

# LEVERAGING SCADA TO MODERNIZE OPERATIONS IN THE KLAMATH IRRIGATION PROJECT

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## ABSTRACT

The U.S. Department of Interior's Bureau of Reclamation (Reclamation) operates the Klamath Irrigation Project in Oregon to divert, store and supply irrigation water to over 200,000 acres of farmland below Upper Klamath Lake. Reclamation has partnered with irrigation districts to undertake an active modernization program including the implementation of a Real-Time Water Management SCADA System for remote monitoring of the main diversions on the Project boundaries and at key control points within individual irrigation districts. Data are recorded at frequent intervals, transmitted to base station computers in headquarters offices where it is displayed, manipulated, and stored. This paper presents an interim assessment of the complex issues concerned with SCADA project implementation in a basin-wide environment with multiple irrigation districts, describing the engineering points of particular innovative, and field-tested concepts. Performance specifications and design standards are discussed to illustrate the specialized details critical for successful integration.

## INTRODUCTION

### Background

The U.S. Department of Interior's Bureau of Reclamation (Reclamation) Klamath Irrigation Project is a system of main-stem and tributary dams, diversion structures and pumping stations that store and deliver water for agricultural water users and national wildlife refuges on about 240,000 acres through a system of over 1,400 miles of canals and drains. The water must be managed in accordance with legal obligations arising from the Endangered Species Act (ESA) and federal tribal trust responsibilities.

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To a majority of farmers in the Klamath Irrigation Project, the irrigation curtailment in 2001 drew attention to the existing water delivery system's limitations involved with delivering specific quantities of scarce water under reduced supply allocations. The physical infrastructure design and functions in the Project – based mainly on +50-yr old hardware and technology – limited the ability of managers and users to effectively respond to water shortages due to drought or reallocations for environmental requirements.

Efficient use of water diverted for irrigation requires the capability to deliver precise flow rates and volumes to known points throughout this complex system, and to quickly respond to changing demands. Rapid Appraisal Process (RAP) evaluations and water balance analyses conducted by the Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo, identified priority sites for modernization and recommended technical solutions, according to an assessment of the overall modernization and water conservation objectives.

Modernization efforts undertaken by irrigation districts in the Klamath Irrigation Project include, among other actions, upgrading existing telemetry systems to provide remote control and monitoring on a real-time basis at key points, improving water delivery service to water users. The work completed to date has been possible due to a coordinated effort between the USBR Klamath Basin Area Office, irrigation district staff, professional engineers from ITRC, and Watch Enterprises of Grants Pass, Oregon. This project was primarily funded by the Bureau of Reclamation, Mid-Pacific Region, Klamath Basin Area Office, with irrigation districts providing cost sharing.

### **Real-Time Water Management System**

One objective of the Real-Time Water Management Supervisory Control and Data Acquisition (SCADA) System is to collect and disseminate high-quality, accurate and reliable data to partner irrigation districts in the Klamath Irrigation Project, who use the information for real-time decision-making about water deliveries. A second objective is to directly provide some of this real-time information, and additional information from Reclamation-operated sites, to the Reclamation Area Office in Klamath Falls. Prior to this project, Reclamation had no project-wide SCADA capabilities.

The location and function of each SCADA site is summarized in Table 1. At present there are seven (7) sites being remotely monitored as part the Klamath SCADA Project and another six (6) sites are under construction. As part of the system, base stations with human-machine interface (HMI) computer systems were established at four irrigation districts and the Area Office. An additional six (6) sites have been identified and preliminarily designed for the next phase of the system.

The first portions of the SCADA system were made operational in August 2004.

Table 1. SCADA sites in the Klamath Irrigation Project.

No	*	District	Site	Description	Purpose
1	pp	Langell	North Canal	Replogle flume and RTU	Remote monitoring
2	pp	Valley	West Canal	Hydroacoustic flow meter and RTU	Remote monitoring
3	cp	Irrigation District	East Malone L.	Hydroacoustic flow meter and RTU	Remote monitoring
4	cp		Office	Master RTU and Computer HMI	Base station
5	ip	Horsefly Irrigation District	Harpold Dam	Langemann Gate automated for upstream water level control	Remote monitoring Auto. level control
6	ip		Office	Master RTU and Computer HMI	Base station
7	cp	Klamath Irrigation District	Miller Hill Pumping Plant	GE Panametrics ultrasonic flow meters (wetted transducer) and RTU	Remote monitoring
8	cp		B Canal	Automated radial gate upstream water level control RTU and Hydroacoustic flow meter	Remote monitoring Auto. flow rate control
9	cp		C Canal	Hydroacoustic flow meter and RTU	Remote monitoring
10	cp		D Canal	Hydroacoustic flow meter and RTU	Remote monitoring
11	ip		Office	Master RTU and Computer HMI	Base station
12	pp	Tulelake Irrigation District	D Pumping Plant	GE Panametrics ultrasonic flow meters (wetted transducer) and RTU	Remote monitoring
13	ip		Drain 9	Hydroacoustic flow meter and RTU	Remote monitoring
14	ip		Drain 10	Hydroacoustic flow meter and RTU	Remote monitoring
15	pp		Drain 11	Hydroacoustic flow meter and RTU	Remote monitoring
16	pp		Drain J-14	Hydroacoustic flow meter and RTU	Remote monitoring
17	pp		Drain J-20	Hydroacoustic flow meter and RTU	Remote monitoring
18	cp		Office	Master RTU and Computer HMI	Base station
19	ip	KBAO	Office	Master RTU and Computer HMI	Base station

\* Status current in June 2005.

cp: completed

ip: in-progress – under construction

pp: planned

Data collected by the SCADA system will also be helpful for future water balance analyses, for example to quantify the realistic, true water savings from water conservation efforts (Clemmens and Allen, 2005). Accurate and comprehensive historical records are essential for producing reasonable environmental modeling, and providing verification of water for drought allocations, water banking and water transfers. Uncertainties in surface discharge records accounted for nearly 40% of the total variance in the annual water balance of the Project, accounting for an “error” equivalent to a volume of  $\pm 55,000$  acre-feet (ITRC, 2003).

### SCADA FOR IRRIGATION DISTRICTS

Supervisory Control and Data Acquisition (SCADA) is a process control and measurement system that enables an operator to remotely control and/or monitor sites in an irrigation system. Real-time monitoring, automated control, troubleshooting, automatic data reporting, and archiving are some of the possible capabilities of an irrigation district SCADA system.

SCADA sites with control functions, either automatic or remote manual, can only be accessed through a secure HMI computer terminal system. Information from individual remote sites can be networked to other fixed base stations or mobile stations, some with limited, monitoring-only capabilities such as flow rate information for specific time intervals.

A schematic of the transmission of real-time information from a remote terminal unit (RTU) in the field at a flow monitoring station to the HMI computer is illustrated in Figure 1.

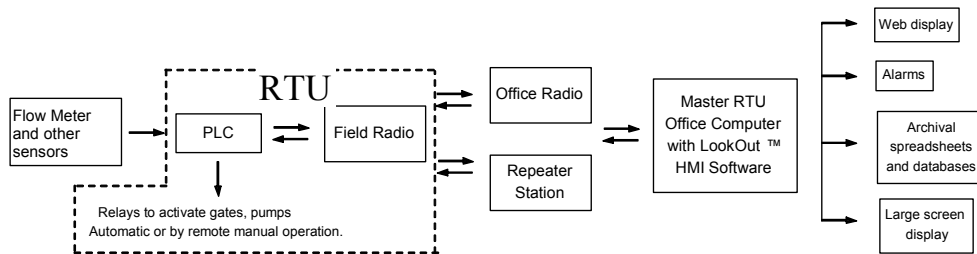


Figure 1. Schematic of the SCADA data transmission network.

The five major components of the irrigation district SCADA systems in the Klamath Irrigation Project are:

- I. Remote Terminal Units (RTUs). RTUs refer to equipment (including a Programmable Logic Controller [PLC], sensors, radio, antenna, etc.) installed at a field site. The electrical cabinets and power systems are housed in a bullet-resistant (armored) vandalism enclosure. Key information such as flow rate and battery voltage can be read continuously on a small LCD screen at the RTU.
- II. Programmable Logic Controllers (PLCs). A PLC is the mini-computer inside the RTU box. Different brands/types of PLCs have been used in the Klamath Irrigation Project for various functions. The PLCs for remote monitoring sites are RUG3 models, Rugid Computer Co. The PLCs for control sites are SCADAPack (ISaGRAF 3.x equipped) from Control Microsystems, or equivalent.
- III. Communications Equipment. Each PLC is connected to a radio with a data communications cable, using the widely accepted Modbus communication protocol. The RTUs communicate with the Base Station HMI computer in

the district headquarters office by transmission on a licensed fixed-frequency radio channel (460 MHz band). Radio transceivers (9600 bps) from Microwave Data Systems (MDS model 4710) installed in each RTU use either point-to-point (directly with the district office) or repeater-relayed signal communication.

- IV. Primary and Secondary Sensor Instrumentation. Real-time water management information, such as the current flow rate in engineering units (cfs or feet elevation) at major canal diversions, is collected by several types of instruments at flow monitoring stations. SonTek/YSI Argonaut flow meters use digital signal processing techniques and Doppler transducers to measure discharge at sites with the requisite conditions. Other types of sensors may include water level transmitters, gate position sensors, and ultrasonic pipe flow meters.
- V. Base Station HMI Computer. All inputs, outputs, and memory register values are transmitted to the HMI computer located in the district headquarters office running National Instruments LookOut™ software. The HMI computer displays real-time and historical information, sends out alarms, and archives information.

SCADA benefits modernization by allowing better accounting of water on a real-time basis in the system, more accurate record keeping for historical analysis and forecasting, and faster responses to user inputs or alarms. This, in turn, is the basis for irrigation districts and water users to manage pending challenges such as the electricity rate hikes and the consequences of proposed water use restrictions due to Total Maximum Daily Loads (TMDLs) or in-stream flow requirements for environmental uses.

### **MODERNIZATION PLANNING AND SCADA**

SCADA is a popular tool in modernization programs, but the initial enthusiasm of managers and engineers has evolved into greater understanding of the costs, technical complexities, and unique difficulties involved with this technology. Responding to external pressures to introduce new technologies and modern modes of operation – both requiring a thorough prior understanding of the internal process in the system– has been a major challenge for irrigation districts.

Creating a SCADA system for multiple irrigation districts, with different needs, operating budgets, and in-house technical resources, as in the Klamath Irrigation Project, is not a simple task. In this case, it required very detailed, comprehensive planning with many meetings and trips to the field. However, the modernization plans for the irrigation districts developed as an outcome of the Rapid Appraisal Process (RAP) diagnostic evaluation serve as the roadmap (Burt and Styles, 2004).

The involvement of ITRC occurs at all stages in the implementation of a SCADA system leading to final field deployment of the system through a series of steps:

1. Rapid assessment of irrigation district system and operations.
2. Introductory SCADA presentation and specific site review
3. Communications evaluation and radio tests
4. SCADA System report
5. Board presentation of SCADA system report (only when specifically requested)
6. Request for Proposals (RFP)
7. Construction
8. Continued support with operation

An RAP evaluation of the service area includes systematic investigations of the primary water distribution canal system and control structures, data collection and surveying, field interviews with project managers and operations staff, and engineering analysis to improve understanding of the internal processes. One of the first decisions made after a RAP is if SCADA is even required in conjunction with PLC controls, or whether a simple device like a flap gate or long-crested weir could provide an adequate solution. For the Klamath Project, a modernization report and SCADA recommendations were developed in consultation with the Districts and Reclamation.

Once a SCADA system is envisioned and approved by an irrigation district Board, it must be considered integral to the modernization package and planned for in all aspects of the construction phase and also, just as important, in terms of follow-up support and budget. To start with, there must be a transparent evaluation of the costs and benefits of the different levels of SCADA investment. Most irrigation districts enter into SCADA gradually, starting with a few remote monitoring sites, and then move into control and automation, learning about the possibilities as they use the system.

Once the integration team is assembled, specific tasks can be assigned and scheduled. The planning information was presented, along with proposed project descriptions for each site, in the SCADA system specifications report. All participants knew their responsibilities and what the sequence of steps would be.

Due to the typical in-house nature of districts' O&M activities, districts are often hands-on involved with deployment of the system while at the same time dealing with a steep learning curve on new technology. Basic maintenance chores and set-up procedures must be clearly described in a detailed O&M manual with system back-ups. Manufacturers are tailoring their software programs and devices to the irrigation market, but working with SCADA requires a high level of computer programming knowledge that districts must prepare for.

SCADA systems are complex and expensive investments, and have many parts that can fail and many details that can go unnoticed in the planning stages. As a result, there are many bumps on the road that must be handled in a timely and effective manner so that predictable problems don't excessively frustrate the district. Obtaining outside expertise, desirably from a specialist in irrigation applications, is necessary, but there must also be a designated person in overall charge of the system at the district. Communication must occur on a regular basis at all stages of the project. Getting the right integrator is absolutely critical.

### **SCADA System Guide**

The specific conditions and data/control options at each proposed SCADA location require a thorough field investigation and analysis and result in project-specific details. However, there are many areas, such as sensors and instrumentation, where the quality of data in a SCADA system is established through adherence to standardized specifications. The *SCADA System Guide* prepared by ITRC for an irrigation district sets forth the specifications and performance requirements for the design, specification, installation, and operation of the system. The subjects covered in the technical report prepared include:

- SCADA site descriptions and functions
- Guidelines for SCADA integration services
- Project specifications and system configuration

The purpose of the *Guide* is to provide a detailed technical overview of how the package of SCADA components fits into a modernization plan whose performance capabilities conform to standard specifications and guidelines, which are set forth in specific performance requirements. Project management benefits from following detailed specifications; these reduce the risks and costs associated with design, construction, and integration of the SCADA system.

To help irrigation districts in planning and contract consultations the *Guide* contains guidelines for integration services pertaining to the following areas:

- a) Deliverables – what the Integrator will deliver to the irrigation districts in regards to training, warranty, backup software, etc.
- b) Ownership of Work
- c) On-Site Assistance – specifying what the Integrator will provide assistance at installation and start-up of SCADA equipment.
- d) Quality Control – quality control of PLC programming used for control.
- e) HMI Development
- f) Controller PI Logic and Tuning – ITRC recommends that a certain form of Proportional-Integral Filtered (PIF) logic be used to control the action of gates and variable frequency drive (VFD) pumps. For canal control, the tuning constants for the PIF logic must be carefully selected – and selection by trial-and-error in the field is not acceptable.

### KLAMATH IRRIGATION DISTRICT SCADA SYSTEM

An example within the Klamath Irrigation Project is the Klamath Irrigation District, which supplies water to approximately 54,000 acres of irrigated land within its service area boundaries. The district operates and maintains the A, B, C, D, E, F, and G Canals, in addition to the associated drainage system and pumping plants. While the physical features and operational methods have been well-established and time-tested over these many years, they did not reflect the benefits made available by newer telemetry control systems and hydraulic control structures.

The District has to perform real-time control and monitoring of flows, canal water levels, and pumping plants over an extensive water distribution and drainage system. Their prior telemetry systems had some limited remote monitoring capability, but did not have the features of modern SCADA systems widely adopted by California irrigation districts over the past 8 years. With support from the Reclamation, the District has proceeded with a modernization program that includes new hardware and control strategies, water measurement devices, communications equipment, and integration into the district's existing SCADA system.

The service area does have some physical characteristics that make modernization more expensive and difficult than may typically be the case for other irrigation districts. Key challenges included:

- The district has some very long canals, which typically wind around to follow the contours, rather than being laid out in a simple rectangular grid.
- Most of the canals are fairly old, often without good year-round access.
- The system has almost no modern control structures.
- Many of the fields within the service area have irregular shapes and are relatively small.

Even with the ability to utilize operational spill at multiple points and internal recirculation, the canal check structures within the system make it difficult to quickly and frequently make flow rate changes throughout the system without adversely impacting flow rates to turnouts and to laterals (Burt et al., 2000).

To combat these difficulties, a strategy (Figure 2) was adopted starting with the main arteries of the delivery system, making them easy and efficient to manage with flexibility. If the long canals can be effectively managed, this gives tremendous flexibility to the short canals. Once the main canals have been modernized, the district can move further down into the system. There is little justification for putting extremely accurate flow meters on farmer turnouts, for example, if the deliveries to those turnouts are not very well controlled.



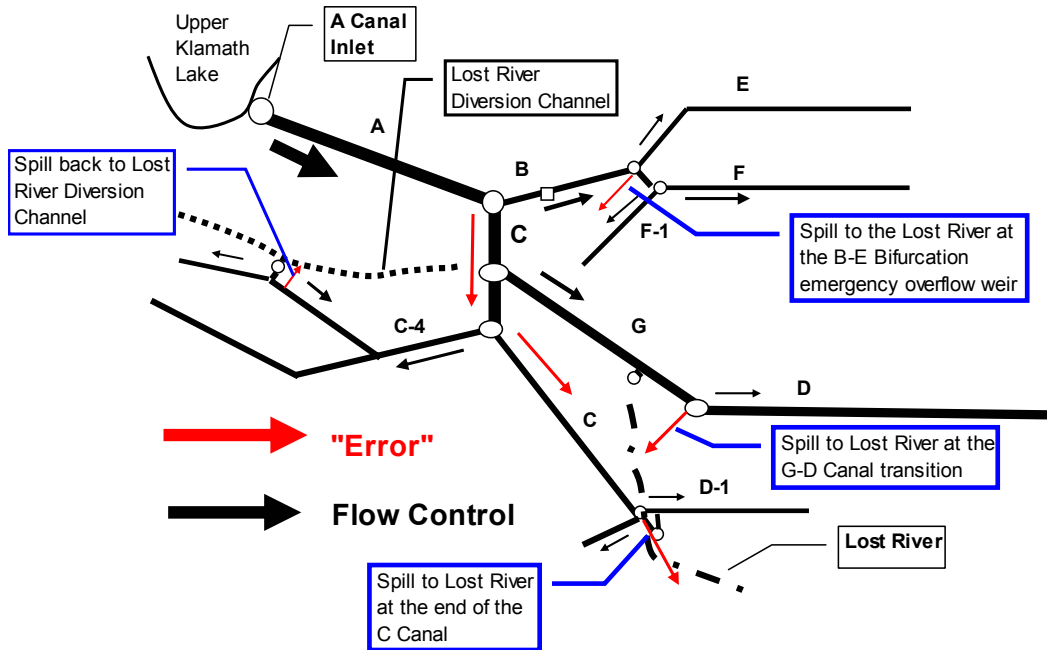


Figure 2. Proposed main canal operating logic with modernized control structures and centralized management of the Klamath ID main canals.

Therefore the process begins with improved measurement and control at the heads of main delivery canals, with SCADA-equipped flow meters and new sensor systems, so that the operators and users deal with a manageable (although limited) supply of water. The improvements fall into broad inter-related categories:

1. Centralized dispatching and control of the main canals
2. Physical improvements to the main canals
3. Advanced SCADA system upgrades and HMI computer

The following sections describe examples of innovative techniques used to set up two different types of SCADA sites:

B Canal: automatic flow rate control and remote monitoring using a hydroacoustic flow meter

Miller Hill Pumping Plant: Remote monitoring of a pump station with old concrete and steel pipe with ultrasonic transit-time flow meters

**B Canal**

The B Canal is a critical operations point, with a capacity of about 300 cfs. The headworks, a 17-ft single radial gate, is shown in Figure 3. Historically there had been problems with steady and reliable control of the headgate, partly due to the hydraulic conditions of this reach of canal that results in very low head across the gate. To improve the automatic control and provide accurate flow measurement, a new RTU running an ITRC control algorithm has been installed that uses real-time data from a hydroacoustic flow meter.



Figure 3. Automated flow rate control on the B Canal radial headgate.

The B Canal headworks was automated for flow control using a hydroacoustic flow meter [SonTek/YSI Argonaut Side-Looking (SL) Doppler] mounted in a 70-ft lined section installed by the District 300 ft downstream of the headworks. The Argonaut SL flow meter is solar powered and serial data is output directly to the RTU via a short-distance, spread-spectrum radio. Standard 4-20mA signal converters were not required. The PLC unit is programmed with a parsing program to select the flow rate computed in the sensor, along with data on water level and flow area.

The concrete lining is recommended for creating a stable cross-section and to protect the sensor from weed growth. The lined banks make it easier to retrieve the sensor for maintenance. An aluminum mounting frame was designed for easy installation and retrieval of the sensor (Figure 4).



Figure 4. Side-looking hydroacoustic flow meter.

Determining the proper timing intervals for sampling and averaging the raw electronic flow meter data required successive field testing. Hydroacoustic flow meters typically output signals with a tremendous amount of noise that eventually (perhaps in 15-30 min. or so) average out properly. The control algorithm must be properly programmed to recognize this noise. Hydroacoustic flow meters must also be calibrated using a statistical regression analysis technique called the Velocity-Index relationship (Styles et al., 2003). Two indexing sessions have been carried out at low-mid flows and more data will be collected per the guidelines.

This project also involved installing a new upgraded RTU, which had to be integrated with the incoming data from existing water level and gate position sensors. The solar-powered RTU is equipped with necessary alarms and the system can switch between using the flow meter and computing flow based on head differential.

### **Miller Hill Pumping Plant**

A modernization recommendation for the District was to eventually install a VFD controller at the Miller Hill Pumping Plant to better match pumped diversions with operational needs in the C4 Canal system it serves, after first installing flow

meters. Previously, if an operator wanted to pump only 10 cfs for orders, they had to actually turn on one of the 35 cfs pumps and spill the rest back to the Lost River Diversion Channel.

To set up the remote monitoring at the plant, new hydroacoustic sensors (GE Panametrics AT868W ultrasonic flow meter, single channel) were installed on the buried discharge pipelines outside the pump house using custom access vaults (Figure 5) built for each sensor. The corrugated pipe vaults have lockable lids with a simple drainage system and gravel bottom. The RTU and display panels for the meters were mounted in adjacent vandalism enclosures.

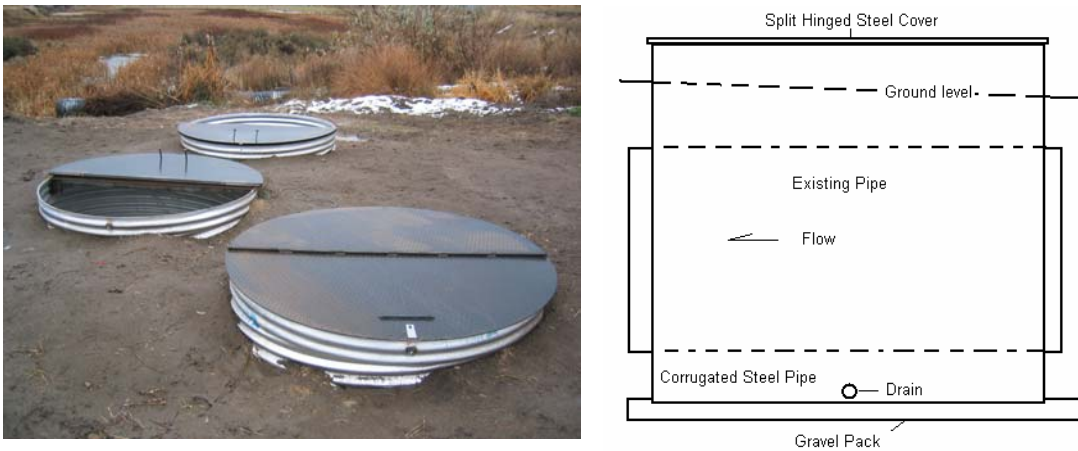


Figure 5. Vault design for transit-time flow meters with wetted transducers on buried concrete pipe.

The wetted transducers on the two (2) concrete pipelines had to be installed using stainless steel saddles as shown in Figure 6. Weld-o-lets fixed at the site were used to install the transducers on the steel pipeline.



Figure 6. Existing concrete and steel pipelines at Miller Hill Pumping Plant showing the saddles used to install GE Panametrics wetted transducers.

At a future date, a water level sensor, installed in the C4-E lateral, can be connected to the RTU to provide real time information to the headquarters. Remote manual on-off capability can also be added to the PLC by connecting to the pump motor starters. The result will be to provide the district with an accurate measurement of the flow rate, the effect of the flow rate on the C4-E Canal, and the ability to modify the flow rate by turning on or off a pump.

### **Dealing with Accuracy and Reliability of Electronic Data**

Accuracy, consistency, and precision all depend upon the combination of good equipment, proper installation and initial calibration, and good maintenance. Excellent maintenance practices are required for long-term reliable discharge records collected by an irrigation district SCADA system. There are several sources of error in discharge measurements that were considered, including:

- The index equation coefficients used to predict the mean channel velocity statistical relationship with measured velocity from the sensor
- The validity of the index equation over the entire range of flows and stages (water depths)
- Errors in calculating the cross-section “area” of the channel or pipe
- Time averaging intervals and computer processing of raw data signals
- Environmental changes to the hydraulic conditions at the site
- Deployment parameters such as the alignment angle and water depth
- Excessive sedimentation or vegetation obstructing the acoustic signals
- Instrument precision

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### **SUMMARY**

SCADA is a valuable tool with tremendous potential for modernizing the operation of irrigation districts. This paper describes the implementation of a Real-Time Water Management SCADA system in the Klamath Irrigation Project. Planning, SCADA specifications, and other guidelines, are discussed.

### **REFERENCES**

Burt, C.M., A. Mutziger, and D. Cordova. 2000. Benchmarking of Flexibility and Needs of Irrigation Districts in the Mid-Pacific Region of the USBR. Irrigation

Training and Research Center. California Polytechnic State Univ. San Luis Obispo, CA. 47 p.

Burt, C.M. and S.W. Styles. 2004. Conceptualizing Irrigation Project Modernization through Benchmarking and the Rapid Appraisal Process. *Irrig. and Drain.*, 53(2): 145-154.

Clemmens, A.J. and R.G. Allen. 2005. Impact of Agricultural Water Conservation on Water Availability. U.S. Water Conservation Laboratory, 4331 E. Broadway Rd., Phoenix, AZ. pp.1-14.

ITRC. 2003. Hydrologic Assessment of the Upper Klamath Basin: Issues and Opportunities. Draft Report for U.S. Bureau of Reclamation, Klamath Basin Area Office.

Styles, S.W., M. Niblack and B.J. Freeman. 2003. Canal Velocity Indexing at Colorado River Indian Tribes (CRIT) Irrigation Project in Parker, Arizona using the SonTek Argonaut SL. Irrigation Association, International Irrigation Technical Conference, San Diego, CA.