigation Delivery and Drainage Systems Committee (IDDS) of the Irrigation and Drainage Council (IDC) of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE), prepared a Manual of Practice (MOP) on canal automation for irrigation systems. Formally referred to as MOP 131 *Canal Automation for Irrigation Systems*, this book focuses on the technical aspects of modernizing irrigation systems through the use of automated canal control systems. MOP 131 is an essential reference for professionals in agricultural and irrigation engineering, as well as owners, managers, and operators of irrigation water delivery systems.

The Task Committee was formed because although there has been continual research in the field of canal automation, there has not been a formal publication on the topic for some time. From the beginning, the Task Committee wanted the final product to be a truly international effort that would be useable in all countries. Indeed, the Task Committee itself was composed of researchers and engineers in multiple countries including the United States, the Netherlands, Australia, France, Spain, Portugal, China, and Mexico. In all, more than 40 different professionals from 8 different countries participated in the development of MOP 131.

This paper provides a brief summary of MOP 131 within the context of the history and future of canal automation.

Keywords: Canal Automation, Automatic Control, Feedback Control, Feedforward Control, SCADA Systems, Water Level Control, Flow Rate Control, Canal Infrastructure

1. BACKGROUND

Canal automation always has had the potential to save water and improve efficiency of irrigation water supply projects or of irrigation district operations. Recently, there have been a number of technological and engineering advances in the field of canal automation. While these advances have been documented via conference proceedings and peer-reviewed journal articles, a comprehensive document outlining the state-of-the-art in canal automation was lacking.

The American Society of Civil Engineers (ASCE) decided to fill this void by commissioning the development of the Manual of Practice (MOP) 131: *Canal Automation for Irrigation Systems* (Wahlin and Zimbelman, 2014). MOP 131 was developed by the Task Committee on Recent Advances in Canal Automation (TCRACA) which was formed under the Irrigation Delivery and Drainage Systems (IDDS) Committee under the Environmental and Water Resources Institute (EWRI) of

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ASCE. EWRI is an entity within ASCE that focuses on water resources instead of civil engineering in general. The TCRACA members gathered information on canal automation research and practice from around the world in their efforts to document the application of new technologyto the progress of designing and implementing irrigation canal automation. The TCRACA was a truly international effort with researchers and practitioners from the USA, the Netherlands, Australia, France, Spain, Portugal, China, and Mexico all participating in the development of MOP 131.

MOP 131 is designed to provide guidance on how and when to implement canal automation within the context of canal modernization but not covering the full range of canal modernization issues. The manual also provides practical guidance on some of the more routine aspects of canal automation.Note that while MOP 131 was developed by the cooperative efforts of eight different countries, it has not been formally adopted by the administrations of those countries.

2. HISTORICAL PERSPECTIVE ON CANAL AUTOMATION

In order to plan for a successful canal modernization program, with measurable goals and objectives, that provides water users (irrigators) with improved flexibility, it is not only interesting but also very helpful to review how the science of irrigation canal automation arrived at today’s technology. For purposes of this paper, a historic review will principally be from the perspective of the USA. A broader perspective would require more time and space than allowed herein.

Then, as now, members of ASCE, working through committees of what was then the Irrigation and Drainage Division, which later merged into EWRI, paved the way for presenting and discussing improved operations of irrigation water supply systems. Their deliberations were published in 1968 as *Automation of Irrigation and Drainage Systems* which contained papers from a conference held in Phoenix, Arizona (ASCE, 1968). A paper by the Salt River Project (SRP), a U.S. Bureau of Reclamation (USBR) project, discussed efforts to develop a supervisory control system for distribution canal operations that relied on new technology to measure gate openings, compute gate flows, monitor water levels, transmit data to a centralized operations center, and remotely move gates.

During the same general time period, the California Department of Water Resources (DWR) was in the process of designing the USA’s largest state-built water and power project to move water from northern California to cities and irrigators in water short southern California. This project became known as the State Water Project (SWP). Power usage and power generation were to be key elements of the SWP along with the multi-basin transfer of water. Optimizingpower generation and movement of water, while minimizing power usage, required the development of an innovative canal operation strategy. The research developed from this project was presented in several publications from 1964 to 1976 and included topics such as hydraulic transients, check structure hydraulics, and computerized control. The research also resulted in the formulation of a computerized model of the aqueduct that simulated unsteady flow in the SWP.

The USBR has the primary responsibility for the design and construction of water resource infrastructure for the purpose of providing irrigation water to irrigable lands in the western USA. As such, the USBR took the early lead in investigating ways of enhancing the operational efficiency of irrigation water supply districts (projects). While weirs, flumes, sluice gates, and radial gates were in common usage, the integration of electro-mechanical devices to make the task of water masters and ditch riders easier, more precise, and timelier, came about as a result of the USBR directing its researchers and design engineers to take a leadership role in the early development of canal automation equipment and procedures. Subsequently, the USBR published *Water System Automation – A State of the Art Report* (USBR, 1973). Concepts presented in this reference, such as optimum operation will result only from proper control of the entire system, are still applicable today.

ASCE's Irrigation and Drainage Division moved the technology forward in 1987 by organizing a conference in Portland, Oregon called*Planning, Operation, Rehabilitation and Automation of Irrigation Water Delivery Systems* (ASCE, 1987). This included presentations by French engineers discussing their implementation of Dynamic Regulation in the system of Canal De Provence, NEYRTEC Automatic Equipment, and BIVAL for downstream control. Dr. John Merriam introduced a definition for flexibility as being when the irrigator has control of the frequency, rate and duration of irrigation. Only through maximizing flexibility can the irrigator maximize their productivity and economic return.

Through the programs and projects of his employer, The World Bank, Herve Plusquellec was able to make presentations to many canal operators and water supply agencies throughout the world using a comprehensive state-of-the-art 35-mm slide presentation (Plusquellec, 1988). He was instrumental in bringing the concepts of improved canal operations and modernization to many who had previously not been aware of such concepts and ideas.

This was followed by USBR's publication titled *Canal Systems Automation Manual* (USBR, 1991). This was an update of previous USBR publications with discussions on the practical aspects of canal operation, control, and automation. The manual began with fundamentals and basic concepts, continued with more specific details, and finished with the more complex aspects of control theory analysis. The manual was divided into three parts that address three levels of readership: Volume 1 - water users and operators, Volume 2 - planning and design engineers, and Volume 3 - research and development specialists.

Understanding that to move the field of canal automation forward required that researchers and designers be able to model unsteady flow in a canal system, ASCE's Irrigation and Drainage Division undertook the task of providing a definitive treatise on unsteady flow modeling of canals (ASCE, 1993). Later, an EWRI task committee created a comprehensive and detailed review of canal control algorithms (Malaterre, Rogers, and Schuurmans, 1998). Both of these task committee efforts provided for a meaningful advance in the formulation and verification of canal control theory and practice. Many of the ASCE/EWRI task committee members joined with EWRI in 1999 to organize and conduct a United States Commission on Irrigation and Drainage (USCID) workshop on the *Modernization of Irrigation Water Delivery* (USCID, 1999), with much of the focus being on current canal automation endeavors.

While the above is certainly not an exhaustive presentation of canal automation research and development, it does provide a broad summary and a snap shot of how long water district managers have looked to technology to improve and enhance the delivery of irrigation water to their customers. It also provides a flavor of the approaches, technology, and agencies that have contributed to the field of automatic canal operations. As pointed out earlier, the goal of MOP 131 is to bring all these past accomplishments together in a single publication that is up to date and useful to both system operations personnel, planners, and design engineers.

3. OVERVIEW OF MOP 131

MOP 131 consists of eight chapters and a glossary. A brief summary of each chapter follows.

3.1 Chapter 1: Modernization Process, Constraints, and Concepts

This first chapter in MOP 131 is probably the most important one. It provides a general overview of the potential benefits of irrigation canal modernization and discusses considerations for assessing whether or not an irrigation or water district should implement automation as it modernizes. If automation appears to be a viable component of modernization, then Chapter 1 describeshow to proceed. This chapter also provides a general overview of the potential benefits of canal automation.

First, it is important to define the concept of *modernization*. Modernization is a combination of technical, managerial and organizational upgrading (as opposed to mere physical rehabilitation) of irrigation schemes with the objective of improving resource utilization (e.g., water, labor, economics, and environment) and water delivery service to farms (Wolter and Burt 1997). Such modernization investment focuses on the details of the inner workings of an irrigation project. Planners and engineers for irrigation projects frequently equate modernization with practices such as canal lining, piping, and computerized automation; however, such investments are often of low initial priority if one examines the steps needed to improve overall performance. Computerized automation is typically implemented in later stages of modernization, after basic needs such as flow measurement and accounting procedures have already been completed. Modernization is a *process* that sets specific objectives and selects specific actions and tools to achieve them over an extended period of time.

There are no "single answers" as to how and when to implement automation as part of modernization because of the complexity and variety of combinations of the water supplies (surface versus conjunctive use), water allocation policies, water quality, timing of flows, adequacy of the water supplies, topography, aquatic weed problems, soil types as related to seepage and bank stability, usage of return flows, types of existing structures, and so on. There are, however, some basic principles that should be followed to achieve a high level of success in designing, constructing, and implementing a canal automation project. Concepts discussed in this chapter include:

(i) Defining potential benefits of modernization and automation.

(ii) Defining incentives for modernization.

(iii) Defining realistic/evolving expectations and costs.

(iv) Assessing the existing system.

(v) Defining institutional and operational constraints as related to automation.

(vi) Selecting the appropriate canal operation strategy.

(vii) Developing a plan for emergency response/safeguards.

(viii) Defining where automation fits into a modernization plan.

(ix) Defining the typical sequence of actions in the modernization process.

3.2 Chapter 2: Physical Infrastructure

Chapter 2 provides an overview of the types of structures and devices used for flow or water level control in canal systems. For each structure or device included, there is a photograph along with a discussion on the advantages/disadvantages, the power requirements, and the serviceability of the structure. In addition, the presentation includes a discussion on what measurements need to be made while using the structure. Only structures or devices useful from an automation perspective are discussed. Concepts discussed in this chapter include:

(i) Working with an existing irrigation system. Decisions need to be made regarding whether to incorporate existing irrigation system infrastructure or to replace the existing infrastructure with new infrastructure.

(ii) Conveyance system considerations. The type of canal automation that is physically possible and practical is dependent upon the physical characteristics of the existing canals and water allocation policies.

(iii) Gates for check structures. A summary of widely available check structure configurations is provided, including PLC-based, electrically moved check structures and non-PLC controlled “automatic” check structures.

(iv) Instrumentation and measurement. A discussion is provided regarding instrument considerations that are common to canal automation including water level, gate position, and flow rate measurements.

(v) Pumps. Pumps are an integral part of many automation schemes that must supply or accept water at variable rates that can change from minute to minute without advance notice.

(vi) Regulating (buffer) reservoirs within the irrigation system. Regulating reservoirs have been used successfully in the western USA to reduce canal spillage, simplify canal operation, and increase the flexibility of the water delivery systems.

3.3 Chapter 3: SCADA Systems

Chapter 3 presents considerations regarding the design and implementation of a Supervisory Control and Data Acquisition (SCADA) system that will support the advanced automation of irrigation canals. This chapter includes discussion of design criteria, applicable technologies, installation, testing, and commissioning of the system. This section of MOP 131 focuses on the SCADA infrastructure itself and not on the control algorithms in the SCADA system processors, which is left for a later chapter. Concepts discussed in this chapter include:

(i) Basic introduction to SCADA systems. SCADA refers to a broad and ever-changing spectrum of electronic hardware, computer software, and communications infrastructure that provides a platform for remote monitoring and control in a variety of industrial applications. In canal applications (or irrigation systems),SCADA system complexity ranges from simple systems that allow operators to monitor a few water levels or flow rates over a radio network, to large-scale, multi-server systems capable of automatically controlling large canal networks over fibre optic and microwave communication networks. Whether small or large, SCADA systems can provide real-time monitoring; remote supervisory or automatic control; alert or emergency notifications; troubleshooting; and automatic data reporting and archiving capabilities.

(ii) Basic SCADA system components and function. In simple terms, a SCADA system consists of a central base unit, which provides facilities for data storage, manipulation, and visualization. The base unit communicates with one or more remote units (e.g., at a canal check structure) through some communications infrastructure. The remote unit communicates with sensors and implements control instructions issued from the base unit.

(iii) Control options in SCADA systems. Automatic control options for SCADA systems can be categorized into three basic groups: local control, central control, and distributed control.

(iv) SCADA project considerations. A discussion is provided detailing considerations for SCADA projects such as system evaluation, building an integration team, system maintenance, and cost.

3.4 Chapter 4: Control Operation and Control Concepts

Chapter 4 presents basic canal control methods and their intended operational goals. A brief discussion of concepts required for implementation is also provided. The limitations for each method are described in terms of the overall control strategy. It is important to note that the concepts discussed in this chapter are not necessarily mutually exclusive, because different concepts can often be used on different parts of the same canal network. Each concept has advantages and drawbacks and each fits better with certain overall strategies. Concepts discussed in this chapter include:

(i) Introduction to the control of irrigation canals. In general, control for irrigation canals can be grouped into two categories: supply-oriented and demand-oriented. It is important to note that most canal control strategies include aspects of both supply-oriented and demand-oriented systems.

(ii) General strategies for control of irrigation canals. A common approach to canal automation is to make gate adjustments at each site successively and then return to each gate to make corrections depending on the observed situation. These initial changes and the later corrections can be interpreted as *feedforward* and *feedback* control actions, respectively. The initial changes in settings to provide the new flows downstream are feedforward actions, while the corrections based on the actual situation are feedback actions. Remote control, where observations are communicated to a central control room and, from there, gate adjustments can be remotely implemented, simply allows the users to perform these actions more quickly, more often, with better timing, and with the ability to see more of the canal conditions at once. Automatic controls allow these adjustments to be made automatically. Automation allows control actions to be made more often and, in theory, more precisely. But fundamentally, these different approaches (manual/local, manual/remote, automatic) use the same basic strategies.

3.5 Chapter 5: Canal Hydraulic Properties

Chapter 5 discusses the hydraulic properties of canal pools and structures, as they relate to needs for canal automation. Since this publication is geared toward modernization of existing canal networks or systems, detailed design considerations are not included. However, changes may be needed to the infrastructure to implement new technologies during modernization, so that the system will allow greater flexibility and thus potentially improve performance. This chapter also presents methods for describing the hydraulic response of canal pools, particularly how water levels respond to changes in flow rate. Concepts discussed in this chapter include:

(i) Design issues. Various design issues such as freeboard, canal lining, intermediate structures, and flow capacity are discussed.

(ii) Canal structure hydraulics. Summary information regarding the hydraulics of typical weirs and gates used in irrigation canals is provided.

(iii) Canal pool hydraulics. Each pool is unique in its response to changes in flows through control structures. Physical parameters that influence this behavior are longitudinal bed slope, cross section size and shape, length, and bed material. Concepts regarding flow conditions, changes in canal conveyance, pool volumes, and travel time of waves are also discussed.

(iv) Resonance Waves. Resonance waves and their influence on automatic control can be minimized using the filtering procedures discussed.

(v) Identification. Methods for determining important hydraulic properties of the canal pool are discussed. These parameters are crucial for controller design.

3.6 Chapter 6: Control Methods

Chapter 6 presents control system fundamentals and control techniques that are used to develop controllers for water level or flow rate in irrigation canals. This chapter presents methods by which the control strategies discussed earlier in MOP 131 can be implemented via electronic devices such as PLCs, RTUs, computers, etc. The intent of canal automation is to improve the operation of the water distribution system, which typically means better service to farmers; canal automation is intended to improve some aspect of operations by performing controls that would be difficult to do manually and to enhance system monitoring and emergency responses. Concepts discussed in this chapter include:

(i) Introduction to control methods. Various control method concepts are defined including control variables and control-action variables.

(ii) Implementation options. Automatic controls can be organized in a variety of ways: local control, centralized control, hierarchical control, and distributed coordination control.

(iii) Decoupling pools and structures. To simplify the design of controllers (which are usually linear) and to simplify implementation, most canal controllers determine the flow rate change needed for a check structure and then the gate position change required to achieve the prescribed flow rate in separate computations (algorithms).

(iv) Routing demand changes through a canal.Routing water through a canal, also called feedforward control, can be done by using the time it takes a flow rate change to travel from the head gate to turnouts (delay times). Various methods for routing water through a canal, an essential control function, are discussed.

(v) Feedback control. This section describes the mathematical procedures needed to tune controllers for the control of water levels, flow rates and/or volumes within a canal. These methods use measurements of water level and/or flow rate to determine what control actions will bring the water level, flow rate or canal pool volume to a set point value. Details on specific feedback control algorithms such as Linear Quadratic Regulator (LQR), H-

Infinity, Model Predictive Control (MPC), and Proportional Integral (PI) flow control are discussed. There is also a discussion on combining feedforward and feedback control.

3.7 Chapter 7: Verification of Controller Performance

The users of canal automation want to be sure that the automatic control system will function in a way that is useful for their operations. Two essential questions must be answered. First, are the right processes being controlled? Second, is the automatic control functioning in an acceptable manner? This chapter discusses the process that control system designers and integrators should go through so that they can document a successful automation implementation. Concepts discussed in this chapter include:

(i) Performance testing issues. This section deals with performance testing of automated canal structure logic.

(ii) Performance testing with unsteady-flow simulation models. Simulation models are a useful tool for determining the potential performance of canal automation. Many canal automation developers routinely test control algorithm performance for even a single gate with unsteady-flow simulation. This allows the gate to be tested under a variety of flow and operating conditions.

(iii) Performance measures. This section outlines concrete performance measures that can be used to evaluate how effectively a canal automation scheme is controlling the irrigation delivery system. Performance measures for both water level control and flow rate control are presented.

3.8 Chapter 8: Implementation of Control Systems

Chapter 6 addresses the practical implementation of canal automation as a project within a wider modernization program. The automation of an entire lateral or whole canal system is described, rather than just a single check structure, because the challenges and benefits are much larger. This chapter describes the sequence of required tasks, including the customization of control software, the installation and commissioning of the field devices and central server software, the progressive activation of control throughout the canal system, the measurement of overall performance of the new system, and the training of operations staff. Ongoing operational tasks and system maintenance are also discussed. Concepts discussed in this chapter include:

(i) Project initiation. The first step in any automation project is to determine the project objectives. These might include the improvement of irrigator service levels, water savings, and better control of water levels, operational cost savings, or rate of return on investment. Clear, quantified objectives help ensure success by aligning the irrigation district and implementation team and allowing for objective measurement of performance.

(ii) Configuration and customization of software. Discussions are provided regarding RTU/PLC software, communications software, SCADA software, water ordering and demand management software, and network representation software.

(iii) Commissioning. Commissioning is the process by which equipment, a facility, or a plant is tested to verify if it functions according to its design objectives or specifications.

(iv) Control rollout and tuning.Once the commissioning of the SCADA system is complete, the next step is to roll out or activate the control system. In this section, rollout of control refers to the control on a network scale as it encompasses the processes involved in rolling out control at each location. Sometimes the behavior of the actual system may differ from what has been modelled initially. Hence, fine tuning of controller(s) may be required at intermittent stages.

(v) Performance assessment and acceptance. As important as setting the overall project objective is the measurement of the performance of the canal system against those objectives.

(vi) Post-acceptance operation and maintenance. Post-acceptance operations and maintenance is an important part of canal automation. It is the analog of a routine maintenance program that irrigation districts generally undertake anyway, but includes new equipment like the software and new operating procedures.

(vii) Training. An automated canal system requires that operators learn a number of new computer skills and adapt to a new style of operation that involves reacting to operational problems rather than simply implementing routines. This is not dissimilar to the role of a pilot when an airplane is operating in auto-pilot. The pilot must vigilantly monitor instruments and correct for unforeseen circumstances or deal with alarms.

(viii) Manuals. In addition to the training, the irrigation district must be supplied with manuals for every component that makes up its system.

4. CONCLUSIONS

Irrigation district managers as well as state and federal water resource management agencies have for more than 50 year looked to technology to increase their effectiveness, improve their operations, enhance water transmission and delivery, and make their canal systems safer and more responsive.

As the technology provided by the development and enhanced performance of computers made quantum leaps in performance, it was logical for the computing power of these devices to be incorporated into the control of irrigation canals. Beyond the power provided by computer technology, was the requirement for an entire array of associate technology that needed to be developed and adapted for canal control. The associated technologies included equipment to measure water levels, flow rates, and gate movements digitally as well as radio and fiber optic equipment to transmit and receive monitored data. As each of these technologies matured, the engineers and researches responsible for the research and development of canal control adapted these new technologies into their designs. As such, canal control has matured and became more technically rigorous. In a parallel way, the software needed to control canals also matured through the incorporation of new theories or mathematical models into improved control algorithms.

What started out as remote monitoring and control with much of the decision-making left in the hands of humans, has now been refined to the point that automatic control of irrigations canals is a reality. What was lacking was an up to date, comprehensive publication that would not only assist irrigation district personnel but also the consulting engineer community with a practical source of knowledge on the world-wide status of automatic canal control. The professionals who were active participants in the development and implementation of automatic canal control joined forces to collaborate on MOP 131 in order to bring their collective expertise together in ways that would be useful to water resources engineers and managers around the world.

The professionals that contributed to the preparation, review, editing and finalization of MOP 131 are hopeful that MOP 131 is adopted by the water resources community as the definitive publication on the state of the art of automatic canal control, and that automatic canal control will make a substantial contribution to the production of food and fiber for a world that is facing unrelenting increases in the demand for food production with limited water supplies, while at the same time meeting demands to preserve our environment.

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