WATER OPERATION AND MAINTENANCE

BULLETIN NO. 117

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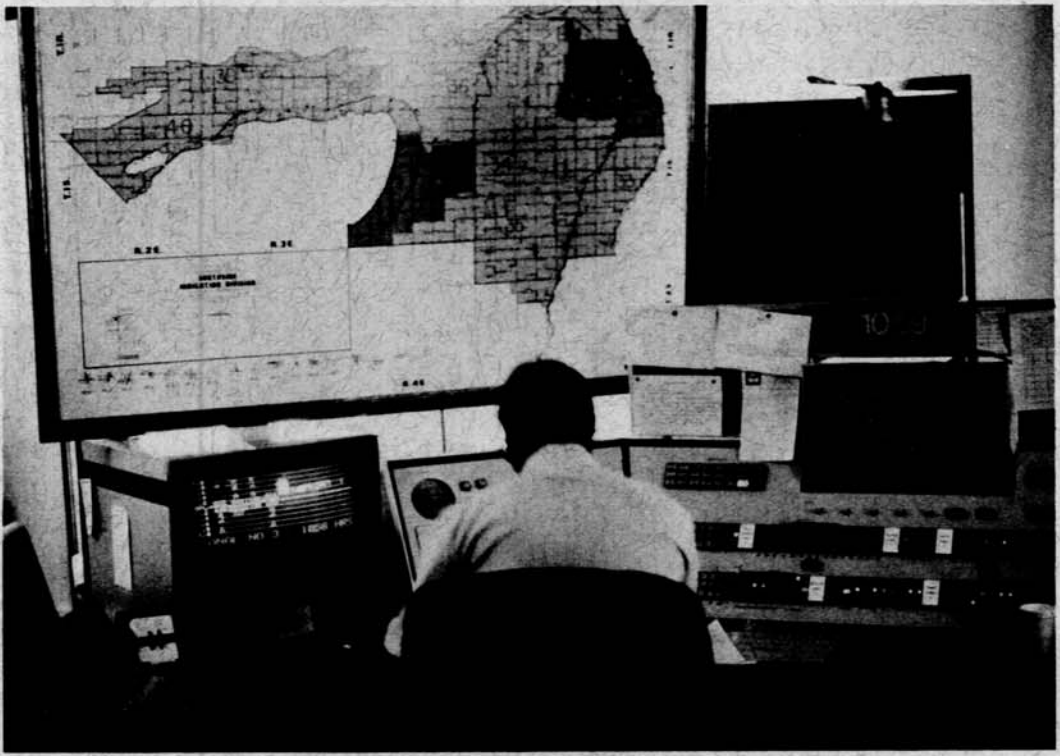

IN THIS ISSUE

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

The Water Operation and Maintenance Bulletin is published quarterly for the benefit of those operating water supply systems. Its principal purpose is to serve as a medium of exchanging operation and maintenance information. It is hoped that the reports herein concerning laborsaving devices and less costly equipment and procedures will result in improved efficiency and reduced costs of the systems for those operators adapting these ideas to their needs.

To assure proper recognition of those individuals whose suggestions are published in the bulletins, the suggestion number as well as the person's name is given. All Bureau offices are reminded to notify their Suggestions Award Committee when a suggestion is adopted.

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Division of Operation
and Maintenance Technical Services
Engineering and Research Center
Denver CO 80225

Cover Photograph:

Control center at the Salt River Project

In May of 1981, the Secretary of the Interior approved changing the Water and Power Resources Service back to its former name, the Bureau of Reclamation.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

WATER OPERATION AND MAINTENANCE
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INTRODUCTION

This issue of the Water Operation and Maintenance Bulletin includes information on recent applications of control systems and controllers to the operation of water projects. Some information is also presented on new developments in measuring water discharge.

The first and third articles on Arizona projects and the Tehama-Colusa Canal (pages 1 and 17) describe control systems using the centralized concept of operating project facilities by an operator located at a central site.

The second article on the Corning Canal (page 12) describes a local control system which normally requires no operator in attendance.

The fourth article on the mechanical-electronic controller (page 22) presents information on the application of a recently developed local controller.

The fifth article (page 27) presents information on the use of radial gates for flow measurement.

The sixth article (page 33) describes a study of investigating the use of a ramp flume for measuring flow.

Some methods of water systems automation rely on accurate flow measurements at numerous facilities being controlled. The use of the radial gate for measurement is ideal for this purpose if good accuracy is attained.

The Corning Canal control system, the mechanical-electronic controller development, and the radial gate measurement study were supported by research funds for water systems automation at the Bureau of Reclamation's Engineering and Research Center in Denver, Colorado.

If more information on the subject presented in this bulletin is desired, please contact Duane Nelson, Division of O&M Technical Services, Engineering and Research Center, Denver, Colorado.

WATER RESOURCE CENTRALIZED (SUPERVISORY) CONTROL SYSTEMS IN ARIZONA[1]

Introduction

There are several projects which generate electrical power and use programable master supervisory control systems. An example is the Central Valley Project control system in California. Although these systems may include some water control functions, they have generally been used for controlling power functions. Project features operated by centralized control systems, primarily for water control, include the Tehama-Colusa Canal, California Aqueduct, Delta-Mendota Canal, Coachella Canal and distribution system, Palo Verde Irrigation District canal system, Imperial Irrigation District canals, Wellton-Mohawk Irrigation and Drainage District canals, Bureau of Reclamation-operated facilities on the Lower Colorado River, Salt River Project canals, and Kansas River Project reservoirs. Some of these control systems have not been entirely completed. Project features which are scheduled or where work has started on centralized control are the Friant-Kern Canal and Reservoir outlet works, Delta-Mendota Canal modernization and expansion, Coachella Canal modernization and expansion, Navajo Indian Irrigation Project canals and reservoir outlet works, Central Arizona Project canals, Fyingpan-Arkansas Project collection system, and Fountain Valley conduit.

This article discusses three centralized control systems in Arizona: the Salt River Project canal system, the Wellton-Mohawk canal system, and Lower Colorado River facilities.

Salt River Project [2]

The Salt River Project started delivering water and power to the Phoenix area in 1911. Today, the project serves an area of 96 422 ha (238 264 acres) with water from the Salt and Verde Rivers and 245 deep wells. Water is supplied for agricultural and residential irrigation in the Salt River Valley and for domestic purposes to eight cities in the greater metropolitan area.

Construction was started in 1970 on a centralized control system which was part of a modernization program for the control facilities. The construction was completed in five phases over a 5-year period. The initial control system is still in use, although some new equipment has recently been added. The completed control system included 79 canal stations on the 222-km (138-mi) canal network. The operator was given the capability to control 206 radial gates, 45 deep well pumps, and 8 large booster pumps from a central location.

Fabrication and installation of the electronic equipment was done by the Data Systems Division of Gulton Industries, Albuquerque, N. Mex. All electrical, mechanical, and structural

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[1] Written by Duane F. Nelson, Water Systems Automation Team Leader, Division of O&M Technical Services, Bureau of Reclamation, Denver, Colo.

[2] Some of the material used in the discription of the Salt River Project control system was taken from a pamphlet published by the Project entitled "Supervisory Control."

work, however, was done by the project. This included the installation of drive mechanism, motors, and motor controllers to raise and lower gates, and stilling wells which house water-level-sensing transducers. The total cost was approximately $3.3 million. The average cost at each remote site was $24,800.

The control center (fig. 1) which is manned 24 hours per day, includes a hard-wired-type console equipped with a black and white CRT (cathode ray tube) for displaying telemetered data, address and command switch buttons, and various visual and sound status indicators. A Hewlett-Packard HP-2116 computer with core and disk memory is used for computing rates of flow through each gate and initiating a telemeter scan at each site periodically for a hard-copy data record. The computer, which does not handle any control functions, is scheduled for replacement this year. Telephone and radio-voice communication facilities are available at the console. A leased, four-wire, multiplexed party-line telephone line is used for control function communications.

Figure 1.–Control center.

At remote sites, water levels are sensed, using floats in stilling wells. Gate position is sensed, using a steel tape attached to a gate-sector extension downstream of the trunion having a radius one-fifth that of the gate (fig. 2). Gate submergence and pump-on conditions are sensed by solid-state probes. Gate positions and water levels are digital encoded, using 10-bit optical encoders made by Renco Co. Each station has batteries to provide standby power. Gates are normally operated for 20-second periods. The operator then checks the new discharge against the desired discharge to determine if a further gate opening change is necessary. A movement period of less than 20 seconds is possible.

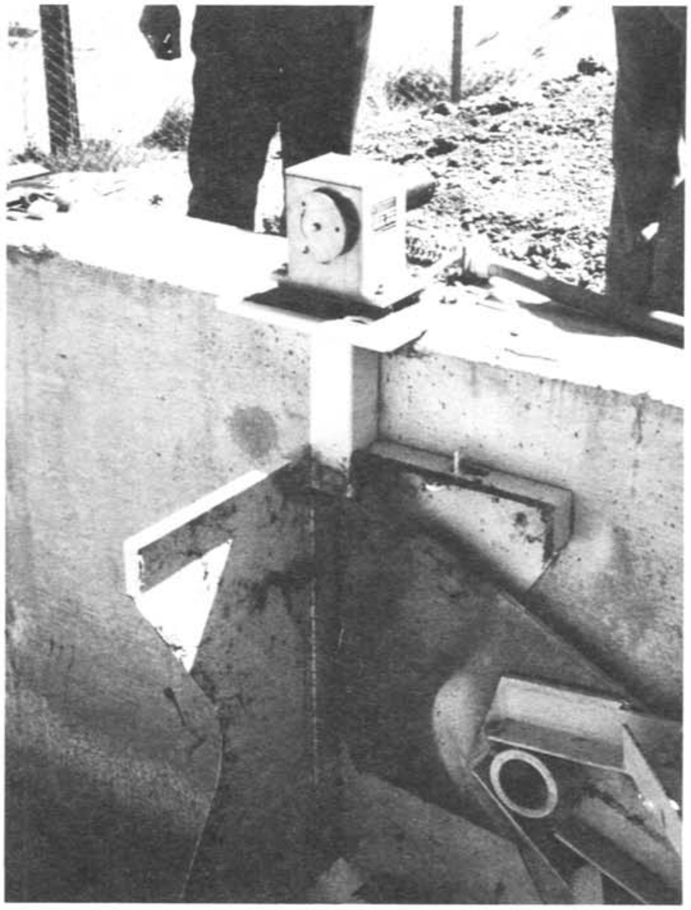

Figure 2.–Gate position indicator.

In 1978, the need to upgrade the control system was recognized and a new Hewlett-Packard computer was purchased to provide backup for the existing computer and to expand the information available to the operator. A color CRT terminal was also acquired. Operating software is presently being developed and tested. Sixty thousands dollars was spent for the equipment. Thirty-six thousand dollars has been spent in the last 2 years for software development. Two contract programers work part time. New graphic displays which visually show where the water is stored in the canal system will be very helpful to the operator (fig. 3).

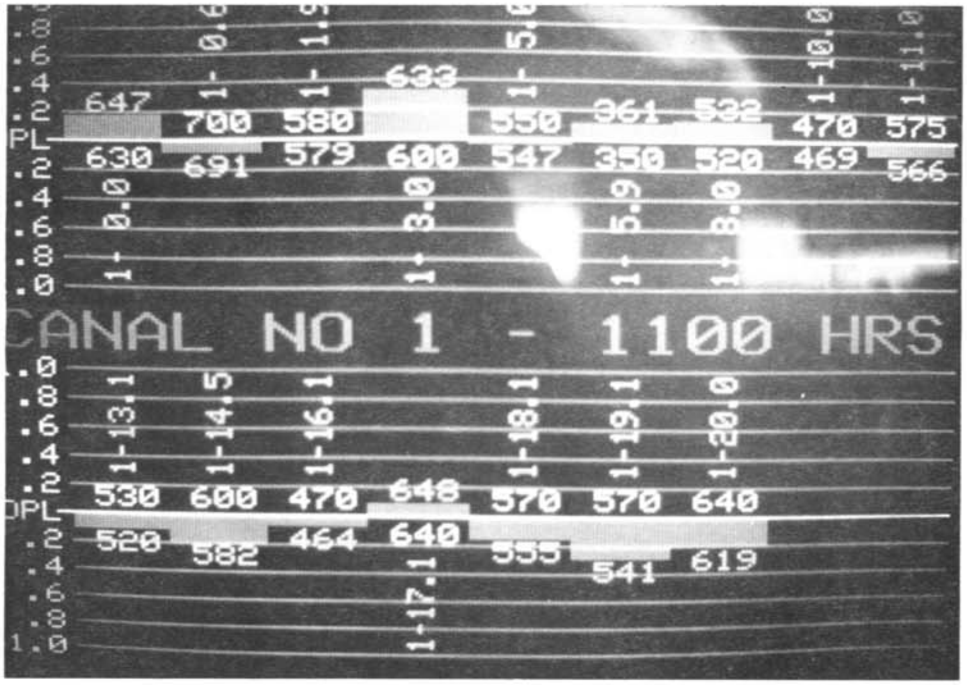

Figure 3.–CRT display at control center.

The control system continuously scans all 79 canal sites on a 31-second cycle to monitor either normal or irregular conditions. Alarm conditions include canal high water, power failure, and communication failure. When any 1 or more of 23 abnormal conditions occurs at a site, a flashing light will attract the operator's attention. The operator can acknowledge the irregularity by depressing a pushbutton on the console. The light will stay on until the abnormal condition is corrected at the site, but will cease flashing when the condition is acknowledged. If the operator cannot solve the problem by manipulating various console controls, help is summoned from technical or field personnel by radio or telephone.

Because the system permits the operator to monitor the entire canal system at one time, water control is more accurate. The operator can follow a change in flow rate down the canal much faster than when the canals were controlled manually, requiring someone to drive from gate to gate. Water is delivered 25 percent faster through the system now than previously. As a result, excesses and shortages of water have been minimized. Prior to the installation of the control system, the changes at canal gates were made by project field personnel who operate the distribution system. Many times, the workload of these people conflicted with canal operations and made timely reports on gate changes impossible. Now, field personnel can devote almost full time to the distribution system. The man-hour savings for the conveyance system was equal to four-and-one-half full-time employees; however, two electonic technicians now are required to maintain the control system. Although one person can do it most of the time, work rules and safety considerations require two. Now that it is possible for one operator to quickly start and stop pumps from the control center, pump operation has been reduced during the summer peak-load periods.

The concept of supervisory control had been discussed many times at meetings of the Board of Governors and Council prior to authorization. Authorization came after six governors and one councilman visited the Coachella Valley County Water District to inspect a control system that had been in service since 1966. The Coachella control system, which will soon be replaced with a more modern system, is an analog system installed by Hersey-Sparling Co. that requires reading of several dials. The visitors were impressed with the centralized control concept, and soon after the visit, approval was given for the Salt River supervisory control system.

Wellton-Mohawk Divisions, Gila Project

The Wellton-Mohawk Irrigation and Drainage District extends for 72 km (45 mi) along the Gila River in southwestern Arizona. The west end of the District lies about 11 km (7 mi) east of the confluence of the Gila and Colorado Rivers. The District headquarters is at Wellton, 48 km (30 mi) east of Yuma. The total irrigation acreage in the District is 26 300 ha (65 000 acres). Construction started in 1949 to deliver Colorado River water to District lands. The first water was delivered in 1952. Water is diverted at Imperial Dam through the Gila Main Canal and thence into the Wellton-Mohawk Canal. Three large pumping plants along the canal lift the water 52 m (170 ft). Other major canals are the Wellton Canal and the Mohawk Canal. The major canals have 26 check structures with nonmotorized radial gates.

The pumping plants have been remotely controlled from the headquarters for 28 years. Plans were made to upgrade the pumping plant control system and, secondarily, to modernize the check structures by supplying power, motors, and remote control equipment. Replacement of pumping plant control equipment was mandatory because of increasing maintenance problems. A contract was entered into with Motorola, Inc., to upgrade the old control system. The work was actually performed by ESI (Engineered Systems, Inc.), Tempe, Ariz., which assumed the services at one time provided by Motorola. A master station and four microprocessor-based RTU's (remote terminal unit) were installed more than 1 year ago. The inclusion of control center facilities to support check structure and power substation RTU's was justified because for a minimal cost, software would not have to be reprogramed later to support these RTU's. Radio is used for communication with the RTU's. The RTU's are located at the three pumping plants and at a power substation. The microprocessor-based master station cost $80,000. The whole system cost $120,000. The control center (fig. 4) is manned 24 hours per day.

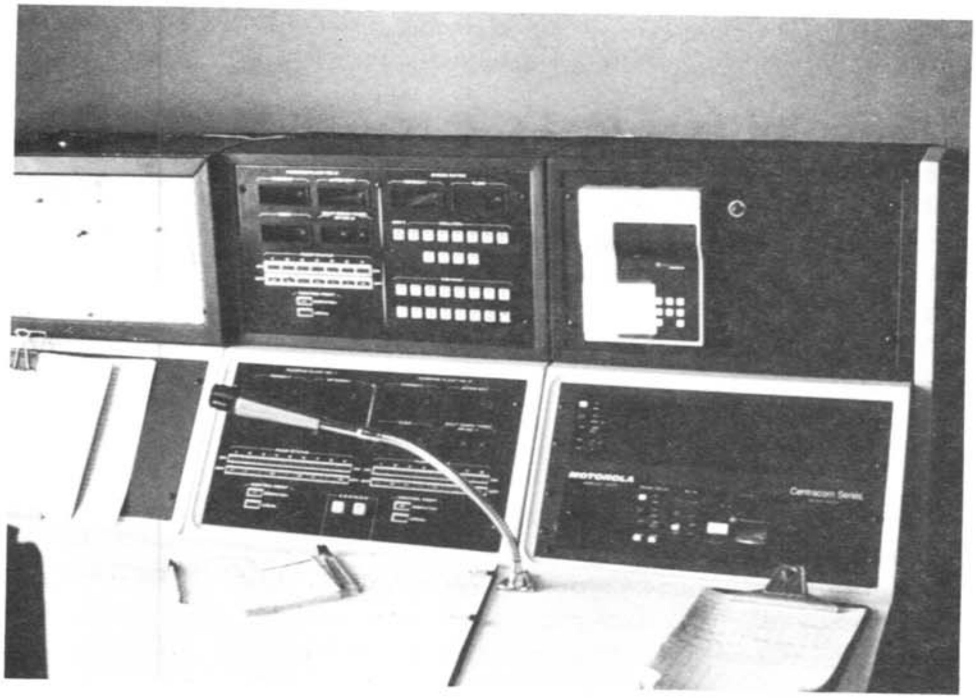

Figure 4.–Control center console.

The District plans to extend the central control to the 26 check structures (fig. 5) over a period of years at about the rate of 2 per year contingent upon favorable results from studies of a prototype structure. The cost will be about $20,000 per structure. Seven thousand dollars is for the remote contol and communication equipment and the remainder is for rehabilitating the structure to include gate motors and related equipment. The structures have one or two gates. The gates will have equal openings, if there are two. Studies are being made for a prototype structure, which is presently undergoing rehabilitation, and control equipment installation. A bubbler-measuring system will be used to determine water levels, and a ceramic slide wire device will be used in determining gate positions. The gate discharges will be calculated and displayed at the control center for canal operation. The discharge will be adjusted three times at 5- to 25-minute intervals. It is assumed that it will be sufficiently close to the target discharge after three adjustments. The ditchrider presently adjusts the canal gates based on discharges. Accurate water measurement devices are installed at most turnouts.

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Figure 5.–Check structure rehabilitation and control equipment installation.

The benefits that may be realized from the centralized control of the canal regulatory structures are better service to the users, reduction in pumping costs, decreased travel, and decreased manpower. The addition of a centralized control system has been considered part of the modernization program and the "state-of-the-art" method to control irrigation systems in modern times. The directors of the Wellton-Mohawk Irrigation and Drainage District have given their conditional support to the control system contingent upon the check structure prototype based upon this reasoning.

Lower Colorado River Facilities, Yuma Projects Office.

The operation of the facilities along the Lower Colorado River is very complex and involves several data collection and operating entities. Parker Dam serves as the main control for release of water for irrigation and domestic requirements in the United States and delivery of water to Mexico. Water released from Parker Dam requires approximately 3 days before it arrives at Imperial Diversion Dam north of Yuma. Imperial Diversion Dam is the main diversion point for water delivered to Arizona and California. On the west side of the river, water is diverted into the All-American Canal, which conveys water to the Imperial Irrigation District, Coachella Valley County Water District, Yuma County Water Users' Association, Bard Irrigation District, and Yuma Indian Reservation. The canal is operated by the Imperial Irrigation District, which has a dispatcher on duty at Imperial Diversion Dam 24 hours per day. On the east side of the river, water is diverted into the Gila Gravity Main Canal for conveyance to Yuma Irrigation District, Yuma-Mesa Irrigation and Drainage District, North Gila Valley Irrigation District, and Wellton-Mohawk Irrigation and Drainage District. The headworks of the Gila Gravity Main Canal, first check-structure gates, Wellton-Mohawk Canal turnout, and the sluiceway gates into the Colorado River are operated by the Bureau of Reclamation. Bureau operators are on duty 24 hours per day at Imperial Diversion Dam.

Senator Wash Dam and Pumping-Generating Plant were built on an arm of the reservoir upstream of Imperial Diversion Dam to provide some river regulation. Six reversible pump-turbines can produce 7200 kW of electricity.

Laguna Diversion Dam, which is located a short distance below Imperial Diversion Dam, originally diverted water to both the California and Arizona sides of the river. These diversions are now made at Imperial Diversion Dam, and Laguna Diversion Dam no longer serves its original purpose. Minor river regulation is possible at this dam.

A small amount of regulation can also be attained at the Yuma-Mesa well field; however, this well field is generally pumped at maximum to meet ground-water recovery and drainage requirements. The Yuma-Mesa well field consists of 12 wells located a short distance south of Yuma. Thirty-five wells are being drilled in an 8-km (5-mi) strip along the SIB (Southerly International Boundary) of the United States and Mexico on the Arizona side of the river as part of the Colorado River Basin Salinity Control Project. Most of the water pumped from the wells will be delivered as treaty water to Mexico. In the past, most of this water has been lost to Mexico in underground flow.

Studies have been made concerning consolidation of river and related data collection and centralized control of regulatory features. These studies have considered the collection of data control of many features not mentioned in the above paragraphs. After careful analysis of the desirability of using centralized control of various facilities, it was agreed that the following facilities should be included in the initial control system configuration. Part of the equipment has been installed and is operating.

Master station at Imperial Diversion Dam (installed)
8 Gila Gravity Main Canal headgates (installed)
12 Colorado River sluice gates (installed)
2 Gila Gravity Main Canal check gates (on hand)
2 Wellton-Mohawk Canal turnout gates (on hand)

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2 Gila Gravity Main Canal check gates (on hand)
2 Wellton-Mohawk Canal turnout gates (on hand)

3 Laguna Diversion Dam river gates (on hand)
6 Senator Wash pumping-generating units (installed) (fig. 6)
12 Yuma-Mesa wells (10 installed, 2 on hand) (fig. 7)
35 SIB wells (6 ordered)
2 Well field outlet gaging stations (on hand)

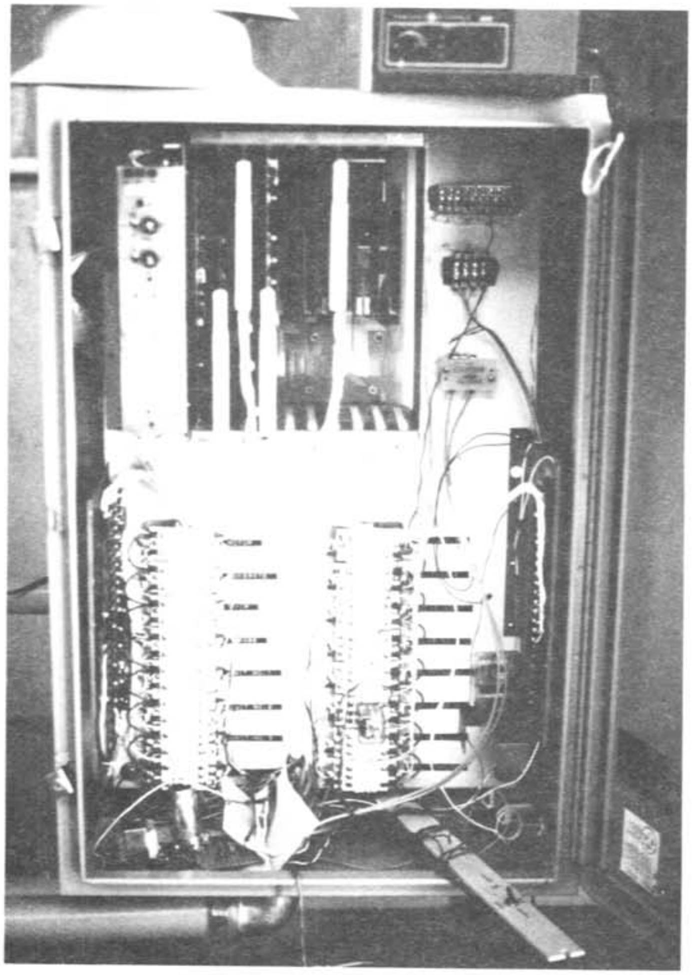

Figure 6.–RTU equipment at Senator Wash Pumping-Generating Plant.

The master station at Imperial Diversion Dam includes a PDP 11-34 computer and a color CRT terminal (fig. 8). The RTU's are microprocessor based. Astrosystem digital encoders are used in measuring gate positions. The encoders cost $1,200 each. Water-surface levels are measured using a potentiometer, pressure-sensitive tape system, or ultrasonic measurement device. Cable is used for communications in the vicinity of Imperial Diversion Dam. Radio is used elsewhere. A monitoring station with a color CRT terminal is planned for the Yuma Projects Office.

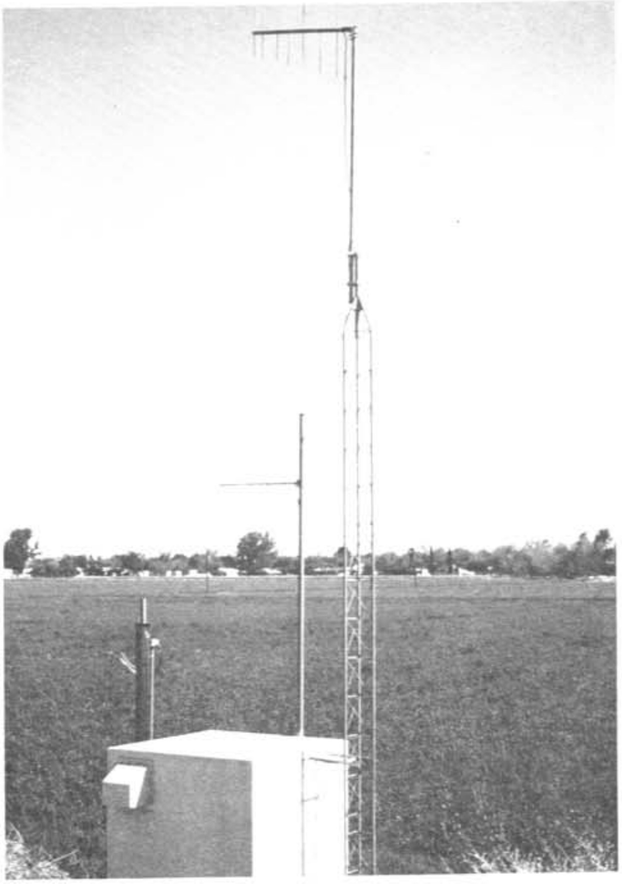

Figure 7.–Yuma-Mesa well field remote station.

Figure 8.–CRT display at Imperial Diversion Dam control center.

The master station cost $110,000, of which $25,000 was for software. The software cost is probably much lower (25 to 50 percent) than normal. The RTU costs were $7,000 for the wells, $15,000 for the Colorado River sluice gates, $10,000 for the Gila Gravity Main Canal headworks, and $5,000 for the Senator Wash Pumping-Generating Plant. The digital gate encoders are included in these costs. The control equipment was supplied by Sangamo Weston, Inc., of Sarasota, Fla., from the GSA supply schedule using RFP (Request for Proposals) procedures.

The equipment is being installed by three technicians. After installation is completed, it is anticipated that one technician, working part-time, will be able to maintain the equipment. The master station will be maintained through a service contract with the computer manufacturer, Digital Equipment Corp.

The control system is being financed by Colorado River Basin Salinity Control Project funds, Operation and Maintenance funds, and funds acquired from the Arizona irrigation districts. Good support has been received from the irrigation districts.

The acquisition of the control system has coincided with a reorganization of the O&M staff. The reorganization has resulted in a reduction in personnel.

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DEMAND OPERATION ON THE CORNING CANAL[3]

Water systems automation plays a particularly important role in applying the total water management concept to water supply systems. Much progress has been made recently in controlling the flow of water in canal systems. The conventional concept of scheduling water releases may become outmoded on many systems. Eventually, a farmer may be able to satisfy the needs of his thirsty crops almost as easily as turning on a faucet in his house.

The technical name given to this concept is "demand operation." It is made possible by automatic downstream control. With downstream control, the water can be made available on demand for canalside turnouts with minimal prior scheduling.

With the conventional controls which regulate the flow of water in most irrigation distribution systems, it is necessary to order the water at least a day in advance. Canal operators must compile all of the water orders to determine the amount needed at each distribution point and then they must adjust the amount of water being released at the headworks of the canal, allowing sufficient time for it to arrive at its destination at the requested time. It may take hours and sometimes days for the new amount of water to travel along the canal. A ditchrider must follow the water as it flows downstream to open the canal gates, one by one, until the new flow reaches the desired location. Often, the ditchrider must revisit all the gates to make finer adjustments.

With automatic downstream control, it may be unnecessary to order water in advance, and the ditchrider will have time to attend to duties other than adjusting canal gates.

Canals are divided into several reaches by a series of gates at check structures (fig. 9). Automatic downstream control uses a water-level sensor at the downstream end of a canal reach to activate a controller, which in turn controls the gate at the upstream end of the reach. This sensor, sensing changes in the water-surface level, provides a signal to the controller to adjust the gate opening automatically to restore the water level to a preset depth. Once the gate opening is changed, the sensor upstream from that gate will activate another controller to change the opening of the next gate upstream.

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[3] Written by Duane F. Nelson, Water Systems Automation Team Leader, Division of O&M Technical Services, Bureau of Reclamation, Denver, Colo.

Figure 9.—Radial gate check structure.

This procedure continues upstream to the canal headworks, resulting in all upstream gates responding to the initial change in water level. With all gates operating in this manner, there is no longer the need for an operator to adjust the gates. Downstream control is particularly appropriate for automating canals where deliveries are difficult to forecast, such as for municipal and industrial water supplies. Waste can be significantly reduced by increasing system efficiency.

The Bureau of Reclamation first became interested in applying downstream control in the 1960's. Through a research contract with the University of California at Berkeley, an investigation of the downstream control concept was sponsored. Additional research at the University and the Bureau of Reclamation led to the development of a controller called the EL-FLO (Electronic Filter Level Offset). Continued testing and development have resulted in a controller which not only automatically controls flow but also, either directly or indirectly, indicates alarm conditions such as high water, low water, gate limits, and loss of power or communications.

EL-FLO control has been applied to the Corning Canal, which uses water diverted into the Tehama-Colusa settling basin from the Sacramento River at the Red Bluff Diversion Dam (fig. 10) near Red Bluff, Calif. The settling basin supplies water to both the Corning and Tehama-Colusa Canals. Water is lifted from the settling basin 22 m (71 ft) into the canal at the Corning Pumping Plant where six pump units of two different sizes are housed. Three of the units are operated automatically to provide a flow which will approximately match the canalside demands. The Corning Canal is a 34-km (21-mi) long, earth-lined canal with a capacity of 14.16 meter^3/s (500 ft^3/s) (fig. 11). Canal flow is regulated by 12 single-gated check structures spaced at intervals along the canal. Eight have radial gates and four have slide gates (fig. 12). The canal has 33 canalside turnouts. Twenty-seven of the turnouts are pump type, of which six are automatic (fig. 13). Most of the turnout valves to farmers' lands are operated by them.

During the first few years of operation when canalside demands were small, the Corning Canal was operated manually. Manual operation was complicated by the addition of automated-pipe distribution systems having pressure-pipe laterals. These automated laterals are essentially demand systems, but their efficiency was limited by the capability of the canal to respond. Operators who manually operated the canal could not satisfactorily predict diversions and match canal flows to demands.

The first modification to aid operation was automation of the Corning Canal Pumping Plant and the settling basin. Later, locally designed controllers were installed at all canal gates pending the development of the new method of automatic downstream control (EL-FLO controller).

After significant progress had been made in the development of the EL-FLO controllers, the equipment was installed to control all gates on the Corning Canal. The installation was completed late in the summer of 1975. The cost of the electronic controllers was approximately $2,500 each. Communications are provided by leased buried cable.

The EL-FLO controllers form a local control system with a centralized alarm system. A centralized control system based on the EL-FLO control method with operator-override capabilities is also feasible.

The Bureau of Reclamation has an ongoing water systems automation research program which includes investigation and development of many methods of water systems automatic control. The development of downstream control methods and equipment is an important part of this program. Improvements to increase the reliability of the EL-FLO controller have already been developed and are being tested. One improvement is to incorporate a microprocessor in the controller which should improve the control system reliability.

Automatic downstream control offers a method of canal control which has several attractive features when compared with other methods in the operation of many canal systems. Systems may be made responsive so that water may be supplied to the user on demand. Efficiency of operation may be increased so that much more water will be saved. Fewer and smaller regulating reservoirs may be required and wasteways may be eliminated.

These, among other features, have attracted the attention of Bureau of Reclamation design and research engineers. The Bureau has taken significant steps to design and apply downstream control systems. Further improvements will be made to make even more responsive irrigation systems which will satisfy the needs of farms and municipalities.

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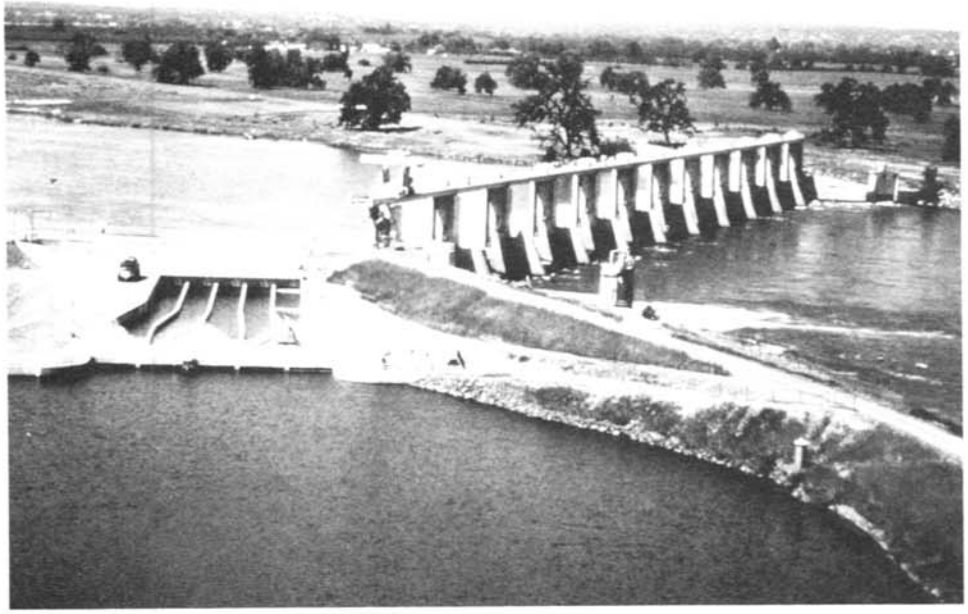

Figure 10.–Red Bluff Diversion Dam and Tehama-Colusa settling basin.

Figure 11.–First reach Corning Canal.

Figure 12.–Automated slide gate check structure.

Figure 13.–Automated canalside pumping plant.

CENTRALIZED (SUPERVISORY) CONTROL OF THE TEHAMA-COLUSA CANAL[4]

Centralized control of a canal implies supervisory control equipment has been installed such that the operating staff can control the various regulatory structures from a central office. The supervisory control equipment may or may not include computers. When computers are included, various degrees of automation can be incorporated to the point that the computer could control the canal without human intervention. This completely automated conveyance system is still a concept for the future, although it is practical to allow the computer to provide a high degree of automation. In contrast with computerized central control, there are systems which offer some of the benefits of centralized control, but rely heavily on human operators to remotely adjust regulatory facilities and make decisions based on skills acquired through past operating experience. The control system being installed on the Tehama-Colusa Canal is a system of this type. Because of the necessary involvement of operators to make system changes, the control concept is called centralized manual control (fig. 14).

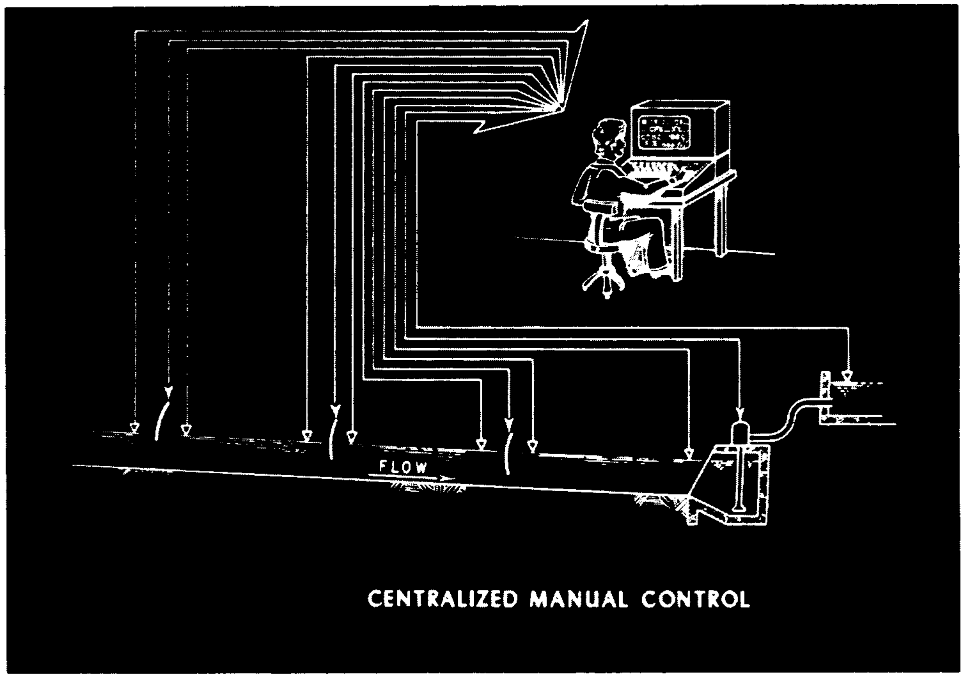

Figure 14.—Centralized manual control.

Centralized manual control has been incorporated on several water resource projects in the United States. Many of these systems have a control console with buttons which the operator pushes to activate corresponding controllable features on the project. Radio, microwave,

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[4] Written by Duane F. Nelson, Water Systems Automation Team Leader, Division of O&M Technical Services, Bureau of Reclamation, Denver, Colo.

landline, and buried cable have been used for communications. Control systems are now available that incorporate microprocessors at the remote terminals and at the master station and include modern display and keyboard entry equipment. Equipment of this sort is being installed as a control system for the Tehama-Colusa Canal in California. The canal is operated by the Bureau of Reclamation.

With centralized manual control water levels, gate opening, pump status, and alarm conditions may be telemetered to a central location from which an operator may remotely control gates and pumps along the canal. Under normal operating conditions, the operator may operate the canal generally in much the same manner as if ditchriders were making adjustments along the canalside. Either upstream or downstream control may be used. However, based on the operator's experience and judgment, he may operate the gates in a different manner which does not depend on upstream flow changes arriving at the control points. As with all centralized control concepts, the capability to quickly respond to emergency situations is greatly accelerated.

The availability of off-line computer facilities greatly increases the operational flexibility and responsiveness of the control system in making scheduled flow changes. The computer also can be beneficial in training new operators.

The Tehama-Colusa Canal is presently under construction. Eight reaches and a regulating reservoir have been completed. The 179-km (111-mi) long canal has the capacity to divert 71.6 m^3/s (2,530 ft^3/s) from the Sacramento River. The gravity-flow diversion is made at Red Bluff Diversion Dam into the Tehama-Colusa settling basin, the starting point for the concrete-lined canal. The canal not only delivers water presently to 19 irrigation districts, but the upstream portion of the canal has a dual-purpose in providing an environment for spawning fish. The Fish and Wildlife Service is making extensive studies in this section and accurate control of the water is essential.

The canal has been designed with the anticipation of incorporating automation and remote control. The design includes a buried communications cable in the canal bank. The finished portion of the canal includes 26 check structures (2 or 3 gates per structure), fig. 15.

Figure 15.–Check structure. Control equipment shelter to left of road.

Equipment for the control system was acquired through contract with ESI (Engineered Systems, Inc.), Tempe, Ariz., and is being installed by Bureau of Reclamation personnel. The digital control system uses microprocessors in executing control functions. Micro-processor-based equipment, which is commonly used in modern control systems, has the flexibility provided by reprograming to add or modify control functions at a later date.

The control system includes remote stations for the 26 check structures, a master station, and 3 control/monitor terminals. The equipment utilizes 8-bit microprocessors. The remote station (fig. 16) may be interrogated for information on up to 3 gate positions, 2 water levels, and 19 alarm conditions, including security, high water, low water, gate raise limit, gate lower limit, power outage, and gate failure. The remote stations on command from the master station will initiate the raising and lowering of gates. A gate may be moved directly to a set point opening or it may be jogged during a short time interval. Gates at a check structure are moved individually during normal operation; however, all gates may be moved simultaneously during emergency situations.

The master station includes a video/keyboard terminal and a printer/keyboard terminal (fig. 17). Operator entries from either terminal are acted upon by the master station. The printer/keyboard terminal prints status, summary, and trend reports for record purposes. The video/keyboard terminal is normally used by the operator for canal operation. Commands may be given to individual check structures or to all check structures simultaneously. Initially, the master station has been installed along the canal near its midpoint. A master station at each end of the canal is planned for a later date. Then, if a break in the communications

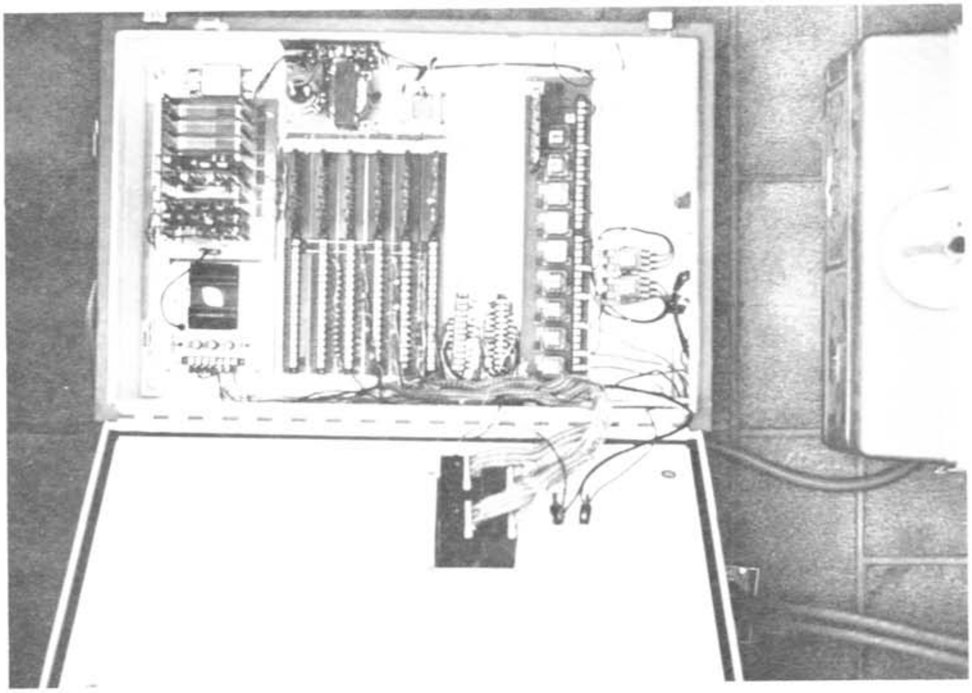

Figure 16.–Remote-station control equipment.

Figure 17.–Master station terminals.

cable should occur, control of all canal control facilities on each side of the break may be accomplished from the respective master station.

A control/monitor station includes a printer/keyboard terminal. The reports, printed at one of these terminals are identical to those at the master station. Control can be accomplished from this type of terminal if contact is made and permission given by a master station. Initially, the control/monitor stations have been installed at operation and maintenance headquarters near the beginning and midpoints of the canal. A terminal of this type will be installed near the end of the canal in the future. The cost of the control equipment was approximately $180,000. The communications cable which was included in the canal construction contracts cost aproximately $1 per foot installed. Radio communications may be used with this type of control equipment at considerably less cost and, therefore, are more commonly used.

Off-line computer facilities are available at the Willow O&M Division Office near the midpoint of the canal. Use of these facilities aids in canal operation. The canal is operated to maintain constant water-surface levels at the downstream ends of the canal pools. The off-line computer facilities will be used to aid in scheduling deliveries and determining how to move the control gates. A newly developed computer program based on "gate stroking" will be used for water-surface control. Gate stroking can be defined as "a series of continuous or discontinuous gate motions which produce a desired water-surface profile in a canal." Gate stroking requires a scheduled type of operation with centralized control. The program was initially developed for an operation study for the Central Arizona Project; however, the first field applications may be on the Tehama-Colusa Canal. It appears that this program may have application on several canals where centralized control is being contemplated.

To study the effect of various control changes, a computer program was written to simulate unsteady flow in canals. This program, based on a mathematical model called "Aqueduct Simulation Model," will be used in modeling flows in the Tehama-Colusa Canal. The Aqueduct Simulation Model is an analysis-type program which simulates unsteady flow. It may be used to check the validity of the other programs and also to determine hydraulic transient conditions during both normal and emergency operations. The model may be used in the future to examine various control techniques and assist in training operators.

The initial operation of the Tehama-Colusa Canal, with the new control system, began during the 1981 irrigation season. Operation results were not available when this article was written. At the beginning of the season, 18 check structures were equipped to be remotely controlled. It is anticipated that it will take 1 year to test the control system and to train operators to utilize the system to its fullest capability. Water-level recorders placed upstream and downstream of all check structures, along with the control system records of gate openings, will give a complete history of operation which will aid in refining future operation policy.

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MECHANICAL-ELECTRONIC CONTROLLER[5]

North Poudre Diversion Dam
Poudre River, Colorado

Introduction

A water systems automation work group has developed several gate controllers for controlling water discharge in open channels as part of the studies for the Bureau of Reclamation's water systems automation team. A research and development effort is being made to develop and test gate controllers that will control water surfaces on irrigation systems and, thereby deliver water more accurately and with less waste and manpower than can be done with ditchriders operating the gates manually.

A controller was installed on the Colorado-Big Thompson Project at the North Poudre Diversion Dam in northern Colorado. It is an electromechanical device which controls a sluice gate to hold a constant water surface upstream from a manually adjusted radial diversion gate to the North Poudre supply canal. The purpose of this report is to discuss the operation of this controller.

Background

The Colorado-Big Thompson Project has provided test sites for testing controller equipment developed as part of the water systems automation program. To date, three controllers of entirely different designs have been field tested at three different sites on the project. In addition to the diversion damsite, a canal headworks and a turnout site have been used to test other controllers.

At the downstream end of a 62-m (203-ft) long flume, immediately downstream from Flatiron Power and Pumping Plant afterbay, a controller using microprocessor chips and electronic circuitry has been installed which controls the water level at that point. It controls two 2058-mm (6-ft 9-in) wide by 2743-mm (9-ft) high top seal radial gates and has operated for several months. The gates regulate the water supply in the Charles B. Hansen feeder canal.

The city of Loveland diverts water from a turnout on the Charles B. Hansen feeder canal to supply a reservoir as part of its municipal water supply. The reservoir was built after the Charles B. Hansen feeder canal had been operating for a number of years. Two 914-mm (3-ft) wide by 914-mm (3-ft) high gates were installed by modifying an existing siphon wasteway to deliver up to 2.0 m^3/s (70 ft^3/s). A Parshall flume measuring device at the

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[5] Written by E. J. Carlson, Head, Hydraulics Research Section, Division of Research, Bureau of Reclamation, Denver, Colo.

downstream end of a 46-m (150-ft) long flume is used to measure the flow. An electronic controller, which senses the water level at the Parshall flume, was installed to operate one of the gates to maintain a constant discharge. The discharge is changed by a ditchrider dialing the desired set point.

Purpose for Installing Gate Controllers

Flows in rivers and canals change frequently and when water is diverted through a gate, to maintain a constant discharge, it is necessary to maintain a constant water surface. The water surface to be controlled may be downstream or upstream from a gate. Using a controller that will hold the water surface within a few hundredths of a foot for a desired water-surface-target level generally provides a much more constant discharge than a ditchrider can maintain by manually adjusting the gates.

North Poudre Diversion Dam

The diversion dam and headworks for North Poudre supply canal were designed and constructed by the Bureau of Reclamation as part of the Colorado-Big Thompson Project. The dam and canal system are operated by the North Poudre Irrigation Co., an irrigation company in the Northern Colorado Water Conservancy District.

The diversion dam (fig. 18) has an uncontrolled ogee overflow spillway 22.6 m (74 ft) long with a 4877-mm (16-ft) wide by 4267-mm (14-ft) high radial sluice gate on its right end. The sluice gate sill is 0.6 m (2 ft) lower than the sill for the 4877-mm (16-ft) wide by 1829-mm (6-ft) high top-seal radial diversion gate at the entrance to the North Poudre supply canal. A 3-m (10-ft) Parshall flume is used to measure the canal discharge at a point just upstream from the entrance to the first tunnel. The canal and Parshall flume are designed for a maximum discharge of 7.1 m^3/s (250 ft^3/s).

Sluice Gate Controller

The controller installed at the North Poudre Diversion Dam is a mechanical-electrical controller (fig. 19). The controller is mounted on a stilling well placed next to the ladder downstream of a trashrack and upstream of the canal gate. The 400-mm (16-in) diameter stilling pool well made from steel plate is mounted so the steel bottom is 533 mm (21 in) above the gate sill. A 15-mm (1/2-in) hole was drilled in the center of the stilling well bottom which allows water to enter in a manner that fluctuations of the water surface are adequately dampened. A still water surface in the stilling well makes it possible to control a gate very close to a given target or set point.

The controller provides a means to establish a set point at which the water surface may be maintained within a dead band of a few hundredths of a foot above and below the set point. Irrigation company operators have adjusted the controller set point to control the water surface at an elevation about 25 mm (1 in) below the top of the ogee crest.

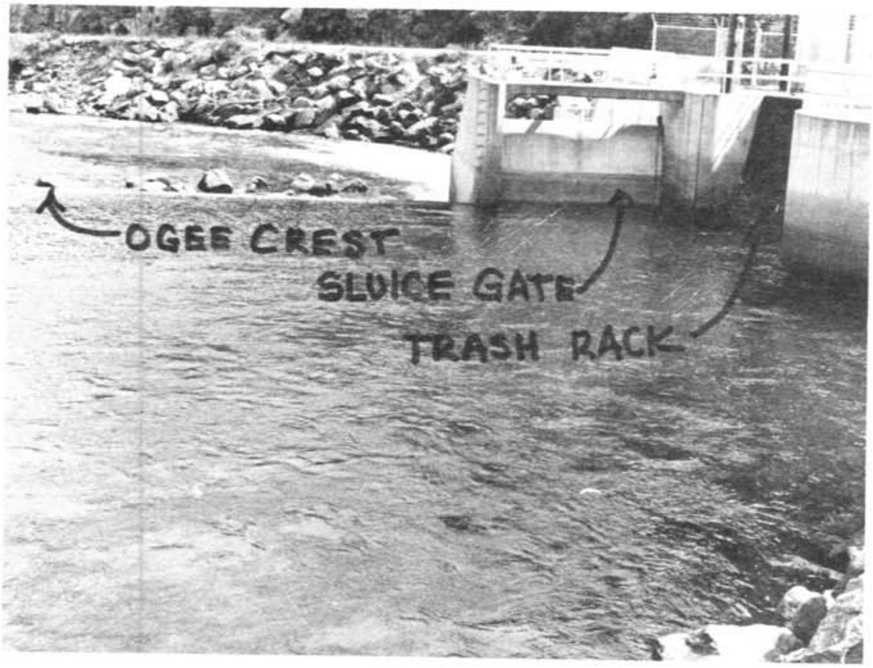

Figure 18–Sluice gate opening is maintained by the controller to hold a constant pool level.

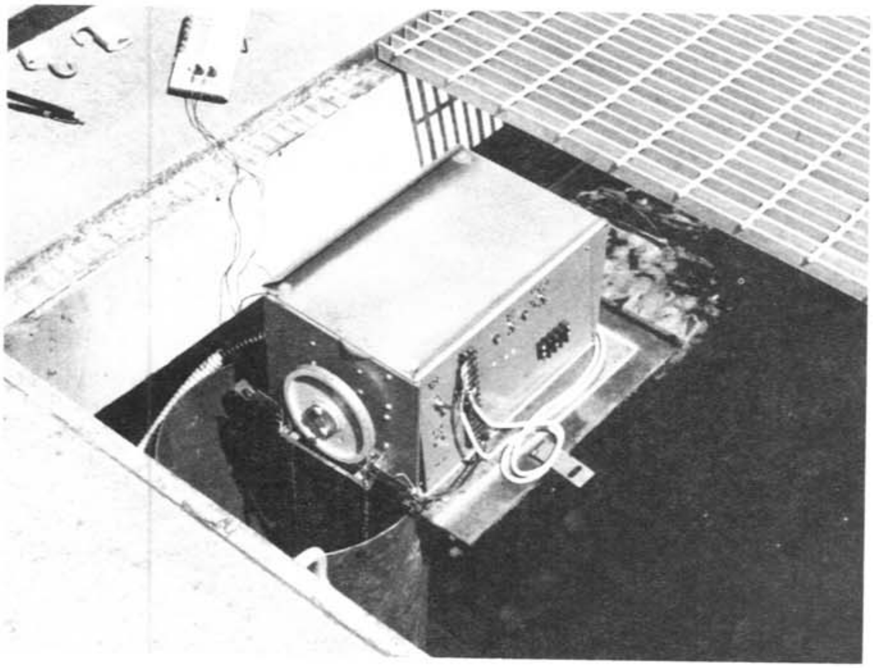

Figure 19.–Mechanical-electrical controller mounted on the stilling well downstream from the trashrack, North Poudre supply canal headworks.

The diversion gate to the canal is calibrated to provide the desired discharge through the Parshall flume for a constant head on the gate. Final settings for a discharge are made by adjusting the gate opening after reading the Parshall flume gage and recorder. With the water surface held constant upstream from the canal diversion gate by automatically controlling the sluice gate opening, the discharge to the North Poudre supply canal is maintained more nearly constant than can be done by manually adjusting the sluice gate opening.

Operation of Gate Controller to Change Gate Settings

The water surface target for the controller can be changed to hold the water surface upstream from the diversion gate at any elevation desired by adjusting the float tape with respect to the wheel pulley. With the pool water surface held near the top of the ogee crest, a maximum discharge of water will flow through the sluice gate while providing the desired canal discharge. This allows a maximum amount of bedload sediment to be sluiced through the sluiceway and downstream into the river and thereby reduces the bedload sediment deposits in the diversion dam pool near the sluice gate and sediment diverted to the canal.

For manual control, without use of an automatic gate controller, the sluice gate is set so a substantial discharge flows over the ogee crest, thereby reducing the discharge through the sluice gate. Consequently, the reduced flow through the sluiceway takes less bedload sediment through the sluiceway and more sediment builds up in the diversion pool near the sluice gate and is taken into the canal. Also, during high riverflows, coarse sediment moves over the left side of the ogee crest causing considerable erosion to the concrete. With the controller operating the sluice gate, the erosion on the ogee crest should stop.

Bypass Gate

A 762-mm (2-1/2-ft) wide by 762-mm (2-1/2-ft) high slide gate is used to bypass a minimum river discharge downstream when the riverflow is low. For this condition, the sluice gate is closed by the controller and any excess flow is diverted into the canal. With the gates set for this condition and the controller operating, if a flash flood occurs in the river, the controller will open the sluice gate as soon as the water surface rises above the the set point in the stilling well. The controller, thereby, operates to maintain maximum canal flow while passing as much excess flow as possible through the sluice gate and minimizing the flow over the dam.

Trashrack

During spring runoff and other high water periods, considerable trash, including branches and logs, are washed down the river. At times, during high diversion flow, considerable trash lodges on the trashrack. An excess head drop occurs across the trashrack and the controller will then cause the sluice gate to lower to maintain the proper target water surface in the stilling well upstream from the diversion gate. If the trash blocks a large portion of the trashrack, the head loss across the trashrack can be excessive to the point where the controller will cause the sluice gate to completely close without raising the water surface high enough to deliver the desired discharge with the set canal gate opening. Under trash conditions, if the gates are manually controlled, insufficient flow would occur in the canal with less blockage of the trashrack.

Trash should be removed from the trashrack regularly to minimize this condition. During the first irrigation season, with the controller in place, excess trash collected on the trashrack one or two times causing a small reduction in discharge in the canal. Routine visits to the diversion dam to remove the trash before the trashrack becomes excessively blocked are required.

The North Poudre Irrigation Co. operating personnel have developed a method based on the following steps for removal of trash from the trashrack by opening and closing gates for a short time and using reverse flow through the trashrack.

1. The sluice gate controller is turned off.

2. The canal gate is then closed and the sluice gate is fully opened manually.

3. The water surface in the pool above the diversion dam lowers causing water upstream from the canal gate to flow back through the trashrack, removing the trash and causing the trash to flow through the sluice gate, and to the river downstream.

4. An operator helps remove the trash with a trash rake.

5. The canal gate is reset to the proper opening and the sluice gate controller is turned on. The pool water surface returns to the previous level and discharge in the canal is returned to normal.

Conclusions

The use of a gate controller to control the sluice gate instead of manually adjusting the gate, requires study and experience to obtain full benefit from the controller. When the operator uses the gate controller as designed and keeps trash off the trashracks, the controller will maintain a more nearly constant discharge to the North Poudre supply canal and will save considerable time in setting the sluice gate and the canal gate. By causing all excess water, except during floodflows, to go through the sluice gate, most of the bedload sediment will go through the sluiceway and much less sediment will be drawn into the canal.

* * * * *

DISCHARGE ALGORITHMS FOR CANAL RADIAL GATES[6]

There is a real need to better define discharge coefficients of canal radial gates the way gates are used to control flow and water levels in a canal system. A direct benefit would result to canal operators who control canal systems manually or by remote manual/automatic supervisory control systems. A better technique defining the discharge coefficients with accuracy could have the potential of using canal radial gates as standard measuring devices. The installation of costly Parshall flumes, weirs, acoustic velocity meters, and many canalside turnout meters could be eliminated, thereby providing an economic benefit to the project.

An extensive research program in the USBR Hydraulics Laboratory using a 1:6 scale model radial gate (fig. 10) has developed a series of mathematical equations referred to as algorithms that represent the complete discharge characteristics of canal radial gates. Existing methods such as the orifice equation do not adequately consider important variations of upstream and downstream water levels, the gate lip seal design, and the gate geometry which significantly influences the discharge coefficient. Initial analysis of the laboratory data confirmed that Metzler's concept for illustrating the complete discharge coefficient family of curves (fig. 21), provides the best scheme for developing algorithms.[7], [8]

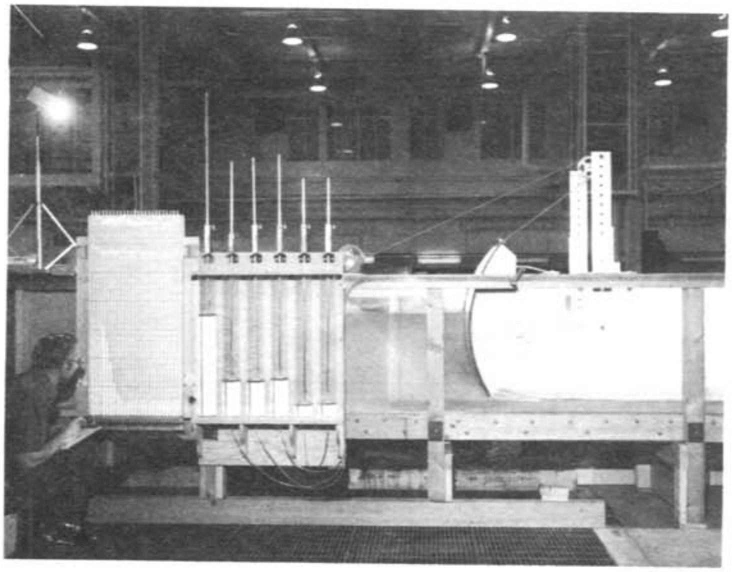

Figure 20.–A 1:6 scale model radial gate.

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[6] Written by Clark P. Buyalski, Research Hydraulic Engineer, Hydraulics Branch, Division of Research, Bureau of Reclamation, Denver, Colo.

[7] Metzler, D. E., "Model Study of Tainter-Gate Operation," M.S. Thesis, State University of Iowa, August 1948.

[8] Ippen, A. T., "Engineering Hydraulics–Chapter VIII, Channel Transition, and Controls," edited by Rouse, H., John Wiley and Sons, Inc., New York, N.Y.

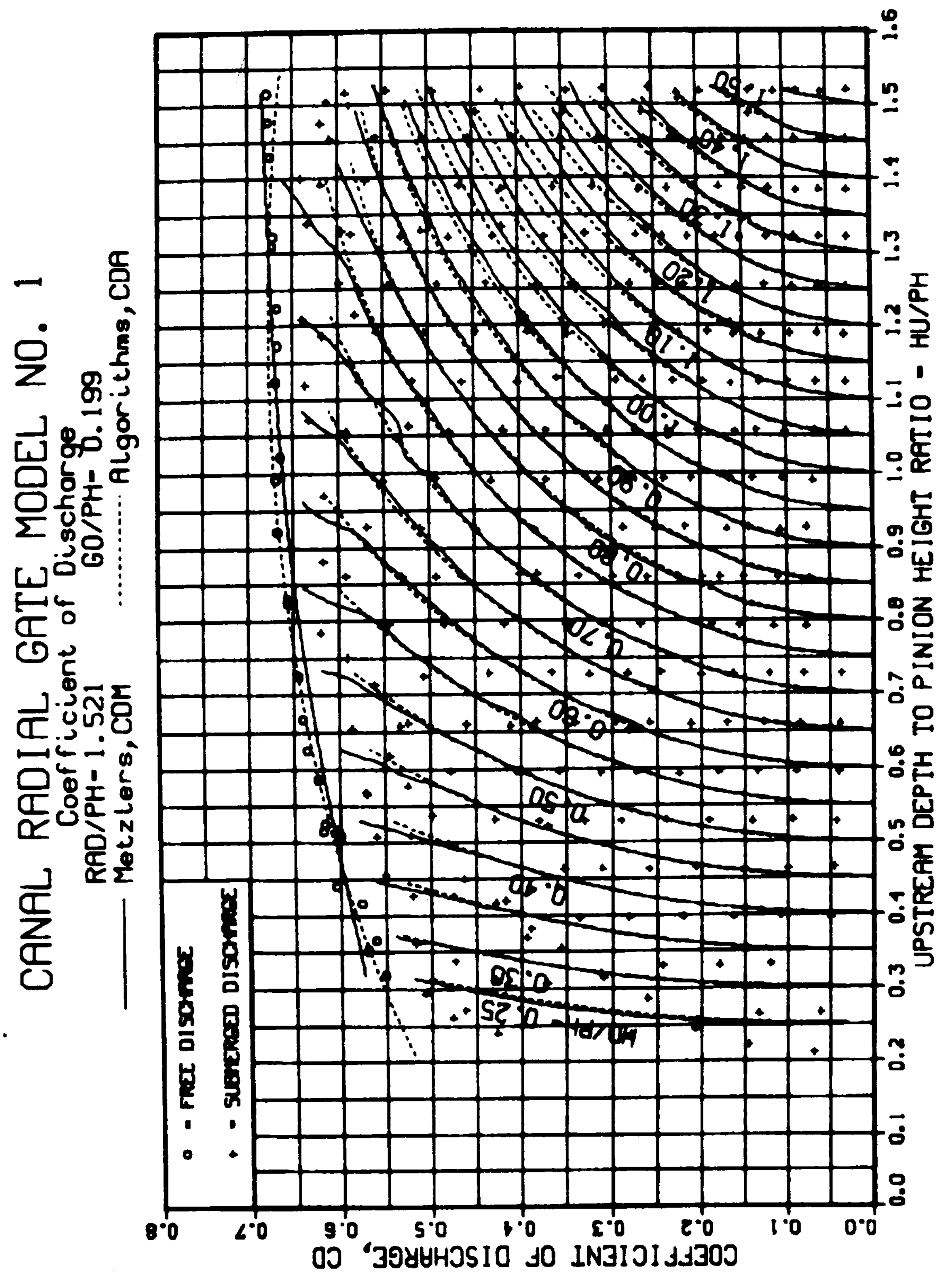
CANAL RADIAL GATE MODEL NO. 1
Coefficient of Discharge
RAD/PH-1.521
GO/PH-0.199
Metzlers, CDM
Algorithms, CDA
o - FREE DISCHARGE
+ - SUBMERGED DISCHARGE
HD/PH-0.25
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
UPSTREAM DEPTH TO PINION HEIGHT RATIO - HU/PH
COEFFICIENT OF DISCHARGE, CD
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

Figure 21.

The general equation for discharge through an underflow gate can be expressed as:

Equation 1

$$Q = CD \cdot GO \cdot GW \cdot \sqrt{2 \cdot g \cdot Y}$$

where:

Q = Discharge through underflow gate
CD = Coefficient of discharge
GO = Gate opening
GW = Gate width
g = Acceleration of the gravity force
Y = A definition of the head term

The definition of the head term, Y, in equation 1 is very critical to the development of the coefficient of discharge, CD. If the head term, Y, is defined as the head differential or the difference between the upstream and downstream water levels of the check gate, equation 1 becomes the well-known "orifice" equation and is used frequently to measure flow. Applying the orifice equation to canal radial gates the way they are used to control flow and water levels in a canal system does not produce an orderly family of curves from which a series of mathematical equations can be developed to represent the discharge characteristics with a high degree of accuracy.

Metzler's concept defines the head term, Y, in equation 1 as the upstream depth, HU, the distance from the gate sill to the upstream water surface. The coefficient of discharge, CD, calculated from equation 1 using the upstream depth, HU, for the head term, Y, must still be associated with the downstream depth, HD, for submerged flow conditions. Figure 21 best illustrates how this association can be achieved. Each data point is plotted with CD as the y-axis coordinate; the upstream depth, HU/PH, as the x-axis coordinate; and the associated downstream depth, HD/PH, is the z-axis coordinate. The three coordinates produce a map similar to a topography map. (Variations in the water depths and gate geometry are greatly simplified using dimensional analysis employing the pinion height, PH, distance as the geometric reference quantity.[8]) A contour mapping process of the submerged flow experimental data established an orderly family of curves representing even values of the downstream depth, HD/PH, shown as the solid lines in figure 21.

The contours of the downstream head, HD/PH, have conic characteristics. A conic curve, usually an ellipse, can be fitted to each curve with extreme accuracy. Therefore, the general conic equation was adopted as the basic algorithm to represent the contours of the map, figure 21, and is expressed as:

Equation 2

$$SCDA = \sqrt{E^{2}\cdot (D + VX)^{2} - VX^{2}} + FY$$

where:

SCDA = Coefficient of discharge for submerged flow conditions
E = Eccentricity of the conic curve and is a function of the directrix, D
D = Directrix of the conic curve and is a function of the downstream depth, HD/PH
VX = Horizontal x-axis distance to the focus of the conic curve and is a function of the E, D, HU/PH and HD/PH
FY = Vertical y-axis distance to the focus and is a function of the downstream depth, HD/PH

The map, figure 21, represents the flow characteristics for a wide range of water levels. However, only one set of gate geometry is recommended; i.e., one gate lip seal design (in this case, the hard rubber bar design), one gate opening, GO/PH, and one gate radius to pinion height ratio, RAD/PH. For each variation of geometry, a new map would be required. Numerous maps were developed from laboratory data from which additional algorithms were developed to vary the constants of the general conic equation 2 as a function of the gate opening, GO/PH, and the radius to pinion height ratio, RAD/PH. The algorithms are based on the gate lip seal having the hard rubber bar design. An additional algorithm adjusts the coefficient of discharge SCDA, equation 2, when the gate lip seal is of the music note design or when the gate lip has no seal (sharp edge). The hard rubber bar design has become the standard gate lip seal. The music note is of an older design and the gate lip without a seal is seldom used. However, analysis of the laboratory data shows that the different gate lip seal designs result in a 6 to 9 percent difference in the flow characteristics.

The same basic approach was applied to the laboratory data of the free-flow conditions except the constants of the general conic equation 2 are not dependent on the downstream depth, HD/PH.

A general use computer program has been developed to solve the canal radial gate discharge algorithms for free- and submerged-flow conditions. The geometry of the check-gate structure is entered as data statements. The program considers the variations of canal geometry upstream and downstream of the check structure and includes a test to determine if the flow is free or submerged. The opening for each gate can be computed by entering the upstream and downstream water elevations (or depth) and the total discharge, or the total discharge can be determined by entering the opening for each date by interactive response with a computer terminal.

The computer program can also provide a series of rating tables, such as shown in figure 22. The number of tables required could range from 40 to about 400 depending on the range

```
                    GRAND VALLEY UNIT HIGHLINE CANAL-STAGE 1, CHECK NO.  1

Q =    350.
HU =   40.16 40.14 40.12 40.10 40.08 40.06 40.04 40.02 40.00 39.98 39.96 39.94 39.92 39.90 39.88 39.86 39.84 39.82 39.80 39.78
 HD                                                      GATE OPENING
39.16  4.58  4.64  4.69  4.75  4.81  4.87  4.94  5.01  5.08  5.16  5.24  5.32  5.42  5.52  5.62  5.74  5.86  6.00  6.16  6.34
39.14  4.53  4.58  4.63  4.68  4.74  4.80  4.86  4.93  5.00  5.07  5.14  5.23  5.31  5.40  5.50  5.61  5.72  5.85  5.99  6.14
39.12  4.47  4.52  4.57  4.62  4.67  4.73  4.79  4.85  4.92  4.98  5.06  5.13  5.21  5.30  5.39  5.49  5.60  5.71  5.84  5.97
39.10  4.41  4.46  4.51  4.56  4.61  4.66  4.72  4.78  4.84  4.91  4.97  5.05  5.12  5.20  5.29  5.38  5.48  5.58  5.70  5.82
39.08  4.36  4.40  4.45  4.50  4.55  4.60  4.65  4.71  4.77  4.83  4.90  4.96  5.03  5.11  5.19  5.28  5.37  5.46  5.57  5.68
39.06  4.31  4.35  4.39  4.44  4.49  4.54  4.59  4.64  4.70  4.76  4.82  4.88  4.95  5.02  5.10  5.18  5.26  5.35  5.45  5.55
39.04  4.26  4.30  4.34  4.39  4.43  4.48  4.53  4.58  4.63  4.69  4.75  4.81  4.87  4.94  5.01  5.09  5.17  5.25  5.34  5.44
39.02  4.21  4.25  4.29  4.33  4.38  4.42  4.47  4.52  4.57  4.62  4.68  4.74  4.80  4.86  4.93  5.00  5.08  5.15  5.24  5.33
39.00  4.16  4.20  4.24  4.28  4.32  4.37  4.41  4.46  4.51  4.56  4.61  4.67  4.73  4.79  4.85  4.92  4.99  5.06  5.14  5.23
38.98  4.12  4.15  4.19  4.23  4.27  4.32  4.36  4.40  4.45  4.50  4.55  4.60  4.66  4.72  4.78  4.84  4.91  4.98  5.05  5.13
38.96  4.07  4.11  4.15  4.18  4.22  4.26  4.31  4.35  4.40  4.44  4.49  4.54  4.59  4.65  4.71  4.77  4.83  4.90  4.97  5.04
38.94  4.03  4.06  4.10  4.14  4.18  4.21  4.26  4.30  4.34  4.39  4.43  4.48  4.53  4.58  4.64  4.70  4.76  4.82  4.89  4.96
38.92  3.99  4.02  4.06  4.09  4.13  4.17  4.21  4.25  4.29  4.33  4.38  4.42  4.47  4.52  4.57  4.63  4.69  4.75  4.81  4.87
38.90  3.95  3.98  4.01  4.05  4.08  4.12  4.16  4.20  4.24  4.28  4.32  4.37  4.41  4.46  4.51  4.56  4.62  4.68  4.74  4.80
38.88  3.91  3.94  3.97  4.00  4.04  4.07  4.11  4.15  4.19  4.23  4.27  4.31  4.36  4.40  4.45  4.50  4.55  4.61  4.67  4.72
38.86  3.87  3.90  3.93  3.96  4.00  4.03  4.07  4.10  4.14  4.18  4.22  4.26  4.30  4.35  4.39  4.44  4.49  4.54  4.60  4.65
38.84  3.83  3.86  3.89  3.92  3.95  3.99  4.02  4.06  4.09  4.13  4.17  4.21  4.25  4.29  4.34  4.39  4.43  4.48  4.53  4.59
38.82  3.79  3.82  3.85  3.88  3.91  3.95  3.98  4.01  4.05  4.09  4.12  4.16  4.20  4.24  4.29  4.33  4.38  4.42  4.47  4.52
38.80  3.76  3.79  3.81  3.84  3.87  3.91  3.94  3.97  4.01  4.04  4.08  4.11  4.15  4.19  4.23  4.28  4.32  4.37  4.41  4.46
38.78  3.72  3.75  3.78  3.81  3.84  3.87  3.90  3.93  3.96  4.00  4.03  4.07  4.11  4.14  4.18  4.22  4.27  4.31  4.36  4.40
38.76  3.69  3.71  3.74  3.77  3.80  3.83  3.86  3.89  3.92  3.95  3.99  4.02  4.06  4.10  4.13  4.17  4.21  4.26  4.30  4.35
38.74  3.65  3.68  3.71  3.73  3.76  3.79  3.82  3.85  3.88  3.91  3.95  3.98  4.01  4.05  4.09  4.13  4.16  4.21  4.25  4.29
38.72  3.62  3.65  3.67  3.70  3.73  3.75  3.78  3.81  3.84  3.87  3.91  3.94  3.97  4.01  4.04  4.08  4.12  4.16  4.20  4.24
38.70  3.59  3.61  3.64  3.66  3.69  3.72  3.75  3.77  3.80  3.83  3.86  3.90  3.93  3.96  4.00  4.03  4.07  4.11  4.15  4.19
38.68  3.56  3.58  3.61  3.63  3.66  3.68  3.71  3.74  3.77  3.80  3.83  3.86  3.89  3.92  3.95  3.99  4.02  4.06  4.10  4.14
38.66  3.53  3.55  3.57  3.60  3.62  3.65  3.68  3.70  3.73  3.76  3.79  3.82  3.85  3.88  3.91  3.95  3.98  4.01  4.05  4.09
38.64  3.50  3.52  3.54  3.57  3.59  3.62  3.64  3.67  3.69  3.72  3.75  3.78  3.81  3.84  3.87  3.90  3.94  3.97  4.01  4.04
38.62  3.47  3.49  3.51  3.53  3.56  3.58  3.61  3.63  3.66  3.69  3.71  3.74  3.77  3.80  3.83  3.86  3.89  3.93  3.96  4.00
38.60  3.44  3.46  3.48  3.50  3.53  3.55  3.58  3.60  3.63  3.65  3.68  3.71  3.73  3.76  3.79  3.82  3.85  3.89  3.92  3.95
38.58  3.41  3.43  3.45  3.47  3.50  3.52  3.54  3.57  3.59  3.62  3.64  3.67  3.70  3.73  3.75  3.78  3.81  3.85  3.88  3.91
38.56  3.38  3.40  3.42  3.44  3.47  3.49  3.51  3.54  3.56  3.58  3.61  3.64  3.66  3.69  3.72  3.75  3.78  3.81  3.84  3.87
38.54  3.35  3.37  3.39  3.41  3.44  3.46  3.48  3.50  3.53  3.55  3.58  3.60  3.63  3.65  3.68  3.71  3.74  3.77  3.80  3.83
38.52  3.32  3.34  3.37  3.39  3.41  3.43  3.45  3.47  3.50  3.52  3.54  3.57  3.59  3.62  3.65  3.67  3.70  3.73  3.76  3.79
38.50  3.30  3.32  3.34  3.36  3.38  3.40  3.42  3.44  3.47  3.49  3.51  3.54  3.56  3.59  3.61  3.64  3.66  3.69  3.72  3.75
38.48  3.27  3.29  3.31  3.33  3.35  3.37  3.39  3.41  3.44  3.46  3.48  3.50  3.53  3.55  3.58  3.60  3.63  3.66  3.68  3.71
38.46  3.25  3.26  3.28  3.30  3.32  3.34  3.36  3.38  3.41  3.43  3.45  3.47  3.50  3.52  3.54  3.57  3.59  3.62  3.65  3.68
38.44  3.22  3.24  3.26  3.28  3.30  3.32  3.34  3.36  3.38  3.40  3.42  3.44  3.47  3.49  3.51  3.54  3.56  3.59  3.61  3.64
38.42  3.20  3.21  3.23  3.25  3.27  3.29  3.31  3.33  3.35  3.37  3.39  3.41  3.43  3.46  3.48  3.50  3.53  3.55  3.58  3.60
38.40  3.17  3.19  3.21  3.22  3.24  3.26  3.28  3.30  3.32  3.34  3.36  3.38  3.40  3.43  3.45  3.47  3.50  3.52  3.54  3.57
38.38  3.15  3.16  3.18  3.20  3.22  3.24  3.25  3.27  3.29  3.31  3.33  3.35  3.38  3.40  3.42  3.44  3.46  3.49  3.51  3.54

NOTE:  UPSTREAM WATER SURFACE ELEVATION = 4700.00 + HU
       DOWNSTREAM WATER SURFACE ELEVATION = 4700.00 + HD

Q =    350.
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Figure 22.–Rating table.

of upstream water levels, HU, desired and the resolution of water levels (0.006 m) (0.02 ft) and discharge (0.14 m^3/s) (5 ft^3/s) required to reduce the amount of interpolation between tables. Having a rating table consisting of 400 pages (each page represents one flow condition) may sound to an operator to be overwhelmingly complicated. However, after the first time the tables are used, it will become evident the tables will be relatively easy to use regardless of the number of tables or pages involved. In fact, the more tables, the easier it is to obtain either total discharge of gate openings because the need to interpolate between pages (when the resolution of water levels and discharge are small) is not necessary. It should be pointed out that it will be necessary to measure the upstream and downstream water surface elevations (or depths) and the gate openings with a resolution of plus or minus 0.002 m (0.005 ft) to maintain good flow measurement accuracy.

The laboratory verification test program compared the predicted discharge coefficient from the final series of algorithms to the experimental data of the submerged- and free-flow conditions within a standard deviation of 3 percent. The algorithms predicted coefficient of discharge is shown as the dashed line in figure 21 as an example of comparison to the laboratory data.

At the present time, a field test verification program is being conducted. About 15 different canal radial gate prototype installations, each having a significant variation in the geometry, are being investigated. The objective is to establish the degree of accuracy that can be anticipated for practical application. Preliminary results indicate the canal radial gate discharge algorithms will have an accuracy equivalent to that of Parshall flumes which have an accuracy in the range of 3 to 5 percent.

The final series of algorithms are much more complicated than originally desired. However, the complexity of the algorithms was necessary to achieve satisfactory accuracy. It was necessary to represent the complete discharge characteristics of a wide range of water levels and radial gate geometry normally encountered in the design of canal radial gate check structures constructed by the Bureau of Reclamation. The computer program developed for general use is easily adaptable to mathematical models used to simulate canal systems. The program can also be used by operators of canal systems in the form of interactive computer terminal response or by developing rating tables. Even though the computer program is relatively large, it is anticipated the program can be adapted to minicomputers, microprocessors, desk calculators, and hand calculators if sufficient memory capacity is provided.

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LABORATORY STUDY VERIFIES COMPUTER CALIBRATION OF RAMP FLUMES[9]

A model study was conducted to gain Bureau experience with ramp flumes; to verify accuracy of computer calibrations; to verify existing design criteria; develop further criteria, if needed; and to determine flume response to some simulated field conditions.

Messrs. J. A. Replogle and A. J. Clemens of the Water Conservation Laboratory, Agriculture Research Service, USDA (U.S. Department of Agriculture), developed computer programs for calibrating measuring flumes. Their programs account for boundary layer development and accuracies of 2 to 3 percent are claimed. Their simplest type of flume consists of a 1:3 approach ramp and a horizontal downstream sill shown in figure 23.

Various technical articles by Messrs. Replogle and Clemens indicate that the ramp flumes are easy to install in existing canals to meet after-the-fact water measuring requirements for operation and conservation needs. Small ramp flumes are reported to cost one-tenth to one-third of Parshall flumes. They are claimed to have small head losses 19 to 64 mm (3/4 to 2-1/2 in), and are thus able to tolerate higher submergences. Submergences of 85 percent for vertical downstream crest face and 95 with an added 6:1 downstream ramp have been cited.

Another important advantage is that they can be computer calibrated, using after-construction dimension measurements. Thus, form slipping and construction errors can be accounted for accurately. Computer calibration allows more tolerance during construction, saving time and cost. The main construction requirements are that the crest is of proper length and is level both in direction and transverse to the flow. The main calibration requirement is that the dimensions, especially the crest width of the ramp and canal section, be carefully measured after construction.

Bulletin No. 107 completely reproduced the article by Messrs. A. J. Clemens and J. A. Replogle from the April 1978 issue of *Irrigation Age*, "New Flume Breakthrough for Ditch Irrigation," describing some Arizona Agriculture Research Center experience with ramp flumes. We were asked by field people if we had any experience or data verifying the claimed accuracy. Our need for experience with ramp flumes was the main reason for making this model study.

Mr. Replogle provided the E&R Center with two computer programs: One is a BASIC program for calibrating simple trapezoidal flumes, and the other is a FORTRAN program capable of calibrating complex trapezoidal flumes with multiple side slopes in the approach and throat section. The programs have been modified and are being used to design flumes at the E&R Center.

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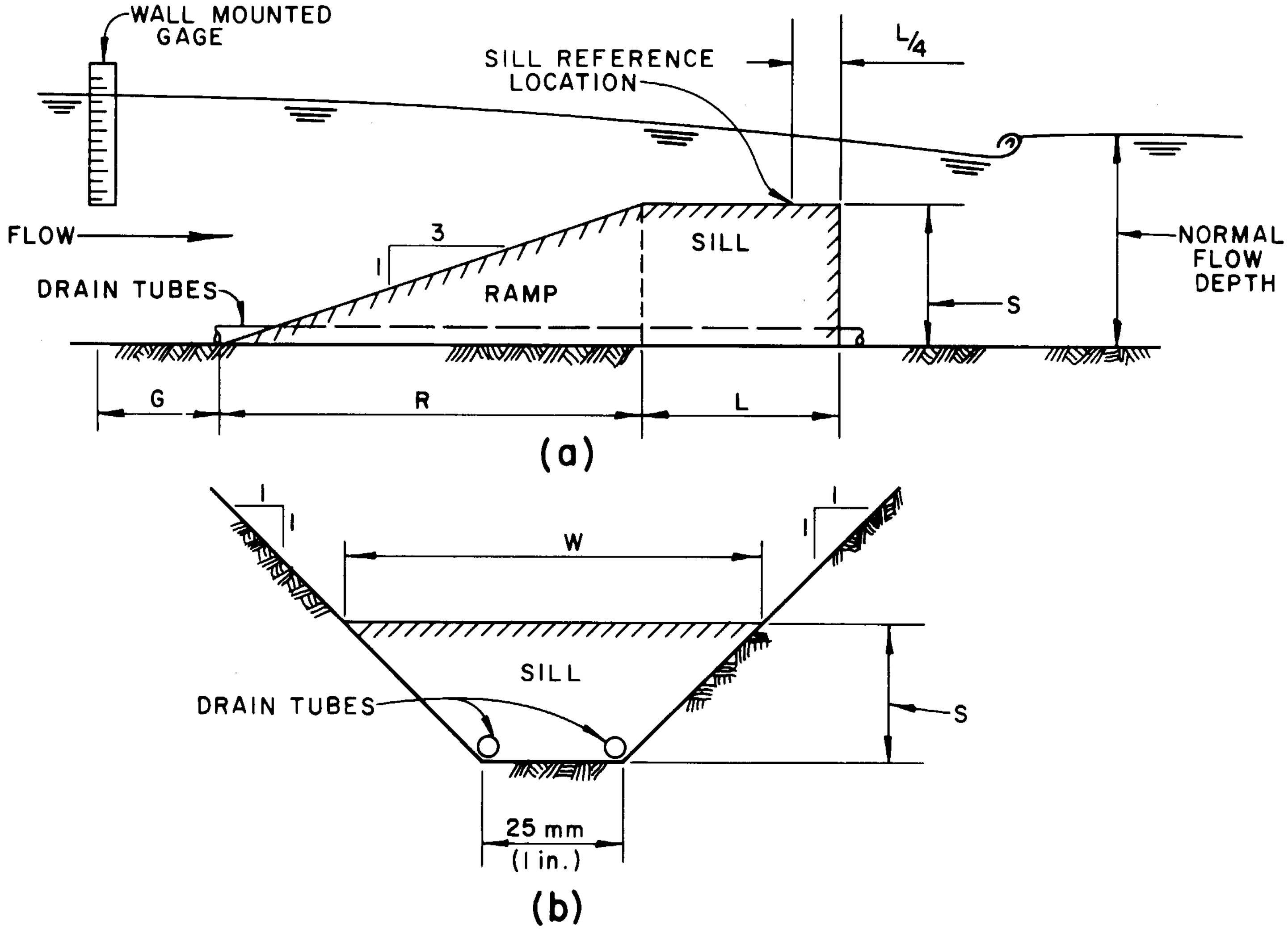

Figure 23.–Approach ramp and horizontal downstream sill.

A ramp flume is actually a form of broad-crested weir. Thus, it is usually necessary that heads less than one-tenth the crest length not be used because friction governs the depth of flow on the crest rather than attaining flow at critical depth and flow undulations occur. Also, heads greater than two times the crest length should not be used because of flow curvature and hydrostatic pressure distribution cannot be assumed.

A 1:3 model was used to simulate 1.4-m^3/s (50-ft^3/s) ramp flume with a crest height about 0.3 m (1 ft) and crest width of 1372 mm (4.5 ft). The approach channel and control section had 1:1.25 side slopes and a 610-mm (2-ft) bottom width. Four different crest lengths were laboratory calibrated and compared to computer calibrations. The submergence limit was determined for one crest length.

Accuracy comparisons of model calibrations and computer calibrations for four different length ramp flumes indicate that computer-calibrated, small-size ramp flumes are at least as accurate as Parshall flumes and have a potential accuracy of the claimed 2 to 3 percent.

The criteria that the measuring head be less than half the crest length should be adhered to in order to approach the potential accuracy of 2 to 3 percent.

Pressure measurements indicated that the ramp flumes are relatively insensitive to measuring station location, and 0.3 m (1 ft) upstream of the toe of the ramp is generally adequate for small ramp flumes in trapezoidal canals. If unusual shaped flumes are designed, the selected measuring station should be three to four maximum measuring heads upstream from the control flow section as a precaution.

Cost estimates for a 26.3-m^3/s (930-ft^3/s) ramp flume were about 45 to 60 percent of that of the Parshall flume for a retrofit situation. Mr. Replogle cited savings of one-tenth to one-third of an equivalent Parshall flume for small ramp flumes. Some of this cost scale effect was probably due to more common foundation requirements for both Parshall and ramp flumes of large sizes.

Model data indicated that submergence limit is about 84 percent of the measuring head which is close to the claimed 85 percent. Thus, the minimum required head loss is close to 15 percent of the measuring head.

The ramp flume is a suitable alternative for more expensive water measuring devices. Despite the relatively high crest completely across the canal bottom, a ramp flume has less head loss than flume devices that converge flow from the sides. They are reported not to have any more significant sediment problems than Parshall flume devices. If designers and project people are interested in using ramp flumes, we can assist them by using the computer calibration programs. Channel geometry and the hydraulics, both upstream and downstream of the measuring site, are needed to check for adequate freeboard and minimum required head loss. Results of computer calculations also would be used to determine discharge measuring limits.

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