COST-EFFECTIVE MONITORING AND CONTROL FOR IRRIGATION DISTRICTS

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ABSTRACT

Today irrigation districts across the United States face mounting challenges to maintain viable operations as facilities age, competing demands for water increase, urbanization spreads, and competition for quality employees is becoming an increasing concern. Issues commonly dealt with by irrigation districts – including weather events, actions of livestock or wildlife, and unintended impacts of human activity – may be unchanged in likelihood of occurrence, but may now represent potential for dramatically increased financial impact compared with historical episodes of similar nature.

Access to real-time knowledge of conditions at key locations, and the capability to remotely operate or adjust operations of control structures at key points in the irrigation delivery system can enable an irrigation district to increase delivery efficiency and quality of service, enhance staff productivity, and respond rapidly and effectively to unexpected events. Supervisory Control and Data Acquisition (SCADA) systems that provide these capabilities are being integrated into the operation of growing numbers of irrigation districts.

In most situations, availability of external funding has played the pivotal role in the feasibility for irrigation districts to consider SCADA. Reclamation's Hydraulic Investigations and Research Laboratory, together with Reclamation's Nebraska-Kansas Area Office, are working to develop monitoring and control systems that could be adopted by districts of any size which can offer affordability within normal operating budgets (i.e. reasonable acquisition and installation costs, installation, operation and maintenance performed by irrigation district staffs with minimal need for on-site technical support).

This paper examines the on-going effort to develop and refine this concept through case studies of two demonstration projects in Nebraska.

INTRODUCTION AND BACKGROUND

Staff at Reclamation's Hydraulic Investigations and Laboratory Services (HILS) Group has been providing technical assistance to irrigation districts that are incorporating electronic monitoring and control capabilities in cooperation with Reclamation Area Offices. Frequently, the projects we have become involved with represent an initial

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venture by a district at utilization of electronic control and communication equipment as part of their daily operations.

A focus of system planning and equipment installation in these projects has been to seek to maximize the inputs from district staff. As might be anticipated, a degree of commonality has been observed with respect to some of the basic desired functions identified by districts. From the perspective of overall system capabilities and modes of system operations however, there tends to be numerous unique aspects and preferences developed by each district which are reflective of a district's operational history and/or of a district's perception of its in-house capabilities.

Against this backdrop of experiences, the HILS staff have adopted a strategy of working to develop systems which districts will largely be able to operate, maintain and even to expand themselves with limited need for outside consultants or integrators. On repeated occasions we have encountered situations whereby "turnkey" installations – developed and installed by others with limited input by district personnel – have been turned over to districts and have subsequently become marginally successful systems at best due to differing perceptions between the district and contractors. This paper employs a case study format to examine two projects recently undertaken by the HILS staff at the Ainsworth Irrigation District and at the Twin Loups Irrigation District in cooperation with Reclamation's Nebraska-Kansas Area office.

AINSWORTH IRRIGATION DISTRICT PROJECT

Project Initiation and Financial Assistance Structure

Ainsworth Irrigation District is located in north central Nebraska. Ainsworth's water source is Merritt Reservoir , located south of Valentine NE which impounds water from the Snake River and from Boardman Creek. Working with matching grant funding under Reclamation's Water Conservation Field Services Program, this project represents an initial step in incorporating electronic monitoring and control into the District's operations.

General Project Features

This project includes monitoring/control equipment installed at the head of each Airport Lateral and Sand Draw Lateral, the District's two uppermost lateral systems. At the head of each lateral, the initial feature installed was a ramp-type long-throated flume. Stilling wells were installed at each flume site.

Airport Lateral Work at the Airport lateral was begun following the 2006 irrigation season with installation of the long-throated flume (seen below in Figure 1).. In spring, 2007 a solar-charged radio/control unit was installed at the flume house which district staff had constructed over the flume stilling well. The districted opted to install hard-wired connections between the flume house control unit and the lateral control gates located approximately 70 yards upstream.

Figure 1. Airport Lateral Flume Site

A shop-fabricated "float and pulley" level sensor utilizing a 10K ohm 10-turn potentiometer as the sensing element was installed at the Airport Lateral stilling well. The potentiometer provides a 0-5 volt DC analog feedback signal to the radio/control unit.

Two side-by-side vertical slide gates control flow into the lateral. Adjacent to the gates, a second solar-charging system was installed along with an enclosure that housed gate relay equipment and the 12 volt battery that supplies energy for the gate motors. The existing hand-wheel operated gates were motorized by installing a chain-drive system. A sprocket was attached to the underneath side of each hand wheel. Gear Motors (12V DC) equipped with sprockets were mounted to the gate apparatus frame in line with the hand-wheel sprocket.

Retaining the hand wheel, as opposed to replacing it with a sprocket, was done in order to enable simplified reversion to hand operation in emergency situations. A shop-fabricated gate position indicator utilizing a nylon gear and a multi-turn potentiometer was installed such that the gear teeth are meshed with the gate stem threads. Limit switches at the Airport Lateral site are tripped by adjustable paddles affixed to an auxiliary rod that was attached to the gate leaf. The gear motor and chain drive system installed on the left gate of the Airport Lateral headworks is shown in Figure 2. Figure 3 shows a gate position indicator unit with the drive gear teeth meshed with the threads of the threaded gate shaft.

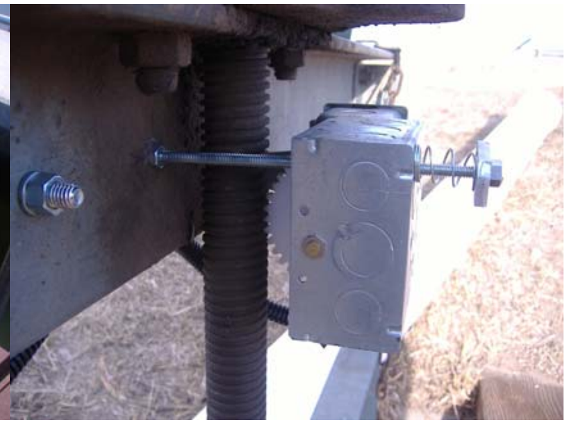

Figure 2. Chain Drive Gate Motorization Figure 3. Shop-built Gate Position Sensor

A bank of toggle switches was installed at the enclosure housing the gate relays. A two-position on/on selector toggle enables operation either in “manual” or “auto”. From the “manual” setting, power is routed to two three position on/off/on toggle switches, each of which is wired to raise or lower one of the canal gates. In the “auto” position, power is routed to the output circuit of solid state relays controlled by digital output circuitry of the electronic controller in the flume house. Wires from the individual gate toggles as well as outputs from the solid state relays are routed to the gate limit switches. Wires returning from the gate limit switches are connected to the coils of mechanical relays that ultimately control energy to the gate motors.

The control unit installed at the Airport Lateral Flume site featured a built-in 5 watt radio unit operating in the 450-470 MHz range. A yagi antenna was installed on a mast attached to the exterior of the flume house. The approximate antenna height is 14 feet. At the Ainsworth office, and omni antenna was installed at a height approximately 20 feet above the ground and 4 feet above the eave of the office roof. Radio path between the Airport lateral which lies approximately 8 miles west of Ainsworth and the District office which is approximately a mile east of Ainsworth is gently rolling terrain. Radio path with the respective antenna heights was not line-of-sight.

Office Base Configuration Signal was routed from the office antenna to a base radio/control unit equipped with display and keypad located in the District’s “ditch rider room”. The base unit was also connected via RS 232 serial linkage to a PC unit in the District Board Room adjacent to the Ditch Rider Room. Access to equipment in either the ditch rider room or the board room was considered important since the business office/board room area is typically open only during regular business hours. The ditch riders have access to the ditch rider room at all times.

The radio/control units installed at both the Airport Lateral flume site and the office base unit are CD 100 models manufactured by Control Design Inc. of Placitas NM. The CD 100 installed at the field site is configured as a bracket mount unit designed for installation in an electrical enclosure in anticipation that enclosure size would be selected to enable housing various associated components on a site-specific basis. The CD 100 unit used for the office base is configured in a plastic enclosure intended for use either as a mobile unit or a wall-mount unit. Figure 4 shows the Ainsworth base unit in the ditch rider room.

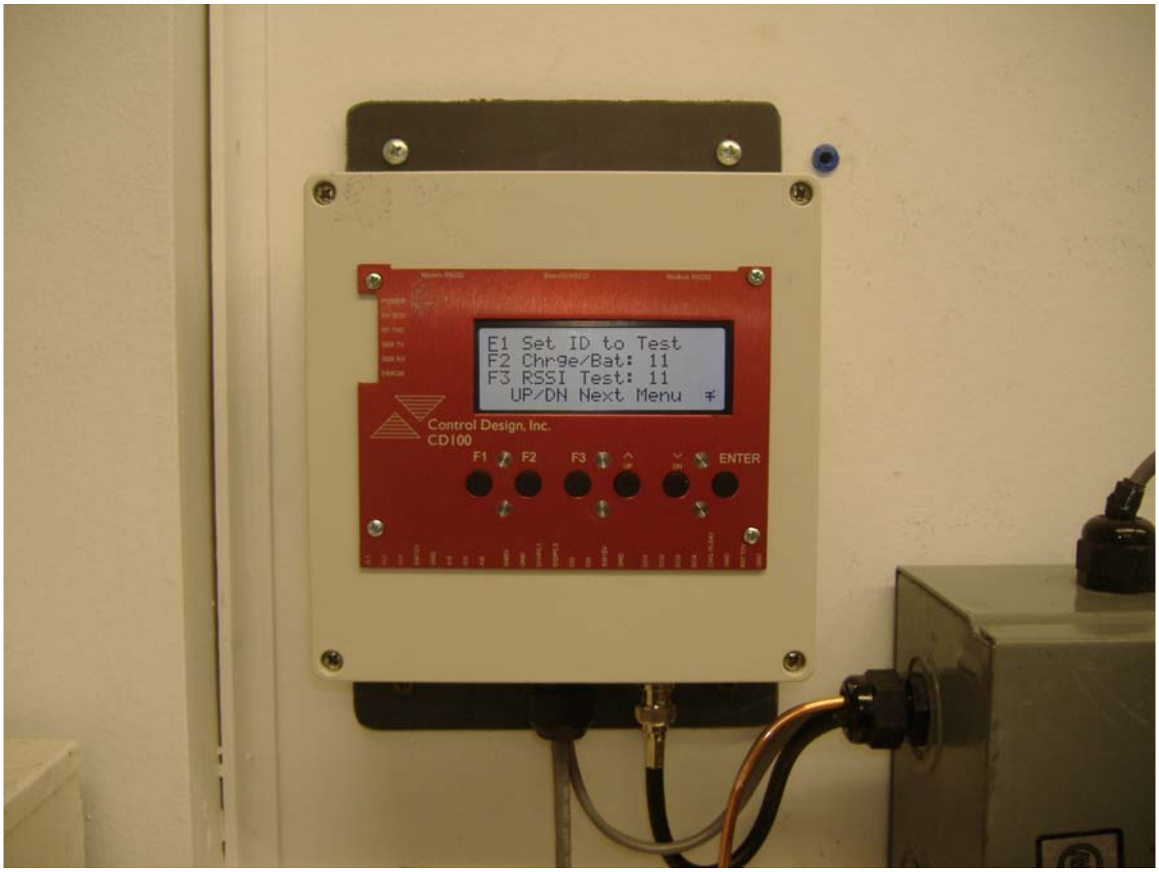

Figure 4. Ainsworth Base Radio/Control Unit in Ditch Rider Room

<u>2007 Ainsworth Project Operations</u> For the 2007 season, the District opted to operate using remote monitoring capability only. Gates at Airport Lateral were operated on-site using the toggle switches in “manual mode”. A program was installed on the controller at the flume house to read water levels on 3 minute poll cycles and calculate flow across the flume. Updated flow level and discharge information, along with a time stamp were written to Modbus polling registers every poll cycle. This information could be read on-site on the field unit display screen or it could be accessed using the base unit in the Ditch Rider room by following on-screen prompts on the base unit display. Information could also be accessed from the linked PC. During the 2007 season, the Airport Lateral ditch rider was able to obtain flow condition updates via cell phone from anyone with access to either the business office or the ditch rider room.

<u>Sand Draw Lateral</u> Following the 2007 irrigation season, the district began work on construction of a second long-throated flume. The new flume was installed at the head of the Sand Draw Lateral. Like the Airport lateral site, a stilling well was installed in association with the flume and a flume house constructed over the stilling well. A shop-constructed float & pulley level sensor similar to the unit at Airport Lateral was installed

at the Sand Draw stilling well. A Control Design CD 100 radio/control unit, along with a solar charging system, were installed at the flume house.

The distance between flume and gates at Sand Draw lateral is similar to the layout at the Airport lateral. A county road crosses the path between the Sand Draw flume and the gate site. The complexity of dealing with a road crossing coupled with a significant increase in price of copper wire from the previous year were factors that led the District to opt for wireless communications between the gate and flume sites at Sand Draw. To accomplish this, the District constructed a second structure as a control equipment house adjacent to the canal gates and installed an additional CD 100 unit.

Similar to the Airport lateral, two vertical slide gates provide flow control at the head of the Sand Draw Lateral. These gates were fitted with chain drive equipment in the same manner utilized at Airport Lateral. The limit switch installation was altered slightly from the Airport Lateral configuration. Instead of attaching an auxiliary rod to the gate leaf, paddles were clamped to the threaded gate shaft at locations that do not impact the range of gate travel. Limit switches were installed at locations that aligned with the paddles. The gate position indicator installed was a shop built gear/potentiometer unit similar to the one described for Airport Lateral.

<u>2008 Ainsworth Project Operations</u> Flow control algorithms were installed on the gate control units at both Airport Lateral and Sand Draw Lateral at the outset of the 2008 irrigation season. A target discharge value (in ft^3/s) is entered into Modbus register 7065. As the program sees a measured flow rate that deviates from the target by more than a pre-determined “dead band” amount, a gate adjustment is called for. For the double gate system at each site, if an increase in flow is needed the program first looks to see which of the gates is lower (less open) then raises that gate a targeted distance. Conversely, for a decrease in flow, the gate which is higher will be operated for incremental closure in a given polling cycle.

Adjustment of the target flow rate may be accomplished in any of three ways. Following on-screen prompts using the on-board six-button keypad, a target rate may be entered on-site. Using the wall-mounted office base unit a user must first select the ID number of the field unit which is to be adjusted. Following a menu-driven process, a user then selects the “Change Target” option. Similar to the on-site process, the current target is displayed. After the value has been modified to the desired new target, on-screen displays direct a keystroke that triggers a radio transmission that writes the updated value to register 7065 on the field unit. The other alternative would be to use the Control Design software package from the PC linked to the base radio/control unit. The field unit ID # is entered, and register 7065 is selected, followed by a “read” command using a button in the software. Once the read command has successfully executed the current value will appear in a window in the software. The desired updated value may be entered in the window followed by a “write” command using a software button.

One glitch reported by the District during the 2008 season occurred during a period where one of the laterals was shut down for a few days following a rainstorm. The automation routine failed to shut gates completely in response to a “0” target value.

Subsequently the District is utilized the manual toggles for complete shut downs, pending a revision of the automation code.

TWIN LOUPS IRRIGATION DISTRICT PROJECT

Project Initiation and Financial Assistance Structure

Twin Loups Irrigation District is located in east central Nebraska. Its primary water source is Calamus Reservoir formed by impoundment behind Virginia Smith Dam on the Calamus River near Burwell NE. Twin Loups has previously established flow monitoring sites with telephone linkage that allows remote monitoring of flow conditions. In a problematic segment of the conveyance system, a less-than-successful previous effort was made to locally automate a short open channel reach of the 6.1 Lateral that feeds into a pipeline. Funding for the present project is broken into two aspects. Automation of the 6.1 lateral is needed to mitigate a design shortcoming. Reclamation is providing full funding for control upgrade of the 6.1 Lateral open channel reach. A remote-monitoring/remote-operating capability for flow control structures on the upper reach of the delivery system are financed under matching grant funding through Reclamation's Water Conservation Field Services Program.

General Project Features

Work on the Twin Loups modernization project was initiated in November, 2007 following seasonal shutdown of the canal system. The 6.1 Lateral consists of approximately one mile of open channel that conveys flow to the entrance of a pipeline. All field deliveries are from the piped section. There is no ability to spill supply/demand mismatch excesses along the open channel reach. Equipment previously installed by Reclamation featured radio/control equipment at each end of the open channel section with local communications only between the two sites. This system had not performed reliably, as evidenced by at least one overflow event resulting in costly damages.

The cost-share component of the project includes two check structures, along with the reservoir outlet works and the flume in the upper reach of the delivery system, all managed by the Dam Tender. The Dam Tender manages releases from Calamus reservoir, along with approximately 16 miles of conveyance reach including the uppermost delivery turnouts on the system. The Twin Loups Irrigation District – which was dedicated in 1986 – is a comparatively recently developed system. As the conveyance system was laid out, an agreement was made to share a reach approximately six miles long with the pre-existing Taylor-Ord Irrigation District. This shared reach lies upstream of the uppermost farmlands served by Twin Loups.

As operations have evolved, the shared reach has essentially become a buffer for the Taylor-Ord system, due in part to Twin Loups comparatively larger proportion of discharge along this reach. Taylor-Ord flow entering the shared reach typically fluctuates significantly, while releases from the shared reach into the lower part of Taylor-Ord's conveyance have minimal fluctuation. In order to manage unpredictable inflow/outflow mismatches from Taylor-Ord, the Twin Loups Dam Tender has typically needed to make multiple daily trips back and forth along his ride which represents a one-way distance of approximately 30 road miles from the lower end of his ride back to the dam outlet.

Targeted capabilities for the component of the project at the upper end of the Twin Loups system was remote real-time monitoring capability for all file sites plus the ability to remotely adjust the reservoir outlet as well as the two uppermost checks. For the project overall, targeted capabilities included real-time two-way communication with all field sites from either the office base or from mobile units. Brief descriptions of installations at each project site are as follows:

Office Base A Control Design Inc. CD 100 radio/control unit was installed at the District Office in Scotia NE. A yagi antenna was mounted on the District's voice communications radio tower. The base radio was installed on the west wall of the District shop adjacent to a communications radio unit. An alarm generating unit was also installed in the vicinity of the two radio units. Wiring installed between the radio/alarm installation and the office space on the east end of the building links the CD 100 via RS-232 serial connection to a PC, and links the alarm unit to the District phone system.

Repeater A repeater radio unit & antenna were installed at the District's Geranium voice radio repeater tower located approximately 20 miles north of the Scotia office. An omni antenna was installed at this site to accommodate radio traffic from multiple directions. Radio signal path tests had confirmed that all field sites for the current project, as well as the District office could communicate effectively with the Geranium repeater site.

6.1 Lateral Control Design Inc. CD 100 radio/control units were installed at each end of the open reach of the 6.1 lateral. At the lateral head, the CD 100 was connected to operate an existing 24V DC gate actuator with latching relay controls. As part of the project, the crest of a long throated flume at the site was raised to eliminate frequently observed problems with excessive submergence. A shop-made float and pulley level sensor was installed at the flume stilling well. Wiring was installed to link the sensor to the CD 100. At the pipe entrance end of the 6.1 lateral a submersible pressure transducer was installed near the pipe entrance transition.

Calamus Reservoir Outlet Flow from Calamus reservoir into the Twin Loups delivery system is controlled by two hydraulically operated gates using an electrically powered hydraulic pump. Pre-existing controls were manually operated hydraulic valves. To accommodate operation through the radio/control unit, the manual operator on the left valve was replaced with an electric operator. A CD 100 radio/control unit installed in the valve house was wired provide hydraulic pump start/stop capability in parallel with existing manual controls. Controls for the electric valve operator were wired through a selector switch that enabled local manual operation of the gate using momentary push button switches or fully electronic operation controlled by digital outputs from the CD 100. String potentiometers installed on both outlet gates provide feedback to the radio/control unit.

Wireless communications with a Parshall flume located approximately ½ mile downstream was accomplished with installation of a CD 100 unit and antenna at the flume. For level sensing, a 10K ohm 10-turn potentiometer was attached to the shaft of a shaft encoder float& pulley level sensor which the Natural Resources District had previously installed at the flume stilling well.

9.5 and 13.4 checks Each of the two checks featured nearly identical existing equipment and setup. Both checks consist of a single radial gate flanked by concrete overflow weirs that are angled inward in the downstream direction. At both checks, the gate winches are powered by AC powered electric motors with a latching relay contactor. The notable differentiating factor between the two sites is that the 13.4 check site has stilling wells for measurement of both upstream and downstream water levels, while there is only an upstream level stilling well at the 9.5 check site. Figure 5 is a view of the 13.4 check from downstream.

Figure 5. 13.4 Check Structure

Figure 6. Gate Shaft Monitor

CD 100 radio/control units were installed with yagi antennas at each check. For each site, existing two-way selector switches (run/off) were replaced with three way selectors (hand/off/auto) in the AC electric controls. Normally open relays operated by digital outputs of the radio/control units were wired in parallel with the "raise" and "lower" momentary button switches of the AC electric controls. A normally closed relay operated by a radio/control unit digital output was wired in series with the "stop" momentary button of the AC controls. Shop-fabricated float & pulley level sensors were installed at each stilling well. A PVC pipe was attached to the canal lining downstream of the 9.5 check for installation of a submersible pressure transducer to sense the downstream level. Gate position sensing was achieved by attaching 10K ohm 5-turn potentiometers to the gate winch shafts. Figure 6 shows this shaft monitoring potentiometer installation.

Mobile Radio/Control Units The Twin Loups project included two mobile radio/control "ditch rider" units. These units were configured with the same plastic enclosure used for the wall mount base-radio unit at the Ainsworth ditch rider room. The ditch rider units were configured with cigarette-lighter plugs and magnetic-base antennas to simplify transfer of the units from vehicle to vehicle or from vehicle to the ditch rider's house.

One unit was provided to the Dam Tender and the other to the ditch rider whose ride included the 6.1 lateral.

2008 Twin Loups Operations Installation of equipment was on-going throughout the 2008 irrigation season at Twin Loups. The 6.1 lateral sites were the first locations brought into service. A program was installed at the 6.1 lateral gate to operate the gate to maintain a target discharge. At the pipe entrance site on the 6.1 lateral, a level monitoring program was installed in which the measured water level was recorded to a Modbus polling register each measurement cycle. From either the office base, or from a ditch rider mobile unit, both sites on the 6.1 lateral could be monitored remotely, and the target discharge at the gate site could be remotely adjusted.

Repeated difficulties were encountered in obtaining needed components for the electric operator for the hydraulic gate control valve at the reservoir outlet. This system was finally made operational late in the irrigation season. Equipment issues were also encountered with the 9.5 and 13.4 checks that prevented completion of installation tasks until after irrigation deliveries were shut down in September of 2008. All hardware is currently in place and functional and will be tested at t he startup of the 2009 season scheduled for late May.

Project Operational Goals

For the 6.1 lateral component of the project, algorithm modification for the pipe entrance location radio/control unit will utilize an observed water level change over a time interval along with channel geometry to calculate approximate discharge excess or deficiency. As the water level at the pipe entrance location is moves out of a “dead band” range the radio/control unit at the pipe entrance will be programmed to update the gate control target, based on the calculated discharge mismatch at the pipe entrance.

At times when, for what ever reason, water levels at the pipe entrance fall below/raise above predetermined minimum/maximum levels, the radio control unit at that site will generate and send out an alarm to the office base and to the mobile units. At the office, the base radio/control unit will be programmed to respond to an incoming alarm by keying up the alarm box it is connected to. The alarm box has been programmed to forward an alarm message through both the District voice radio system as well as to pre-selected phone numbers.

The District’s present objectives for the reservoir outlet and for the 9.5 and 13.4 checks is to remotely monitor conditions and to be able to remotely adjust flow control equipment at each site. For the reservoir outlet the radio/control unit at the Parshall flume will calculate the discharge rate at regular polling intervals. The radio/control unit at the flume will communicate with the unit at the reservoir outlet gate house and update the discharge rate stored in a Modbus polling register. When polled from a remote site, current vertical gate position of each gate as well as the current discharge rate may be obtained with a single inquiry. The Dam Tender will utilize this information to determine whether to make a gate change, and if so will determine a new target vertical gate opening. Using on-screen prompts and the six-button keypad on a mobile unit, an updated gate target may be wirelessly written to the reservoir outlet gate unit.

For the checks, programs have been installed on the radio/control units that monitor gate opening along with the upstream/downstream level differential to calculate discharge flowing under the gate, plus approximate flow rate over the weir walls. Upstream and downstream water levels, measured flow rate passing the check and current gate position values are written to Modbus polling registers in the on-site radio/control units to be available for query from the base or a mobile unit. This information will be utilized by the Dam Tender to identify any desired adjustment in target gate opening. As with the reservoir outlet, a new gate position target may be remotely entered for either check from a mobile unit or from the office base.

SUMMARY

Both the Ainsworth and the Twin Loups districts have opted to approach canal modernization with an incremental start. The features included in the in the initial project scope of each district could be readily assimilated into a broad-scope SCADA operation as the respective districts opt to expand their systems. A focus of Reclamation's involvement in each project was to seek to maximize the opportunities for use of "in house" resources irrigation districts could utilize in planning and installation of canal modernization equipment.

In follow-up efforts, Reclamation is working to provide training that will enable districts to develop a level of in-house capability with operations and trouble-shooting their systems to a degree that long-term operations can carried out in a cost effective manner with minimal need to hire specialist technicians to deal with equipment failures and system glitches that become a part of incorporation of electronic control and communications capability in a system. A training workshop held February 3-5 in Hot Springs SD was attended by personnel of Ainsworth and Twin Loups districts. (Also in attendance were personnel from irrigation districts from North Dakota, South Dakota, Colorado, and from the Republican River basin in southern Nebraska).

Costs of a modernization system can only be fully accounted for after multiple seasons of operation when issues unanticipated at the project outset can be looked back on in terms of staff time costs plus costs for equipment upgrades and replacements plus technical assistance that has been required. Up-front costs for systems installed at both Ainsworth and Twin are quite reasonable when compared with almost any projects of similar scope we are aware of. Neither Ainsworth nor Twin Loups has made any sacrifices in desired functionalities. To the contrary, some of the capabilities that are being developed as part of the Twin Loups system will be fairly unique. To the extent that these systems exhibit performance over time to the levels of reliability and functionality expected, the Ainsworth and Twin Loups projects will provide credence to the concept that incorporation of electronic control and communications equipment can be cost effective for a wide range of irrigation systems.

DISCLAIMER

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