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The Dolores Project: Efficient Irrigation Water Delivery Using Automated Control

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Abstract

This paper discusses project features, control system equipment, and software that make the Dolores Project a showcase of modern water control technology. Built by the Bureau of Reclamation, the project delivers irrigation water through canals, pumping plants, and pressure pipe distribution systems. Project features have been designed to provide water users with a flexible and dependable water supply that will maximize project benefits while conserving water.

The water conveyance network is controlled using a Programmable Master Supervisory Control (PMSC) system that implements the latest monitoring and control technology. The PMSC system has the capability to manage system-wide operations from a central site and download control commands to remote terminal units (RTU) at field sites. Operations personnel have been using the PMSC system since 1992 to monitor and control remote pumping plants and canal check gate structures from the master station. Over that period, the project has achieved water delivery efficiencies of better than 96% (96% of the diverted water reaches the farms) compared to typical values of 80-90% on other canal projects.

Project Description

The Dolores Project, located in the Dolores and San Juan River Basins in southwestern Colorado, develops water from the Dolores River for irrigation, municipal and industrial (M&I) use, recreation, fish and wildlife, and production of hydroelectric power. Irrigation water is diverted from McPhee Reservoir into two main irrigation canals: Dove Creek Canal and Towaoc Canal.

Water for the Dove Creek area is pumped by Great Cut Pumping Plant and conveyed 53 km (33 mi) through Dove Creek Canal and its 11.3-km (7-mi) branch, South Canal. Dove Creek and South canals have a total of 34 gated check structures (cross regulators) and 14 inverted siphons. Water is delivered from Dove Creek Canal and South Canal through six canalside pumping plants that supply seven pipe distribution systems for sprinkler irrigation.

Water for the Towaoc area is conveyed 71 km (44 mi) through Dolores Tunnel, Dolores Canal, Towaoc Canal Powerplant, and Towaoc Canal. Towaoc Canal is 63.6 km (39.5 mi) long with 27 gated check structures, 167 turnouts, and numerous siphons and drop structures.

Project Operations

The primary goal of project operations is to meet delivery needs of the water users. Canal flows must match turnout demands and water levels must remain high enough to supply all turnouts plus steady enough to maintain a constant delivery through gravity turnouts into open laterals. Additionally, canals are operated to prevent rapid water level drawdown that can damage canal lining. Maximum allowable drawdown rates are 15 cm (6 inches) in any 1 hour period or 45 cm (18 inches) in 24 hours. Although the canals have wasteways to spill excess water during emergencies, operators try to eliminate spills during normal operations.

Deliveries to water users are scheduled 24 hours in advance. These schedules are used to predict flow through canal turnouts, check structures, pumping plants, and Towaoc Canal Powerplant. If necessary, schedules are arranged (requested delivery times are modified as required) to smooth system operations, to prevent excessive flow changes, or to keep total demand from exceeding conveyance capacity.

In the Dove Creek area, each canalside pumping plant responds automatically to downstream demand in the associated pipe lateral system(s). Variable-speed motor controllers adjust pump flows based on pressure in a hydropneumatic tank on the pumping plant discharge line. As sprinkler systems turn on and off, the associated flow changes are passed on to the canal through the pumping plant and canal turnout. In the Towaoc area, gravity pressure pipe laterals pass delivery flow changes directly to the canal through turnout structures. All pipe laterals have pressure reducing/sustaining valves to maintain line pressures within a desired range.

Because the primary goal of the Dolores Project is to meet water user needs, canal operations are demand-oriented. Canals are operated to satisfy downstream conditions by adjusting upstream flows. Inflows are adjusted to match outflows and/or to correct downstream canal water levels.

Control System

The Dolores Project has a supervisory control system called a PMSC (Programmable Master Supervisory Control) that provides both automatic and manual control capabilities for the water conveyance and delivery system. The PMSC is a computer-based system that includes data collection, database management, communication, monitoring, operator interface, and remote control of canal gates and pumps. The Dolores PMSC system has one master station and 94 remote terminal units (RTU).

The master station performs the function of collecting data from each remote site, manipulating the data, and presenting data in a useful format for operations personnel. Human operators and software in master station computers determine control actions and telemeter control commands to the RTU's. Master station equipment includes central processor unit (CPU) computers, independent communication processors, disk storage units, backup storage devices, printers, operator work stations, modems for communication with RTU's, an uninterruptable power supply (UPS) unit with transient-protected output, a power line conditioner, testing equipment, and other associated hardware components. Software programs at the master station provide monitoring, control, and diagnostic functions.

The primary functions of the RTU's are to monitor system status (analog data), to telemeter these data to the master station, to perform remote manual open-loop control on command from the master station, and to perform closed-loop functions (e.g. local automatic gate control). An RTU is located at each pumping plant, powerplant, check structure, and several other selected sites. Each RTU provides monitoring and control capabilities for the site where it is installed. Each RTU contains microprocessor hardware, an operator's panel, a power supply, a battery with charger, an input/output (I/O) multiplexer, data acquisition and control equipment, a communications network with at least one modem, and other miscellaneous RTU equipment. All inputs to each RTU (power, status inputs, and control inputs) are optically isolated to protect RTU hardware from electrical transients.

RTU software provides interfacing between the master station, the RTU, and the control equipment at each site. Additionally, all check structure RTU's contain three local feedback control algorithms: P+PR, Colvin, and RTUQ. P+PR and Colvin are upstream water level control algorithms. RTUQ is a gate-flow control algorithm that automatically maintains a target flow through the check structure. Based on empirical gate flow relationships developed by Buyalski [1], RTUQ uses water level and gate position data to compute check structure flow, and adjusts gate position to achieve the desired flow.

The Dolores Project communication system has data communication channels that provide two-way data telemetry between the master station and all RTU's. Most RTU's are provided with primary and backup communication links. Data transmission media consist of dedicated metallic and fiber optics circuits.

Automated Monitoring and Control -- Implementation

Water conveyance features for the Dove Creek area were completed in 1991 and control system operation began in 1992. By 1995, most irrigated lands in the Dove Creek area were in service and canal flows were approaching capacity during the peak of the irrigation season. Towaoc area features were completed in 1995 and the PMSC system became operational for the Towaoc area during the 1995 irrigation season.

Operations personnel have been using the PMSC system since 1992 to monitor and control the Dove Creek area from the master station. Automatic data collection, communication, and display allow operators to monitor past and current conditions throughout the canal system. Data from each RTU is telemetered to the master station and stored in a central database. Using this data, software creates graphical displays on CRT monitors at the operator workstations. Operators can select from a number of display options that show water levels, flows, gate positions, pumping plant conditions, and alarm status.

In general, the monitoring system has performed well. Operators have been able to stay abreast of all important information and conditions. System redundancy has prevented down time; when problems have occurred with system components, failover to backup systems has kept the PMSC on line. Some problems have occurred with communication between the master station and Dove Creek Pumping Plant, which is the most distant site in the Dove Creek area. Often, successful communication with this site requires repeated attempts. These problems have resulted from signal attenuation due to transmission length exceeding the communication link's capacity. (Manufacturer's data used in the design overestimated maximum transmission length.) Designers learned from this situation and avoided these problems in the Towaoc area.

During the first few years of operation to date, operators have been relying primarily on supervisory manual control of canals in the Dove Creek area. Based on delivery schedules and real-time data, operators at the master station have been controlling pumps at Great Cut Pumping Plant and adjusting check gates in Dove Creek and South canals to maintain flows and water levels throughout the area.

An operator is on duty at the master station 24 hours a day. Operations personnel have been very successful in maintaining deliveries and canal water levels during the first few years of operation. Water delivery efficiencies of better than 96% have been achieved, including seepage and evaporation losses. As the Towaoc area becomes developed, manual control will become increasingly difficult. Operators may become more dependent on automatic control software to help them manage the system.

The two local automatic water level control algorithms (P+PR, Colvin) installed in check structure RTU's have been used to supplement the supervisory manual control. These algorithms are able to maintain a nearly constant water level immediately upstream from a check structure. This upstream-oriented operation is useful at selected checks, and performs well. However, upstream-oriented operation is not appropriate for all checks because of the system-wide priority on downstream demand.

RTUQ has been implemented at check structures in the Dove Creek area, with limited success thus far. Control is stable and accurate at some check structures but problematic at others. Good performance requires accurate check structure dimensions, water level and gate position sensor calibrations, and gate discharge coefficients. Errors in any of these parameters can degrade controller performance. RTUQ accurately computes radial gate coefficients, but slide gate coefficients need additional development. At some check structures, sedimentation may change structure hydraulics enough to require recalibration.

Software at the master station includes a global control algorithm called DPMP (Dolores Project Modeling Package). Supervisory automatic control using DPMP has not yet been implemented or tested for real canal operation. DPMP is designed to create flow schedules based on system-wide status and download these schedules to check structure RTU's, where program RTUQ will adjust individual gates. Because all structures are not yet operating successfully with RTUQ, operators have not attempted to put DPMP into service. Additionally, supervisory manual control has been working quite well so far. Manual control will become increasingly difficult as the Towaoc area becomes fully operational, so operators may see more need for DPMP.

System Modifications

Based on operating experience, some control system features have been changed from the original design. The most significant modification has been replacement of water level indicating equipment in the Dove Creek area. Originally, float and encoder equipment was installed to measure water level in float wells upstream and downstream from each check structure. A number of problems were experienced with this equipment, so it was replaced with pressure transducers. Except for the water level measurement at McPhee Reservoir, which has a 30 m (100 ft) range of measurement, all water levels in the Dove Creek and Towaoc areas are now measured with pressure transducers.

Pressure transducers have proven to be more dependable and easier to install, calibrate, and maintain than the float/encoder assembly. Also, the 2-wire transducers are more easily protected from electrical transients than the 12-wire encoders. Modern transducers are able to provide the same 0.3 cm (.01 ft) resolution as the encoders. A potential problem with transducers is moisture in the interface enclosure. At Dolores, interface equipment is in a small box inside the float well, which is a damp environment. A good seal and desiccant (moisture absorbent) inside the box prevents moisture problems.

Dove Creek RTU's contain EPROM (erasable, programmable, read-only memory) modules that store programs such as local control algorithms. Any software changes require "burning" a new EPROM for the RTU with a special piece of equipment that installs the new software into an EPROM, then replacing the RTU's old EPROM with the new one. Towaoc RTU's have battery-backed RAM (random access memory) modules instead of EPROM's. Programs can be changed easily by downloading software into the RTU from a portable computer. This technology advancement has greatly improved operators' ability to update RTU software.

Another modification since initial system installation has been the enhancement of graphical data displays for operator workstations. As anticipated during design, these displays have been improved to meet operator needs. It is important that supervisory control systems be designed to allow this type of ongoing enhancement, so operating personnel can customize their work environment.

Conclusions

In its first few years of operation, the Dolores Project has shown many of the benefits of a modern automated irrigation project. Water deliveries are flexible and dependable, with conveyance efficiencies exceeding 96%. However, full potential has not yet been reached. Some of the project's new features and innovations may not be fully developed or tested for several more years, so it is difficult to evaluate their success now. Based on project experiences to date, some conclusions can be drawn:

- Supervisory manual control is highly valuable. Even without automatic control algorithms, the ability to monitor system-wide data and control all key structures from a central site yields significant benefits. In most cases, a competent operator can do an excellent job of managing the canal system when given these tools.

- Simplicity is almost always a benefit. Program RTUQ was intended to simplify supervisory control by allowing centralized decisions to deal directly with flow rates. To do this, data and software requirements at each check structure RTU became more complex. With complexity comes more opportunity for problems. Operations personnel have been burdened with calibrating the numerous parameters required for accurate performance.

- Dependability is more important than sophistication. If control system components are not dependable, all other measures of performance are unimportant. Even though they had met stringent specifications for measurement precision, most of the water level sensors originally installed in the Dove Creek area had to be replaced for lack of dependability.

- As with most projects of this type, system development must continue through several years of operation. Canal operators must continue the job started by designers and installation contractors, but day-to-day problem solving always takes priority over long-term development.

- The primary measure of success is effective and efficient water delivery. Water users are happy if they get their allotted water with a minimum of restriction, regardless of the methods used by system operators.

References

[1] Buyalski, C. P. (1983). "Discharge Algorithms for Canal Radial Gates". *Publ. REC-ERC-83-9*. Bureau of Reclamation. Denver, Colo.