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INTRODUCTION

As the demand for water increases, there is a growing need to improve the operating efficiencies of water conveyance systems. Many modern water systems must provide timely deliveries to customers with little or no waste of water and power. In much of the Western United States, irrigation represents about 85% of the total water resource demand. Modern irrigation practices require greater delivery flexibility than in the past. Often, canals require automatic control systems to optimize operations and provide greater delivery flexibility to water users.

In recent years, the rapid advancement of automatic control equipment has greatly expanded the field of canal operation and control. **Automation** has become a common term in discussions of modern canal systems. The improved operations afforded by an automated control system have many benefits, including increased crop production, reduced water use and waste, improved service to water users, and better response to emergencies. Buyalski (1979) found that automatic control applied on the Corning Canal in California resulted in benefits exceeding costs by a factor of two.

According to Bos and Nutgeren (1978) manually controlled canal systems have an overall efficiency of about 40%, exclusive of the use of any return flows. Clemmens (1986) states automation can increase canal operating efficiency 10% or more. In addition, Merriam (1987) found that farmers can see an increase of 15% or more in crop yields.

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UPGRADING EXISTING CANAL SYSTEMS

Many opportunities exist for the operation of existing canals to be upgraded by addition of automatic control systems. Control system planning begins with a description of project objectives. Specific expectations and goals should be identified so that the control system can be customized.

Physical characteristics of the existing canal system will limit operation and control possibilities. Constraints created by existing canal features need to be evaluated. For example, the size of the canal prism limits the maximum allowable flow, the amount of flow change and depth fluctuations. The amount of in-channel or off-channel storage can greatly affect the operations of a canal. Other important features include check structures, turnouts, wasteways, and pumping plants.

Operating criteria should be established to create an efficient match between the canal system's capabilities and the operational requirements. One should begin by analyzing the present canal operations, and then pursue alternate methods which would improve operational efficiency. The method of operation should be selected before one designs a control system. Then, local automatic control and supervisory control alternatives can be studied to define specific functions of the control system equipment.

An existing canal system may require structural modifications and additional equipment to accommodate a change in control method. Preparatory details include site investigations, operation studies, and equipment considerations. At this stage, the upgrade feasibility can be studied. Feasibility is based on the estimated costs of the new control system and the benefits achieved.

When project feasibility has been confirmed, final design details are prepared. Specifications are written for procurement, installation, and acceptance testing of the control system equipment. On-site preparations will update or modify the canal facilities as required to interface with the new control system. Then, control equipment is installed, calibrated, and tested. To ensure the equipment will operate as designed, testing is required before and after installation. After it becomes operational, equipment must be properly maintained to keep outages to a minimum.

OPERATION STUDIES

Computer simulation studies are required to optimize the operation of complex canal systems. Studies are necessary to evaluate and verify the different methods of operation and control for various flow conditions. A canal system without wasteways or re-regulating reservoirs has little margin for error when flow is near maximum capacity. Control during abnormal and emergency conditions is critical. The evaluation, selection, and development of complex control techniques requires analysis with mathematical models. Operation studies should include:

- Selection of control parameters for local automatic controllers.

- Development of supervisory control strategies and procedures for off-peak pumping, and abnormal or emergency operations.

- Evaluation of the canal system design--such as the type and location of check gate structures, wasteways, and storage facilities--to improve response and recovery characteristics.

- Evaluation of alternative delivery concepts; e.g., testing the effects of different turnout flow changes on the overall canal operations.

- Development of mathematical models that predict water supply and demand and optimize pump/generating schedules for complex canal systems.

Computer simulation of local canal controllers allows the operator to predetermine control constants, deadbands, and time delays before installation. Computer studies save trial and error in the field at the potential expense of the canal. A combination of technical expertise and practical experience is required to conduct operation studies properly and to develop the requirements and specifications for the control equipment.

AUTOMATION REQUIREMENTS

Preparing a canal system for control equipment installation may require modifications such as check gate motorization. The addition of water level measurement equipment and enclosures for control equipment will also be required. Figure 1 is a typical microprossor based RTU (Remote Terminal Unit) installed on a canal check structure.

Figure 1 - Microprocessor based Remote Terminal Unit

Control equipment requirements vary with the method of control. **Local automatic control** involves monitoring and control of a remote site by on-site equipment without human intervention. Modern canal-side controllers are microprocessor based, similar to a personal computer. Typically, each remote site has an RTU that performs the functions of data collection, communication, and control. Local automatic control systems often include a one-way communication channel to transmit alarm signals to a central site, alerting operators of potential problems.

The RTU must interface with analog or digital sensors. Depths, flows, and gate positions are monitored and converted to digital data. RTU operations are defined by a set of logic and mathematical statements known as a control algorithm. Algorithms receive and interpret data and compute appropriate control responses. A microprocessor RTU can function as a local automatic controller or as part of a supervisory control system. **Supervisory control** involves monitoring and control of the canal from a central site, giving the operator a global view of the entire canal system. Data from the RTUs are communicated, stored, and displayed graphically at the central site for use by the operator.

Different levels of supervisory control range from manual to automatic, with varying degrees of operator intervention. **Supervisory manual control** essentially transfers the duties of the ditchrider to the central site. An operator at the central site controls check gates, pumps, and sometimes turnouts throughout the canal system. **Supervisory automatic control** allows certain control functions to be performed automatically at the central site or RTU. **Supervisory computer-directed control** uses comprehensive central computer programs to calculate and carry out complex control functions involving more than one RTU site.

Supervisory control requires a master station. The master station is a computer-based system that serves as a communications controller, system data base, and operator control center. Typically, the master station has a 16- or 32-bit computer for data handling, monitoring, control functions, and communications. Alarms are provided to alert operators to abnormal conditions such as high or low water levels, power loss, loss of communications, or intrusion. Supervisory control software is an an expensive component of the system.

A combination of supervisory and local automatic control allows the central site operator to make changes only when needed. Small flow mismatches can be controlled automatically at the individual remote sites, independent of the master station. When the local controller is unable to maintain adequate control, an operator can intervene using supervisory control.

A communication system is required between the master station and the RTUs located at the remote sites. The communication system allows two-way transmission of digital data. Possible types of communication systems are metallic cable, single channel VHF or UHF radio, or fiber optics.

Control equipment must be tested before it is installed on the canal system to ensure that it performs as specified. After control equipment is installed, it needs to be performance tested to ensure calibration, interfacing, and communication are correct and will perform adequately.

Eventually, control system equipment will require maintenance, recalibration, and repair. A preventive maintenance program must be initiated upon installation. A good preventive maintenance program will keep equipment failures and outage times to a minimum. An inventory of spare parts and components will aid timely repair. Periodic testing and examination of equipment should be scheduled.

Qualified technical expertise and training are important basic requirements. Local automatic and supervisory control methods require technical expertise to implement and maintain a successful control system. Operator training should be provided to familiarize operations personnel with control hardware and software. A critical requirement is the formulation of standard operating procedures for a canal, such as startup and shutdown procedures and maximum allowable water level fluctuations in the canal.

CONCLUSIONS

Canal automation can be an expensive venture, but worthwhile. The feasibility of a new control system depends in large measure on judgment. Often the tangible benefits--benefits that have a clearly defined dollar value--are less than the cost of the new control system. Usually, intangible benefits--those benefits whose dollar value is difficult to assess--will make control system implementation worth the endeavor. Canal automation will be discussed in more detail in Reclamation's Canal System Automation Manual (1990, 1991).

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