WATER DELIVERY SYSTEM AUTOMATION ON CANADIAN RIVER PROJECT

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Introduction

A review of the proceedings of several previous conferences treating with automation of irrigation and drainage systems reveals that very little has been said concerning the automation of pipe systems. Literature available on this subject generally discusses complex municipal water systems which are beyond the scope of most irrigation and drainage systems. While the Canadian River Project described in this paper delivers only municipal and industrial water, the remote supervisory and automatic control concepts incorporated in this 322-mile aqueduct are directly applicable to pipe irrigation systems. The Bureau of Reclamation has in operation several small irrigation systems which incorporate these concepts. However, the Canadian River Project serves as a better vehicle for describing several types of system automation than do these small irrigation systems.

The Canadian River Project, located in the northernmost part of the State of Texas, serves water from Lake Meredith on the Canadian River to 11 cities in that State which have a combined population of about 375,000 people. Extensive groundwater pumping in the area for irrigation and for municipal and industrial supply threatened to deplete the available supply so that it was necessary for the cities to seek a more reliable water supply. Under the laws of the State of Texas, 11 cities organized the Canadian River Municipal Water Authority which contracted with the Bureau of Reclamation to design and construct the project with repayment of the reimbursable costs to be made by the authority. The project was completed in 1968 and was transferred at that time to the authority for operation and maintenance.

Principle features of the project include Sanford Dam on the Canadian River, which forms Lake Meredith, and a 322-mile aqueduct system. The aqueduct system includes 10 pumping plants, three regulating reservoirs, and numerous appurtenant line and terminal structures. The pipelines vary in size from 96 inches down to 10 inches in diameter. The entire water conveyance system is remotely and automatically controlled.

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Untreated water is delivered to four of the cities: Borger, Pampa, Amarillo, and Plainview. The water supply for the other seven cities (Lubbock, Slaton, Tahoka, O'Donnell, Lamesa, Levelland, and Brownfield) is delivered first to a central treatment plant at Lubbock. The treated water is reinjected into the aqueduct and delivered to the seven cities through the remainder of the aqueduct system.

For purposes of identification, the aqueduct system has been divided into three main divisions designated as the Northern, Central, and Southern Systems (see Figure 1). The Northern System, extending from Sanford Dam to Amarillo, also includes the East Aqueduct, a branch which serves Borger and Pampa. The Central System extends from Amarillo to Lubbock, and the Southern System includes the remainder of the Main Aqueduct and the Southwest Aqueduct. These three systems represent three basic types of hydraulic design and operation for water conveyance pipelines, namely: a pumping system (the Northern) comprised of several lifts; a gravity-flow pool system (the Central); and a gravity-flow pressure system (the Southern).

Northern System

The Main Aqueduct of the Northern System delivers water from Lake Meredith to Amarillo Regulating Reservoir. Four pumping plants situated along this 35-mile reach of aqueduct are required to lift the river water to the regulating reservoir. The lift varies from 655 to 800 feet, depending on the level of Lake Meredith. The Amarillo Reservoir is the highest point on the aqueduct system. Pumping plant No. 2 (Main Aqueduct plants are numbered consecutively from Lake Meredith) is operated by remote supervisory control, but it is also subject to certain semiautomatic operations to cope with emergency conditions. Pumping plants Nos. 1, 3, and 4 are fully automatic.

The availability of energy for driving the prime movers for the pumps had much to do with the aqueduct system's design and the selection of its plan of operation. There was an abundant supply of low-cost natural gas available in the area but not an abundant supply of low-cost electrical energy. However, the possibility of using off-peak electric power for pumping coupled with lower first cost and lower maintenance costs of electric prime movers were favorable considerations for electrical energy. Each of the four pumping plants in the Northern System has five equal sized pumping units. The size of each unit is pumping plant No. 1 is 1,750 horsepower; and pumping plants Nos. 2, 3, and 4
MAP OF MAJOR SYSTEMS

FIGURE 1
PROFILE - NORTHERN SYSTEM

FIGURE 2
are 1,250 horsepower. One unit in each plant is used for standby; the maximum connected load is 23,750 horsepower (since all five units at pumping plant No. 1 can operate when lake level is low). The energy source must, of course, be capable of handling the peak load requirement even if such load occurs only once a year for a short period of time. It was apparent that the pumping plants would impose a heavy load upon the local electrical power system; however, it was also recognized that electrical energy would be available at a lower cost provided that pumping was curtailed during periods of peak energy requirements for other purposes.

Studies were made to select the most economical alternative of several plans. These plans considered both gas- and electric-driven prime movers, continuous or off-peak pumping, and various aqueduct pipe diameters and related capacities of the Amarillo Regulating Reservoir. The plan selected as a result of these studies provides electric prime movers with off-peak pumping, allowing the power company (Southwestern Public Service Company) to control the time when the pumps are running. It is also possible for the power company to shut off the pumps during an emergency situation on its power system. However, they are obligated to pump up to 95 percent of the time when necessary to meet the demand.

Operation of the Northern System is keyed to maintaining an aqueduct supply of water in Amarillo Regulating Reservoir (750 acre-feet capacity). This is accomplished by remote supervisory regulation of the pumping units in pumping plant No. 2, and related automatic operation of the other three plants. Pumping plant No. 2 was initially controlled by the power company from its central power dispatching office in Amarillo. Subsequently, the operating system has been modified to permit remote control of this plant by the Canadian River Municipal Water Authority from its office near Sanford Dam. The schedule for pumping is provided to the authority by the power supplier to achieve the water requirements estimated by the authority. The change was necessary to eliminate excessive cycling of the pumping units.

Pumping plant No. 1 lifts water from Lake Meredith and discharges a design flow of 183 second feet through about 2 miles of 78- and 72-inch-diameter pipe into Forebay No. 2. Forebay No. 2 is a small concrete-lined reservoir which contains float switches for automatic start-stop operation of units at pumping plant No. 1. It also contains float switches that automatically shut down two units of pumping plant No. 2 for low-water conditions in the forebay and restarts the units when the problem is corrected. The East Aqueduct, which is automatically controlled by downstream demand, also bifurcates from Forebay No. 2. The capacity
of the Main Aqueduct from this forebay to Amarillo Regulating Reservoir is therefore reduced to a design capacity of 160 second feet.

Pumping plants Nos. 3 and 4 are also preceded by small concrete-lined forebays which contain float switches for automatic operation of those plants. The float switches operate automatically at specified elevations in Forebays Nos. 3 and 4 to initiate starts and stops of units in the adjacent pumping plant according to the rise or fall of the forebay water level. High- and low-water-level float switches are provided to activate alarms which are indicated in the control headquarters and for emergency shutdowns of the next upstream and adjacent pumping plants. Automatic "reset" and "restart" are provided for a low-level shutdown; however, a high-level shutdown requires manual onsite reset of the affected float switch.

Following a power interruption, units in pumping plants Nos. 1, 3, and 4 restart at set time intervals by use of automatic timers. Units at pumping plant No. 2 must be restarted from the control station at specified times related to the automatic operation of other units. These features and procedures for restart are required to prevent undue dips in voltage and resultant electrical transients in the power system. Further, the starting sequence limits hydraulic surges in the pipeline.

The aqueduct system is designed to prevent draining the pipeline due to power failure or emergency shutdowns by automatically operated valves located immediately downstream of the upstream pumps. When the system is stopped, the water contained in the reach of pipeline from each pumping plant to the next forebay possesses considerable inertia which must be overcome when the system is restarted. The head provided by the pumping plants to overcome this inertia must be applied in increments by controlling the time between starts of units to limit hydraulic surges created by startup.

The Northern System, in effect, incorporates three types of operation. Pumping plant No. 1 operates on a downstream demand principle regulated by Forebay No. 2. Pumping plant No. 2 operates with remote supervisory controls but has imposed upon it certain automatic protective controls required because of the relationship to the other plants. Pumping plants Nos. 3 and 4 respond to the water levels in their upstream forebays.

The monitoring and control equipment at the headquarters, coupled with protective relays at the pumping plants, permit unattended operation of all plants and reservoirs. Various controls automatically rotate
the use of the pumping units to equalize the pumping time and wear. "Emergency run" controls are provided at each plant to permit onsite manual operation.

The automation of the Northern System has operated well as designed. A few minor adjustments and modifications have been made to further improve the system. These include such items as adjustment of the operating band in the forebays to minimize cycling of the pumping units and an addition of a self-starting generator to provide power for radio communications in case of power failure.

Central System

The Central System conveys water from the Amarillo Regulating Reservoir by gravity through about 115 miles of pipe to the Lubbock Regulating Reservoir. The pipe varies in diameter from 96 inches to 54 inches, the capacity being successively reduced from 160 second feet to 85 second feet at the points where deliveries are made to the cities of Amarillo and Plainview. Flow through this section is monitored and controlled remotely from the authority's control room by operation of two 30-inch, motor-operated butterfly valves near the upper end of this reach. The rate of flow through the 42-inch-diameter Amarillo turnout is also remotely monitored but is regulated by the city at the terminus of the 1½-mile-long lateral. This arrangement prevents dewatering of the gravity-flow lateral when the delivery rate is reduced or stopped. In this reach of aqueduct, a series of pipe check and pipe stand structures are installed to keep the pipe full when there is no flow. The construction costs of this reach were minimized by use of these checks which made the pipeline design gradient the same as the hydraulic gradient. While control of this gravity-flow pool system is simply one of releasing the flow into the aqueduct, particular care was required in design of the system and careful operation is also required to prevent hydraulic surging. 3/ The time of response from inflow at the Amarillo Regulating Reservoir to releases at the Lubbock Reservoir is considerably slower than is possible with the Northern System. This time delay in ability to meet changes in demand was overcome by appropriate sizing of the Lubbock Reservoir.

Southern System

As discussed previously, this system delivers treated water from the Lubbock treatment plant to seven of the cities. Pipe diameters in
PROFILE - SOUTHERN SYSTEM

FIGURE 4
this system range from 54 to 10 inches. The Main Aqueduct makes delivery through a gravity-flow pressure system to five of the cities. Delivery is pumped through the Southwest Aqueduct from its bifurcation with the Main Aqueduct to the remaining two cities. The four pumping plants of the Southwest Aqueduct operate on a downstream demand principle similar to the method of operation of pumping plant No. 1. The Main Aqueduct and a portion of the Southwest Aqueduct were designed as gravity-demand systems with control valves located at terminal structures and at convenient locations along the pipelines to step down the hydrostatic head, thereby reducing construction costs.

To control the gravity flow into the regulating tanks and terminal facilities of these systems, rate-of-flow controllers were installed in sets of three at most locations. The valves on the controllers, though installed in parallel, open in sequence according to downstream demand. Each valve is controlled by a float in an adjacent downstream regulating tank. The first valve begins to open as water in the tank falls and is fully opened if the water level reaches the lower limit of its related modulating range. At that time, the second valve begins to open and continues to open as the water level continues to drop. The third valve operates in a similar manner. This design virtually eliminates the valve cavitation which would occur at low flows upon a system designed to use only one large butterfly valve and also increases the system's reliability.

Each rate-of-flow controller has a local rate setter which controls the rate of flow through that flow tube. A flow controller valve remains at a constant position as long as the water level in the regulating tank remains constant. When the downstream demand is reduced, the valves close in reverse order of their opening. Flow controllers at each delivery point along the aqueduct are also equipped with local rate setters to assure equitable distribution of water and prevent unwatering of the pipeline. These rate-of-flow controllers maintain rates of flow within 1 percent of the desired rate regardless of the hydraulic head imposed on the upstream side of the controllers. They also control surging by limiting the rate of valve closure.

In addition to the three valves in parallel, there is a fourth larger butterfly valve on the main line just upstream of the three parallel valves. The large valve is fully opened or completely closed by float switches in an upstream structure. When water in an upstream structure drops to a predetermined low, the valve closes to prevent draining or unwatering any part of the intervening pipeline system. The valve
30 Motor-operated butterfly valve
16" Rate-of-flow controller

FLOW

20" Rate-of-flow controller
16" Rate-of-flow controller

PLAN

FLOW INTO MAIN
FLOW TO SO. LUBBOCK T.O.

FLOAT MODULATION RANGES

1st 16" flow controller range
2nd 16" flow controller range
20" flow controller range

All three rate-of-flow controllers are fully open when water surface is at or below El. 3197.1

REGULATING TANK NO. 6

ELEVATION
PRESSURE REDUCING STATION AT
REGULATING TANK NO. 6

FIGURE 5
reopens automatically when the low level is cleared and a reset level is reached. At delivery points throughout the gravity-fed portions of this Southern System, flow-control stations featuring the type of control just described are utilized.

Hydropneumatic rate-of-flow controllers were initially installed in the system. A considerable number of problems developed in a short time due to the difficulty of maintaining proper calibration of the system, loss of surge control, corrosion of dissimilar metals used in the systems, and carbonate scale forming on the working parts. Several of these controllers have been replaced with electronic rate-of-flow controllers which were not on the market at the time of construction. Flow-controller maintenance requirements are expected to be reduced considerably based on the performance during the past 2 years of one new unit at the Slaton terminal.

Operation of the System

The Canadian River Municipal Water Authority is responsible for the operation and maintenance of the total system. All operation and maintenance is accomplished with only 27 permanent employees, plus some seasonal help. This would not be possible without automation. With continuous attendance, it is estimated that about 40 additional employees would be required at an increased cost of about $300,000 annually. An extensive communication system would still be required for manual operation of the system.

Summary

The Canadian River Municipal and Industrial Water Supply Project illustrates three types of automation that have ready application to irrigation pipe systems. The Bureau of Reclamation incorporates these methods of control in irrigation systems where appropriate. The Canadian River Project, which has been in operation since 1968, has demonstrated that substantial economies can be achieved through automation. The reliability and success of this control system make them worthy of consideration in the design of other conveyance aqueducts and distribution systems.
