

SYNCHRONOUS RADIO MODEM TECHNOLOGY FOR AFFORDABLE IRRIGATION SCADA SYSTEMS

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ABSTRACT

Engineers at Reclamation's Water Resources Research Laboratory, funded through Reclamation's Science and Technology program, and in cooperation with the Colorado Division of Water Resources (State Engineer's Office), the Lower South Platte Conservancy District (LSPWCD), and the South Platte Ditch Company (SPDC), have established a demonstration project to monitor and evaluate control equipment that features an innovative radio technology. Irrigation practices in the South Platte valley in Northeast Colorado include extensive conjunctive use of both surface diversions and pumped groundwater. As a result of extended drought conditions and court rulings that have altered the administration of groundwater pumping in Colorado, the region is currently facing a dramatic increase in the number of sites at which flow measurement is required. The State of Colorado is facing an associated exponential increase in the amount of data that needs to be acquired and processed.

The control/communication equipment under evaluation is produced by Integrated Controls Technology Inc. (IC Tech) [Formerly Control Design Inc.] The primary objective of the field study is to assess the potential of the IC Tech equipment as a cost-effective means of collecting and transmitting flow measurement data. The equipment was put into service in early March, 2005, at two sites on the SPDC's artificial recharge system. One of the units was relocated in late April, 2005, to the SPDC main flume to continue performance observations through the irrigation season. Flow data from the demonstration sites is telemetered over distances extending up to twenty miles via signal pathways that do not provide clear line-of-sight transmission paths.

The IC Tech units evaluated include both a radio modem for communication and a programmable logic control system capable of monitoring flow rates, recording data, and controlling canal gates. The cost of the IC Tech radio/controller units is competitive with other popular controller-only systems. Depending on the water-level sensor selected, a solar powered station with an IC Tech unit can be installed at a canal structure for a price in the range of the cost of paper-chart recorders

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which are currently used at most open channel flow recording stations in the region.

This paper provides documentation of performance of the IC Tech equipment during 2005 in the Northeast Colorado demonstration study. General performance information supplied by the Lower Rio Grande Conservancy District – which has been using similar IC Tech equipment over multiple seasons – is also included.

INTRODUCTION

A vital component of successful Supervisory Control and Data Acquisition (SCADA) systems for canal operating systems is a reliable two-way communications system. Radio telemetry is often an attractive communication option since the operational costs are usually minimal after the initial installation costs have been expended. Other wireless communication alternatives typically have monthly fees (i.e., cell phones) or charges based on volume of information transmitted (i.e., low-orbit satellite systems). Once a radio system is in place, there are no non-maintenance operational costs (other than periodic licensing fees for systems operating on licensed frequencies). A chief concern with radio communications systems is adequate signal strength. Frequently, costly towers and/or extensive repeater systems are necessary radio network components that can dramatically increase system costs.

As part of the Bureau of Reclamation's water-management mission, the Water Resources Research Laboratory (WRRL) has an ongoing program to identify and evaluate new or alternative techniques and equipment that can enhance water conservation and delivery efficiency while lowering costs. The Middle Rio Grande Conservancy District (MRGCD) reported that they were having positive results in this area using radio/control equipment from IC Tech of Albuquerque, New Mexico, for remote data acquisition and control. Their experience indicated that IC Tech equipment was both reliable and cost competitive compared with other control/communications systems MRGCD had tried.

Based on the information provided by MRGCD plus contacts with IC Tech, WRRL staff concluded that the IC Tech equipment would be a good candidate for a field evaluation. The goal of the evaluation was to determine if such equipment might be an appropriate option to help further cost-effective water conservation efforts for other Reclamation partners. The Northeast Colorado demonstration site selected is in an area where a strong need for information on technologies of this nature exists, and it offers a convenient proximity to the WRRL's location in Denver.

CONTROL SYSTEM HARDWARE

The IC Tech radio/control units feature a programmable logic controller (PLC) and a radio modem installed on the same circuit board, eliminating the need to pass information between the modules through a communications port. The IC Tech radios feature what the company describes as a synchronous modem technology that, according to IC Tech, enables a superior degree of signal acquisition compared with conventional modem technologies. The company reports that signal transmissions of up to 120 air miles are being utilized in existing deployments of their equipment. It is the apparently unique radio technology and potential range which makes the IC Tech equipment particularly intriguing for applications in irrigation delivery systems.

The systems are Modbus compatible and programs for the PLC are written using the BASIC 52 programming language. Six radio module options are available. These radio options include one unlicensed and two licensed VHF bands plus three licensed UHF bands. Selection criteria for the appropriate radio option includes the required distance of transmission and the type of terrain. Radio modules used in the field demonstration site are UHF units operating in the 450 – 470 Mhz band.

Three PLC configurations are offered. The high-end “A” unit were used in the field demonstration tests. These units were equipped with the optional 4 X 20 LCD display and 2 X 5 keypad. The “A” units are equipped with the following standard features:

- Eight available 12 bit analog inputs (one of which can be configured for SDI-12 inputs)
- Eight optically isolated digital inputs (four can be used as runtime and pulse counters)
- Four relay isolated digital outputs
- 128K battery-backed non-volatile SRAM
- 64K non-volatile flash memory
- Real-time clock with battery backup
- Charging controller for solar or other DC sources
- Three communications ports
 - Com0 RS232 (BASIC 52 port)
 - Com1 RS485 (MODBUS port)
 - Com2 RS232 or RS435 (Modem port)
- Switched sensor excitation voltage (battery voltage)
- Switched sensor excitation onboard 24 volt converter
- LED indicators for power and modem functions
- Industrial grade components, rated -30°C to 70°C (radio) and -40°C to 85°C (all other components)

- Approximately 16500 MODBUS floating point data storage registers that may be used for storing data to be telemetered by radio and/or for onsite datalogging

Two office locations in the study were equipped with less costly “B” units. The optional display and keypad were not installed on these units since they were connected to the office computer systems. The standard configuration of the “B” units is identical to that of the “A” units with the following exceptions:

- Four available analog inputs (none is SDI-12 compatible)
- Four digital inputs (no pulse counters)
- Two relay isolated digital outputs
- Switched battery (12V) excitation voltage only (no 24V converter)

The third PLC option, “C” units, have the same capabilities as the “B” units but cannot be equipped with a display and keypad.

FIELD TEST SITE BACKGROUND

Irrigation in northeast Colorado’s South Platte Valley dates back to the late 1860’s. Canal systems were constructed to carry water diverted from the South Platte River. The limited river flow during the latter summer months led to construction of several off-channel reservoirs in the region. These reservoirs began storing water from the non-irrigation and spring runoff periods during the early part of the 20th century. By the 1930’s irrigators began drilling groundwater wells to supplement surface-water supplies. Well drilling expanded rapidly during the extended period of below average precipitation in the 1950’s. With an increasing number of wells in operation, the effect of well pumping on stream flow in the South Platte River became a growing issue.

A Colorado law enacted in 1969 requires that well users have available sources of augmentation water that could be used during times of demand to offset depletions to stream flow resulting from past groundwater pumping. The purpose of the law was to ensure that senior surface-water diversion rights would not be injured by the diversions of junior wells. In the early 1970’s, irrigators began to construct and operate artificial groundwater recharge systems. Return-flow credits from the recharge systems, along with releases from off-channel reservoirs serve as sources of augmentation water. A pair of Colorado Supreme Court rulings handed down in 2002 and 2003 dramatically changed the way in which the 1969 law was to be administered by the State Engineer’s Office.

One impact of the rulings was that the amount of augmentation water required to offset injury due to groundwater pumping was dramatically increased. To meet this increased demand, the rate of development of recharge systems rapidly expanded. A second impact of the rulings was that every well would need to be equipped with a totalizing flow meter. While many wells were already equipped with flow meters, a large percentage were not. Over a two year period, the

number of sites from which flow data needs to be accumulated and processed by the State Engineer's Office increased several fold. State budgetary issues have necessitated that this be accomplished without an increase in the State Engineer's Office staffing.

Prior to 2005, the overwhelming majority of open-channel flow measurement sites with flow recorders installed were equipped with paper chart recorders and nearly all pumps with meters were equipped with mechanical meters. Data handling for these systems requires extensive field travel for on-site data acquisition plus manual transfer of data records into digital format. Adoption of automated discharge data acquisition and transmission processes would significantly reduce the labor required to collect such data and speed up the availability of processed information. The water users and the State Engineer's Office are key stake holders which would benefit from such a system.

The LSPWCD was created to be the local management entity for Reclamation's Narrows project on the South Platte. This project was authorized in the late 1960's but was never funded. Since its inception, the District has played an active role in the full spectrum of water issues facing area users, including development and administration of augmentation plans and artificial recharge facilities. Beginning this year, the LSPWCD is providing a field office for the State's Division One River Commissioner at their office complex in Sterling, Colorado. An IC Tech base unit installed at the LSPWCD office is linked to a PC in the River Commissioner's office on which radio telemetered data is stored in a text file.

The SPDC developed one of the earliest (and most senior in right) artificial recharge projects which has been in operation since 1974. SPDC also holds the senior irrigation diversion right in Water District 64 on the South Platte River. As a result of these two factors, diversion activities are ongoing for much of the calendar year. This condition made SPDC an attractive partner for a demonstration test site. A second base station was set up at the home of one of the SPDC board members. This station enables the SPDC to independently monitor both flow conditions and performance of the telemetry system. It also provides a redundancy in storage of flow data from the 15-minute data-retrieval intervals.

DEMONSTRATION PROJECT INSTALLATIONS

The IC Tech units were initially installed at two measurement structures on the SPDC recharge project in early March, 2005. One was installed on a trapezoidal venturi flume identified as the G2 site. The second was installed on a contracted rectangular weir identified as the Sandhill site. Flow at both sites had previously been recorded on Stevens paper chart recorders. The Stevens recorder at the Sandhill site had been damaged by livestock during the summer of 2004 and was

not functional for the Spring 2005 recharge season. The Stevens recorder at the G2 site was operated to provide flow recording redundancy as the performance of the IC Tech equipment was being monitored.

Figures 1 and 2 show the SPDC G2 and Sandhill flow measurement sites. The IC Tech unit installed at the G2 trapezoidal venturi flume (shown in Figure 1) is mounted to the pole supporting the solar panel. The radio antenna is attached to the solar panel mounting bracket. An ultrasonic water-level sensor is installed over the center of the flume approach section approximately 2.5 ft above the flume walls. The existing Stevens recorder is mounted in the box atop the stilling well. Figure 2 shows IC Tech founder Jim Conley (on ladder) and SPDC Board Member Charles Bartlett installing a IC Tech radio/controller unit near the Sandhill suppressed rectangular weir.



Figure 1.



Figure 2.

The G2 site was equipped with an LA15 ultrasonic water-level sensor from Flowline. Ice is often a problem during the recharge season, and the SPDC selected the ultrasonic technology as an affordable sensor alternative which has no components in contact with the water. Sensor slope and offset values were field calibrated after installation. A stage-discharge table for the G2 trapezoidal venturi flume – apparently developed by the State Engineer’s Office – was provided by the River Commissioner. A fourth-order polynomial curve was identified that provided a near-exact fit to the rating table data. The curve equation was written into program code allowing the PLC to compute the discharge from the water-level sensor data.

The Sandhill site is located a few hundred feet from a well-traveled gravel road, (unlike the G2 site which is in a pasture almost a mile from the nearest public road). With the enhanced accessibility of the Sandhill site, both the River Commissioner and the SPDC expressed an interest in expanding the demonstration aspects of the site by installing two water-level sensor technologies. An LU05 ultrasonic sensor from Flowline was installed over the

weir approach flow and a Sutron SDI 12 shaft encoder was installed in the stilling well. At initial installation, depth of flow as determined by the shaft encoder was utilized for calculating discharge and totalized volume values. Flow depth calculations from both level sensors, along with computed discharge and totalized volume values for this site are written to polling registers for radio transmission of data.

The IC Tech base unit installed at the LSPWCD office is located in a communications closet at the rear of the office complex, as shown in Figure 3. From this location, information is passed via a previously unused telephone wire pair to a desktop computer in the River Commissioner's office at the front of the building. The antenna is mounted on a 10 ft mast attached to an outside wall adjacent to the communications closet. Figure 4 shows the antenna at the LSPWCD office. As mounted, this antenna is approximately 18 ft above the ground and appears to be at a lower elevation than the roof of a nearby building (seen at lower right in the background of Figure 4) which is in the line of the signal paths to both measurement sites.



Figure 3.



Figure 4.

The second IC Tech base unit is located at a SPDC Board Member's residence, approximately 1.5 miles from the Sandhill measurement site and 2.5 miles from the G2 measurement site. At both the LSPWCD office and at the SPDC Board Member's residence, the IC Tech base radio units are programmed to poll each of the field measurement sites at 15 minute intervals. This information is then passed to a personal computer where it is recorded to a text file on the computer hard drive. With both units independently polling and storing information, a redundancy in data storage exists.

To provide a further level of data storage redundancy, the flow level computed for each 15 minute polling cycle is datalogged on-site in the IC Tech units in MODBUS data storage registers. A date stamp is entered for the first polling cycle after midnight each day. As programmed, fifteen-minute water-level data is stored for more than 160 days before the oldest data begins to be overwritten.

The data stored in the IC Tech units may be accessed either by connecting a laptop computer to the field unit, or by use of polling commands entered into any remote IC Tech unit in communication with the site.

SPDC MAIN CANAL INSTALLATION

With the start of irrigation season and associated wind-down of the recharge season, the IC Tech unit installed at the SPDC Sandhill site was relocated to the upper measurement flume of the SPDC main canal on April 20, 2005. This allowed for continuous evaluation of the equipment both prior to and during the irrigation season. The water-level sensor installed at this site was the ultrasonic LU05 sensor from Flowline which had been used at the Sandhill site. The direct-path distance between the upper flume site and the LSPWCD office is approximately 20 miles, and no features of the town of Sterling (location of the LSPWCD office) are visible from the site.

DEMONSTRATION PROJECT PERFORMANCE OBSERVATIONS

IC Tech Data Radios

Availability of a suitable radio signal path was a primary concern during planning and equipment installation for the demonstration project. From the Sandhill site, only the tallest structure in the town of Sterling (a grain elevator) is visible. As seen in Figure 4, between the LSPWCD office and the SPDC field measurement sites, a nearby building presented an immediate line-of-sight obstacle. A further complication is that the LSPWCD office is in the northeastern part of Sterling while the SPDC is located southwest of town. The signal path crosses in excess of a mile of town including numerous structures and electrical transmission lines that would potentially impact radio signal transmission. The SPDC had made arrangements with a local wireless internet provider for temporary installation of a repeater station on a tower clearly visible from all project installation sites in the event that problems with radio signal reception were experienced.

At the initial power-up of the radio system on March 4, 2005, signal strength was measured between both of the field measuring stations and each of the base stations. The signal received at the LSPWCD office was found to be near the low end of the recommended range. The IC Tech representative assisting with installation suggested that putting the demonstration project in service without installing a repeater station would be appropriate for evaluating the performance of the IC Tech equipment under less-than-ideal conditions.

Over the first three months of operation, the data reception rate at the base stations was evaluated. The transmission routes of up to 20 miles between the SPDC recharge system field sites and the LSPWCD office (as expected) proved to have lower successful data transmission rates than rates observed at the closer

SPDC board member's home. During the time period from March 4, 2005, through June 6, 2005, there was an 88.6 % successful transmission rate with the LSPWCD office for signals from the G2 site, where the transmission path is obscured by a hill. For the period from March 4, 2005, thru April 19, 2005, there was a 99.3% successful transmission rate with the LSPWCD office from the Sandhill site. From April 27, 2005, thru June 6, 2005, there was a 99.6% successful transmission rate with the LSPWCD office from the SPDC Main Flume.

IC Tech Programmable Logic Control Units

The IC Tech control units – which are programmed using the BASIC 52 language – include features that make them versatile for a broad spectrum control applications on canal structures. The setup of Modbus registers allows simplified access to stored data and for viewing or changing program execution variables. The programming structure and the included features combine to make the training requirements needed to become functional with the IC Tech equipment comparatively straight forward. No operational problems were encountered with the IC Tech control units during the March 4 through June 6 2005 time period.

Associated Non-IC Tech Equipment

The primary non-IC Tech equipment in the demonstration sites include solar panels – which have given no indication of problems – and water level sensors. As stated above, an ultrasonic LA15 sensor from Flowline was installed at the G2 site. This sensor generally performed well. An apparent glitch in sensor output that was experienced on two occasions was later found to be the result of the control unit analog input circuits returning to default settings when the unit experienced momentary shutdown due to a detected surge (caused by lightning strikes in the proximity). The analog input default setting issue was easily corrected by adding two commands to the system initiation portion of the operating program.

At the Sandhill site, the original setup included a Sutron SDI-12 shaft encoder (provided by the State) as the primary unit and a Flowline ultrasonic LU05 sensor to provide a second level reading. Within the first few days of operation, problems were encountered with the shaft encoder. The problems seemed to be related to power connections internal to the sensor. By all appearances the unit would be without power, however checks using an electrical multi-tester showed full excitation voltage at the terminals on the IC Tech unit and at the plug connection coming into the shaft encoder.

After repeated toggling of the power switch on the Sutron unit, it would power up and remain functional for a period of time not longer than a day. After the first visit to investigate the shaft encoder shutdown, the primary-secondary

relationship of the two level sensors was reversed by editing the program code. Depth of flow derived from input from the ultrasonic sensor was utilized to calculate discharge and totalized flow. When the equipment from the Sandhill site was relocated to the SPDC main flume, only the LU05 ultrasonic sensor was transferred.

FEEDBACK ON IC TECH RADIO/CONTROLLER UNITS FROM OTHERS

On June 14, 2005, WRRL engineers were participating in a tour of canal systems with remote communications capabilities that included a visit to MRGCD in Albuquerque NM. MRGCD Hydrologist David Gensler, who is in charge of implementing MRGCD's ongoing modernization efforts, related that MRGCD is utilizing IC Tech equipment exclusively for its radio communications with field sites after having limited success with other radio equipment.

The MRGCD system features a repeater located atop Sandia Peak from which line-of-sight paths are available to field sites in the northern part of the district. Gensler stated MRGCD is getting "essentially 100% successful transmission rates" over distances of up to 70 miles. MRGCD is utilizing IC Tech radio/control units both for flow measurement sites as well as for locally-automated gate control. Gensler also noted that MRGCD is able to purchase the IC Tech radio/control units at approximately one-half the cost of control-only units available from the company from which they have been purchasing overshot canal gates.

FUTURE DEMONSTRATION PROJECT PLANS

For the 2006 season, the SPDC will add automation of spillway structure gates and monitoring of flow at a near-by lift pump to the tasks handled by the IC Tech unit installed at their main flume site. They also plan to install an IC Tech radio/control unit at their river diversion structure, located approximately 2 miles upstream from the main flume. Diversion structure gates will be automated to maintain constant diversion rates, despite fluctuations in river flow. The SPDC goal is to be able to send a flow set point to the unit monitoring the main flume and controlling the spillway. Then – based on this target discharge and on flow conditions at the spillway – this unit would generate set points for the diversion structure and wirelessly communicate set point changes to the diversion control unit.

The SPDC is also working on agreements with two neighboring ditch companies interested in independently performing flow monitoring and automated control tasks on their systems, while using a common radio frequency license and common data collection and data processing systems. Interest in this cooperative effort is the result of observations of the 2005 SPDC demonstration project made

by shareholders of the other districts. The districts have jointly applied for funding through the Colorado Water Conservation Board for a 2006 project expansion of the demonstration project.

SUMMARY AND CONCLUSIONS

Engineers at the WRRL are continuously seeking information on technologies needed for modernization of canal operations that represent enhanced value – either in terms of improved performance, or in terms of providing a similar performance level at lower cost. The demonstration project that is the focus of this paper is in a region facing critical needs for enhanced technologies for obtaining, transmitting, and distributing flow measurement data.

The demonstration project – set up with a limited budget – includes only IC Tech radio equipment. No inference in comparative performance between the IC Tech equipment and other commercially available radio systems is intended by WRRL based on the observed performances reported. Rather, the observations of this study simply suggest that the IC Tech radio equipment provided a promising level of performance under less than ideal conditions for radio signal transmissions. Based on these observations, IC Tech equipment offers intriguing potential as a cost effective communications and control alternative for SCADA canal operating systems.

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