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OF
CENTRAL VALLEY PROJECT CANALS

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Edwin F. Sullivan
and
Clark P. Buyalski
Office of the Regional Director
Bureau of Reclamation
Department of the Interior
Sacramento, California

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By
Edwin F. Sullivan, 1/ F., ASCE
and
Clark P. Buyalski, 2/ A.M., ASCE

Introduction

Canal operation is one of the important components of the operation of the Bureau of Reclamation's Central Valley Project. The Central Valley Project is a two billion dollar enterprise providing water and power service throughout northern and central California in an area some 500 miles long and 100 miles wide. The project includes reservoirs, powerplants, pumping plants, canals, and various other related features. There are nine main canals in operation or under construction with a total length of 685 miles. The first canal was placed in operation in 1940. Others have been in operation for lesser periods and three are still under construction. Some of the canals are of large capacity and others are small. Most of them are used for delivery of irrigation water, but some provide significant municipal and industrial service, and some provide fish and wildlife benefits.

With this wide diversity as to time of construction, size, and type of service, it is only natural to expect that operating conditions vary significantly.

This paper describes some of the past experience of the Bureau of Reclamation in operating the canals of the Central Valley Project and its plans for the future.

1/ Assistant Regional Director, Region 2, Bureau of Reclamation, Sacramento, California
2/ Civil Engineer, Irrigation O&M Branch, Region 2, Bureau of Reclamation, Sacramento, California

Modes of Operation

Canal operation can be divided, for convenience of discussion, into three basic classifications: conventional, remote, and automatic.

The conventional mode of operation is basically a manual operation, although labor saving devices and machines may be used to assist. The basic procedure involves (a) an order by the water user, (b) a change (increase or decrease) in the input of water at the head of the canal to meet that order, and (c) operation of the canal by having the "ditch-rider" follow the wave by which the change is propagated downstream, making adjustments in the control structures, such as check gates, turnouts, and occasionally wasteways when the front of the wave arrives. An experienced operator can anticipate the water arrival at the scheduled time of the requirement within acceptable limits. Practically, there are difficulties in making the proper adjustments. This type of operation is greatly personalized. On a large canal many people are involved. The "ditchrider" in the field must anticipate and report what his "watermaster" in the office needs to know. A team effort is involved, and each must use judgement in his respective area of responsibility. The success of the operation depends in large measure on the skill of the team, which is based on how well the members of the team have learned, through experience, the reaction of the water in the particular canal as flow conditions vary.

The remote mode of operation involves the use of electronic telemetering devices which bring operating information from the canal into the central office and remote control devices which are used to adjust flow control structures from the central office by "push button control." In a remote operation, the need for the "ditchrider" is eliminated or reduced and direct operational control is given to the "watermaster" in the central office. Thus the "human input" tends to be moved from the field to the office and from the physical to the intellectual. The remote mode of operation enables one person to have concurrent information on the entire canal system. Thus changes in one portion of the system that will affect other portions can be noted promptly and appropriate adjustments made. It is possible to have capability in a remote system to make simultaneous adjustments of flow at many control structures, which facilitates the rapid mass transfer of water, resulting in an improved operation.

Automatic canal operation is attained through a mechanical and/or electronic system in which the components are designed to sense and interpret changes in flow conditions and to make necessary adjustments to meet the operating needs. The "human input" in this case, involving a blend of technical knowledge and practical experience, goes into the design of the system. The "human input" is reduced to a degree where it is virtually eliminated from the actual operation. The

automatic sensing and control devices may in some cases be self-contained and be located on the canal itself. In other cases the information may be telemetered into the central office where automatic or computerized equipment evaluates the situation and operates the control structures.

These three modes of canal operation (conventional, remote, and automatic) are not mutually exclusive. In many cases canal operation involves the use of a combination of two or perhaps all three. The relative merits of the three approaches depend on the circumstances of use. In some cases one system will be better than another, or a combination will be even better.

The Central Valley Project has a wide variety of conditions of canal operation. The conventional method of operation is the most prevalent at the present time, but installations involving remote and automatic operation are being used to an increasing extent. The new canals now under construction are being studied to establish the best mode of operation. The older canals are being reviewed to determine what changes are desirable and justified.

The rest of this paper is devoted to a description of three specific examples of canal operation on the Central Valley Project, with the hope that they will illustrate the alternative approaches and the progress being made to select the best in each individual case.

Friant-Kern Canal

The Friant-Kern Canal is one of the largest of the Central Valley Project canals. It originally was designed for operation in the conventional manner. However, almost from the beginning of its operation, there has been a sustained effort to develop automatic operation.

The Friant-Kern Canal begins at Friant Dam on the San Joaquin River about 20 miles northeast of Fresno, California. The canal is a main conveyance system and delivers a supplemental water supply southerly a distance of 152 miles, terminating near Bakersfield. The canal begins with a capacity of about 4,000 cubic feet per second and reduces to about 2,000 cubic feet per second in the end reach. Construction began in 1945 and was completed in 1951.

The headworks consist of four 96-inch hollow-jet valves in the left abutment of Friant Dam which can regulate the flow within few percent of the desired discharge. These valves have vernier adjustment capability which enables the operator to set the valve opening very close to the desired discharge. Most of the Friant-Kern Canal is concrete-lined with a maximum bottom width of 36 feet, a normal depth of 15 feet, and a maximum top width of 75 feet. The bottom slope varies from 0.0001 in the upper reaches to 0.00006 in the lower reaches with an overall average slope of about 0.000098, (a total drop of 79 feet for

the whole canal or about one-half foot per mile). There are 14 check structures in the canal with radial gates varying in number from one to five. The spacing between check structures varies from 5.5 to 23 miles and the drop in invert elevation between checks varies from 3 to 12 feet.

The average water delivery through the Friant-Kern Canal is 1,500,000 acre-feet annually. However, the supply is quite variable and ranges from less than 600,000 acre-feet in dry years to over 2,000,000 acre-feet in wet years. Thus, flow conditions are quite variable from one year to the next. The major use of water is for irrigation. Deliveries are made on a regular basis to 23 water districts, but in a wet year the number may nearly double. There are 100 turnouts from the canal ranging in capacity from over 1,000 c.f.s to less than one c.f.s. The turnouts are distributed throughout the length of the canal, except that there are only a limited number in the first thirty miles.

The nature of the service requires expert forecasting by the Bureau of Reclamation to predict the water supply that will be available to the Project. The individual water user submits his water requirements in advance to his respective irrigation district. Each district then gives its total requirement to operating personnel of the Bureau of Reclamation, which compiles the orders to obtain the water needs for the entire canal. Scheduling procedure is done on a yearly, monthly, weekly, and daily basis with each schedule progressively refining the water requirements

needed. It may take up to three days for water to reach the lower reaches of the canal.

Management of some of the main canal turnout diversions is given to the water districts. The turnout gates are opened at the beginning of the irrigation season by canal operators and the gates are left open until the irrigation season has ended. It is the responsibility of the district to maintain a uniform diversion in accordance with its scheduled amount. Each turnout is visited every day by canal operators and they record the rate of flow and the quantity taken since the previous day. If the rate and the amount taken differ substantially from what was ordered, the district is promptly notified and is requested to take corrective measures to adhere more closely to the schedule.

The basic operating problem on the Friant-Kern Canal is that of compensating for mismatches between water orders and water deliveries. The arrival time of a flow change will often differ from the scheduled time at a particular point of delivery. It is difficult for irrigation districts to maintain a uniform flow and adhere precisely to their scheduled orders. The amount of transitory storage in the canal prism will vary with the magnitude of the change in flow. These flow situations; i.e., minor mismatches, differences in arrival time, and variances in turnout delivery, contribute to unsteady flow conditions in the canal.

One of the most troublesome problems is maintaining constant water depths at a turnout. Good service to the customers requires this problem to be minimized. A fluctuating water level at the main canal turnout causes a change in discharge in the distribution system which adversely affects the water users schedule.

Soon after the Friant-Kern Canal was put into operation and before the service area was fully developed, the problem of maintaining a constant water level above the White River check structure, mile 112.9, developed for reasons discussed above. In fact, it was so difficult that men were required to be stationed at this check 24 hours a day, 7 days a week in order to maintain proper service to a major turnout nearby. This was not only a costly operation but also an inefficient one. Even under continuous vigilance, undesirable variations in the water level could not be eliminated.

Bureau operating personnel realized that an automatic device with good sensitivity to water level changes was needed to improve efficiency. They developed a simple automatic device to adjust a check gate whenever the upstream water level deviated more than a predetermined amount from a desired set point. It was named the "Little Man" when the local canal superintendent reported that this successful device was the best little man he had on his crew. The first

"Little Man" was put into trial operation in 1952, and was an immediate success. Since that time, as experience accumulated, the original design has been modified and improved. Sixteen similar devices have been installed on check gates in the canal and on several Parshall flumes used to make water deliveries.

By use of this "Little Man" device the Friant-Kern Canal operation can be considered to be automatic for daily flow changes of less than 100 c.f.s. Flow changes greater than 100 c.f.s. are still taken through the check structures by the "ditchriders" in the conventional manner.

The system components of the "Little Man" device are designed specifically to maintain a constant water level by adjusting the controlling check gate. The design concept is an ON-OFF, TWO-POSITION CONTROL. The system is "ON" only when the water level being controlled by the check structure deviates from the desired set point, which is usually the designed water depth of the canal. The plus or minus deviation in the water level from the preselected set point activates the appropriate electrical circuit to raise or lower the check gate.

The water level sensor is generally located above the check structure. The gate is signaled to raise when the water level rises above the set point and to lower when the water level drops below the set point by a prescribed amount, usually $\pm$ 0.02 foot. Timeclocks are used to energize

the gate hoist motor starter to allow a few seconds of travel and then provide an interval of rest time between gate movements. These time sequences are necessary to prevent excessive gate travel or overshooting.

Recently, additional water level sensor components were added in parallel to accomplish gate travel movement proportional to the magnitude of the deviation from the same preselected set point. The additional components sense larger water level deviation increments and each stage resets the timeclock sequence and increases the time of gate travel with shorter intervals between gate movements. The design concept is now an ON-OFF, RESET, TWO-POSITION CONTROL.

An additional feature has also been added recently. The desired set point is motorized so that it is adjustable to provide greater operational flexibility. This feature is used primarily when the canal is to be unwatered. The motor, which is manually actuated when desired, continuously drives the set point downwards, and the system will then, in effect, sense a high water level and signal the gate to open, lowering the water surface. The design concept can now be called ON-OFF, RESET, ADJUSTABLE, TWO-POSITION CONTROL.

Further details can be found in the Department of the Interior, Bureau of Reclamation, Irrigation Operation and Maintenance Bulletin No. 20 for April, May and June 1957, and No. 58 for October, November and December 1966.

The "Little Man" device has been in use on the Friant-Kern Canal since 1952. As experience has accumulated it has been possible to give the "Little Man" more capabilities and to refine its limits. Its development to date has been largely through practical experimentation, recognizing the need to solve a particularly troublesome operational problem.

The "Little Man" has been successful in solving the problem of maintaining constant water levels on the upstream side of individual check structures. This involves "UPSTREAM CONTROL." The basic action of "UPSTREAM CONTROL" is to transfer the effects of mismatches downstream by changing the downstream discharge. Operating under this concept, provision must be made somewhere downstream to accommodate the positive and negative discharges. This is done on the Friant-Kern through the use of an equalizing reservoir at mile 121.5 with an effective capacity of 700 acre-feet which regulates the flow to smooth out this variation.

For reaches between check structures below the equalizing reservoir, the "Little Man" water level sensor is located a short distance downstream of the check structure. The device maintains a constant water level at this point in the canal by adjusting the upstream controlling check gate. The operating concept at the check structure below the equalizing reservoir therefore involves "DOWNSTREAM CONTROL." The basic action of "DOWNSTREAM CONTROL" is to transfer the effects of the mismatches upstream by changing

the upstream discharge. The equalizing reservoir is then used for the dual purposes of smoothing out the flow changes downstream as well as upstream.

Through use of the "Little Man" device, a successful mode of operation has been developed for the Friant-Kern Canal. Field operating personnel have stated that the "Little Man" does what it is told to do and asks no questions. They have come to depend on it to provide a substantial degree of self regulation of check structures.

Use of the device has made it possible to operate the canal with fewer people. It also has resulted in relatively constant water levels in the canal, which is particularly beneficial to the water users in facilitating uniform deliveries through turnouts. The automatic mode of operation as achieved on the Friant-Kern Canal has provided another benefit. Operation spill, characteristic of a conventional mode of operation, has been eliminated with a resultant saving of water.

The present use of the "Little Man" has developed over a period of 16 years. No effort was made to determine the monetary benefits received from the system during this period of time. However, the "Little Man" has reduced manpower, provided better service to water users, and saved water over the years. The control devices have been built by field operating personnel for a few hundred dollars each. There is no doubt that benefits achieved outweigh the cost.

Delta-Mendota Canal

The Delta-Mendota Canal is another large canal of the Central Valley Project. Until recently, it was operated in the conventional manner. In 1968 a telemetering and remote control system was placed into operation to effectively meet new operating requirements developed by the addition of the San Luis Unit, which will utilize off-season capacity of the Delta-Mendota Canal to transport its water supply for the first 70 miles from the Delta.

The Delta-Mendota Canal begins at the Sacramento-San Joaquin Delta and extends southerly along the west side of the San Joaquin Valley. This canal is a main conveyance system delivering a supplemental water supply to the western side of the San Joaquin Valley. It is 117 miles long and terminates at the Mendota Pool located on the San Joaquin River. The canal begins with a design capacity of 4,600 cubic feet per second and reduces to 3,210 cubic feet per second in the end reach. Construction began in 1946 and was completed in 1952.

The headworks consist of the Tracy Pumping Plant having six centrifugal pump units each rated at 767 cubic feet per second and each pump motor requiring a power supply of 15,000 kw. The Pumping Plant receives its water from an intake channel connected to Old River which is a tributary channel in the Delta. The six pump units lift the water

200 feet through three 15-foot diameter penstocks to the gravity point of the Delta-Mendota Canal, mile 3.5. From the gravity point, the first 95 miles are concrete-lined and the remaining 18 miles are earth-lined. The concrete-lined section has a maximum bottom width of 48 feet, a normal depth of 16.5 feet, a maximum top width of 107 feet, and a bottom slope of 0.00005 (3 inches per mile). The earth-lined section has a maximum bottom width of 62 feet and a maximum top width of 139 feet. There are 20 check structures in the canal spaced on an average of every six miles.

The average annual delivery planned for the original Delta-Mendota Canal was 1,600,000 acre-feet, over one-half of which is carried through to the end of the canal. With the addition of the San Luis Unit, the delivery will be increased to about 3,000,000 acre-feet annually.

The water for San Luis will be diverted at mile 70 into the intake channel of the O'Neill Forebay Pumping Plant. The O'Neill Pumping Plant then lifts this water 50 feet into the O'Neill Forebay Reservoir. From this point, the water can either be diverted directly into the San Luis Canal or pumped into the San Luis Reservoir and stored for later release. In 1967, for the first time, 250,000 acre-feet of water was routed to the San Luis Unit this way.

The major use of water is for irrigation. Deliveries are made to 37 water districts from the Delta-Mendota Canal. There are 213 turnouts from the canal ranging in size from 200 c.f.s. to less than 1 c.f.s. The inlet capacity from the canal to the Mendota Pool is 3,200 c.f.s. which is often reached during the peak of the irrigation season. The inlet capacity to the O'Neill Pumping Plant is 4,200 c.f.s. The Delta-Mendota Canal will be operated at close to full capacity the year round in order to meet both the original canal needs and the added San Luis load.

The procedure for compiling the water needs of the Project is similar to that explained on the Friant-Kern Canal. The water users along the Delta-Mendota Canal are given responsibility for managing their turnout diversions from the Canal. However, unlike the Friant-Kern Canal which receives its water by gravity releases from Millerton Lake, and can be regulated closely at its head, the Delta-Mendota Canal has six large centrifugal pumping units each with a designed discharge capacity of 767 c.f.s. Therefore, the input to the Delta-Mendota Canal can only be regulated in increments of one pump discharge. The problem of input regulation is further complicated by the desirability of operating with offpeak power insofar as possible.

Under these circumstances maintaining constant discharges in the upper reaches of the Delta-Mendota Canal is virtually impossible. The combination of daily orders to main canal turnouts and the order to the

Mendota Pool seldom matches the discharge of an integral number of pumps. It is necessary to operate a unit for only a portion of a 24-hour period. Therefore, part of the period, the Tracy Pumping Plant is either supplying too much or too little water to the canal. However, over a 24-hour period the supply averages out to coincide with the demand.

The pump unit (or units) that are required to be operated for only a portion of the 24-hour period are scheduled, insofar as practical, for operation between the hours of 10 p.m. and 7 a.m. This 9-hour period of time is the offpeak period of power operation.

When pumping offpeak, the canal is required to store water. The first 70 miles of canal consisting of 13 checked pools are used for this purpose. The water level usually is at a minimum in the canal at 10 p.m. and the increased offpeak pumping begins at this time. Under the previous conventional operation of the canal, a "ditchrider" began his trip down the canal following the positive surge wave. He arrived at the first check structure just ahead of the surge wave and recorded the upstream and downstream water levels for later use by the Watermaster. When the positive surge wave arrived, he opened the check gate according to the amount specified on his trip sheet issued to him by the Watermaster. The revised gate opening passed the increased flow except for a specified

amount which was held back to increase storage in the first pool. This sequence of gate operation progressed downstream with the "ditchrider" arriving at each consecutive check just prior to the surge wave which travels about 12 miles per hour. It would take the "ditchrider" about 5.2 hours to reach check 13 at mile 70. He then returned to the Tracy Pumping Plant along the canal bank and made spot checks and again recorded the upstream and downstream water levels at each check structure.

If there was a scheduled change in delivery to the Mendota Pool, another "ditchrider" would take over below check 13 by adjusting the check gates in a similar procedure except water is not stored in these lower reaches. Downstream of check 13 the operation of the check structures is different in that constant water levels are maintained upstream of each check.

When the offpeak pumping increment was stopped, another "ditchrider" began a trip down the canal following the same procedure as the 10:00 p.m. change except the check gates were lowered as the negative surge wave arrived. The new gate position was such that the flow downstream was reduced by the decrement in pumping except for the amount to be taken out of storage. The storage was reduced at a constant rate during the onpeak hours to return the check pools to their original levels again just prior to the next offpeak cycle. The water levels usually changed one to two

feet during a 24-hour period. Water users along this section of canal have learned to accept this water-level variation and have made provisions in their operation to accommodate it. Their turnouts are designed for the lowest operating level and their turnout gate openings are set such that they obtain an average flow corresponding to their total scheduled demand for the day.

The conventional operation described above can normally accommodate a two pump differential between the onpeak and the offpeak periods taking 5.2 hours to initiate flow changes at mile 70, the diversion point to the San Luis Unit's O'Neill Pumping Plant. This means that only about half of the 9-hour offpeak period can be utilized for pumping at O'Neill. However, the full nine hours could be used if the two pumping plants, Tracy and O'Neill, were started simultaneously and all the check gates opened at the same instant at the beginning of the offpeak period and then the reverse happen at the end of the nine hours.

In order to operate under this remote mode concept, the facilities require "push button control" from a centralized location. Recently a telemetering and remote control system was installed on the Delta-Mendota Canal for the first 70 miles including check 13 and the O'Neill Pumping Plant. The system has operated throughout the 1968 irrigation season providing operational capabilities to accomplish an offpeak pumping operation.

The remote control system gives the Watermaster the capability to monitor water levels (above and below) and gate openings at the 13 check structures each of which has three radial gates. Alarms are triggered by high and low water levels above each check structure and by power outage at any check structure. Any or all of the three radial gates at the 13 check structures can be raised or lowered to any desired position. The monitoring and control is done on a selective basis using a digital type telemetering system. The communication channel consists of a buried cable along the top of the canal bank.

The radial gates at each of the 13 check structures can, within a matter of minutes, be commanded to raise or lower to an opening specified by the Watermaster. The entire change for all 13 checks is completed in about 20 to 25 minutes depending on how far the gates have to be moved, since they travel at a speed of only about one foot per minute. This short period of time required to initiate new instructions to all the check structures to move the gate to a new position permits a simultaneous change in discharge for the entire 70 miles. At the same time the operator at the control console can start or stop pump units at O'Neill Pumping Plants. Once the start or stop button is pushed, the units automatically go through a startup or shutdown cycle. The status of each unit is monitored from the same console.

Centralized control became necessary as the operation of the Delta-Mendota Canal became more complex. Routing winter and spring flood runoff into the San Luis Unit combined with the desire to attain an optimum offpeak pumping operation required a remote control system for the canal and the O'Neill Forebay Pumping Plant. Operations now include a three pump offpeak change at Tracy and O'Neill Pumping Plants simultaneously, equivalent to a change (increase or decrease) of flow of 2,300 c.f.s. A four or five pump change (3,800 c.f.s) appears possible.

The accomplishments of the system have increased flexibility, reliability, and efficiency of operation. The requirement has been reduced from a three 8-hour shift to a one 8-hour day shift for "ditchriders" from mile 3.50 to mile 70. Including the estimate of power savings, the overall system has benefit to cost ratio of 3 to 1. The cost includes the requirements for the additional services of a hydraulic engineer and an electronic engineer to operate and maintain the control system. Contractual cost for installing the necessary remote control equipment and associated appurtenances such as stilling wells was $662,000.

The power benefits resulting from the offpeak operation during the buildup years of the San Luis Unit make up the largest share of the benefits. After the San Luis Unit reaches the ultimate demand in 10 years,

the Delta-Mendota Canal will run at or near its full capacity for several months. When the canal is operating at full capacity, check gates are not needed for water surface control. The remote control system of the canal will not be used as frequently for the purpose of facilitating an offpeak pumping operation during this time. However, its primary purpose will shift to that of providing instantaneous shutdown of the canal in the event of pump failures occurring at either Tracy or O'Neill Pumping Plants.

Corning Canal

The Corning Canal is one of the new features of the Central Valley Project. This canal at the present time is being operated in the conventional manner although some automation is being used at the first check structure and at the Corning Canal Pumping Plant. A program is in progress to use it for prototype tests to confirm recent theoretical studies of a method of automatic DOWNSTREAM CONTROL. The system is sophisticated in theory but physically it requires electrical components which are simple in comparison to the degree of automation that is expected to be achieved.

The Corning Canal begins on the west bank of the Sacramento River near Red Bluff and extends southerly 21 miles terminating near Corning, California. The canal begins with a capacity of 500 cubic feet per

second and reduces to 88 cubic feet in the end reach. Construction began in 1956 and was completed in 1960.

The headworks consist of the Corning Pumping Plant which has six centrifugal vertical shaft pumps, three rated at 53 c.f.s. and three rated at 115 c.f.s. The pumping plant diverts its water from a settling basin just downstream from Red Bluff Diversion Dam. The pumps lift the water 59 feet into the Corning Canal through six discharge lines, three 36 inches in diameter for the three small units, and three 60 inches for the three large pump units. The canal section is of earth-lined construction. The canal with a bottom width varying from 22 feet to 10 feet has an average slope of 0.00019 for a total drop of 21 feet in 21 miles or one foot per mile. The normal water depth varies from 7.2 feet to 3.6 feet. There are 14 single-gated check structures spaced on an average of 1.5 miles.

The annual delivery at the present time is 18,000 acre-feet but ultimately it will reach 118,000 acre-feet. The water supply is used mainly for irrigation purposes. Deliveries are being made to six irrigation districts. At the present time there are 19 regular turnouts into pipe distribution systems ranging in size from 18 to 36 inches in diameter. Seventeen of the turnouts are of the pump type. Management of some of the main canal turnouts is carried out by the water districts.

The most troublesome problems confronting the operation of the Corning Canal are maintaining inlet flow to match the water demand and preventing unscheduled turnout diversion changes from passing into the lower reaches of the canal which have small carrying capacities. A rejection of any one of the pump turnouts which have relatively large capacities compared to the capacities of the lower reaches could occur unscheduled because of a power failure or failure of a pumping unit. The reduction in turnout diversion rejects back into the canal. If prompt action is not taken to lower the upstream check gates and to reduce the inlet pumping by the appropriate amount, the rejection will extend into the lower reaches and trigger undesirable operation of wasteways before corrective measures can be taken. Some of the turnout pumps are automated (ON-OFF, TWO-POSITION CONTROL) for the purpose of maintaining a constant pressure head on the distribution system. A sudden decrease in this pressure for any reason could start the turnout pump automatically resulting in a sudden unscheduled increase in the turnout diversion. The increased turnout diversion could cause a serious shortage and disrupt service to turnouts in the lower and smaller reaches of the canal if prompt corrective measures are not made to raise the upstream check gates and increase the pumping at the head of the canal.

The first check gate and one of the small pumping units at the Corning Pumping Plant are automated. At the first check structure an automatic set point controller to maintain a constant flow through the check gate

has been installed. The flow rate desired or set point, is set on a dial by the "ditchrider." System components sense the hydraulic parameters and determine the flow through this check gate by solving the orifice equation ($Q = CA\sqrt{2gH}$) using computer type circuitry. This flow is compared to the set point, and the system automatically raises or lowers the gate to obtain the set point flow.

The canal reach between the Corning Canal Pumping Plant and the first check structure, a distance of 4.55 miles, is used as a regulating reservoir for the canal downstream. The water level at the downstream end of this reach is used to signal one small pump at the Corning Pumping Plant to start when the water level has lowered one foot below the design depth and to stop when the water returns to the higher level. This automatic operation is ON-OFF, TWO-POSITION CONTROL.

The automatic set point flow controller at the first check structure compensates for the variable water level upstream within the one foot variation and maintains a constant flow downstream through the check structure. However, from this point downstream the "ditchrider" after "dialing" the desired input, operates the canal in a conventional manner.

Canal deliveries at the present time are less than the ultimate requirements. However, as the demands continue to build up in the future, the problems discussed previously will be difficult to handle with the

conventional mode of operation. Additional automatic systems capable of recognizing abrupt flow changes and making the necessary adjustments rapidly in the flow rate upstream will be required for efficient operation.

Recognizing the need for a more sophisticated automatic control system that will respond rapidly to large sudden variations in turnout diversions, the Bureau of Reclamation has sponsored an investigation of the DOWNSTREAM CONTROL concept through a research contract with the University of California at Berkeley.

The goal of the research program was a practical method of DOWNSTREAM CONTROL with a high degree of self regulation requiring virtually no supervisory intervention.

The program recognized the need for considering the effects of hydraulic transients in the canal on the function and stability of the automatic features. Studies made on an analog simulator and with a mathematical model of a canal, also developed in the same research program, have defined the necessary elements of a responsive system of DOWNSTREAM CONTROL including feedback control, and demonstrated its feasibility "on-the-bench."

In a simplified case of DOWNSTREAM CONTROL, a lowering of the water level from the target value in the downstream reach would signal the

upstream gate to open by an amount which is proportional to the "offset" from the target value. The target value is the preselected depth of water in the canal when the flow is zero and the gate is closed. The gate has a definite and proportionate position for each value of the "offset."

Significant factors involved in DOWNSTREAM CONTROL are:

1. A water level sensor is located at the lower end of a reach of canal between two checks and provides the feedback signal to control the upstream check gate. If all the check structures were equipped with "feedback," the response to a change in demand will ratchet rapidly upstream to the inlet of the canal.
2. A communication link for the full length of the pool, between the check structures is required to transmit the signal to the upstream check gate.

The DOWNSTREAM CONTROL is compatible with the operation of the automatic set point flow controller at the first check. Flow, instead of gate opening, can be made directly proportional to feedback. The set point dial which is now manually set by the "ditchrider" will be equipped to automatically dial the desired flow rate.

The advantages inherent in the concept of DOWNSTREAM CONTROL are appealing. Water is transferred downstream from its source to its point of use in response to an increase in demand and only when the demand occurs. The reverse effect takes place when the demand is decreased. The system can be made to respond rapidly and takes corrective action immediately to abrupt and unscheduled changes in turnout diversion. This action reduces the necessity to spill water and minimize the occurrences of shortages in the lower reaches.

As the final phase of the research program, a series of prototype tests will be conducted on the Corning Canal during the 1969 irrigation season, to confirm and/or extend theoretical analysis. The tests will provide field data to evaluate overall accomplishments in regards to the program objectives. These data will be useful in developing specifications for adapting the system to other projects.

Plans for the Future

Each unit within the Central Valley Project is presently being examined individually to determine if modernization by remote and/or automatic operation would improve its operation. In some cases, such as Delta-Mendota Canal, remote control became necessary as the operation of the unit became more complex.

Plans are being made to update the conventional operation of the lower reaches of the Delta-Mendota Canal below check 13, mile 70, by utilizing the capabilities of remote or automatic control or a combination thereof.

A remote control system is proposed for the Contra Costa Canal and Pumping Plants. The need for remote control on this canal differs from that of the Delta-Mendota Canal. Municipal and industrial uses make up 90 percent of the total annual delivery. The nature of municipal and industrial deliveries on a "demand basis," with the use of Contra Loma Reservoir for regulation, requires centralized control for the entire system for efficient operation to meet the daily variable demands.

Three canals now under construction, Tehama-Colusa, Folsom-South, and Pleasant Valley, have included plans in the preliminary designs to incorporate various degrees of the remote and automatic modes of operation. Operational problems in each of these canals will be similar to those discussed above.

Future large projects, not yet authorized, such as the East Side Canal and the West Sacramento Canal will incorporate remote and/or automatic modes of operation to provide operational flexibility.

These future units will transfer large quantities of water to meet turnout demands; to store winter and spring flood runoff in offstream reservoirs; and to attain an optimum offpeak pumping operation, and will require the flexibility offered by remote and automatic modes of operation.

Along with the modernization of various project units, there has been a general trend towards centralization of the entire system, i.e., the Central Valley Project. It can be expected that computers will provide more and more assistance in forecasting, scheduling, and controlling water and power operations.

Summary

The experience gained from operation of three canals, Friant-Kern, Delta-Mendota, and the Corning Canals is reviewed and generalized. Three basic operational requirements have been identified: (a) maintenance of constant water levels at turnouts; (b) matching inlet supply to demand; and (c) instantaneous transfer of water to provide a more responsive system and to optimize offpeak pumping. These canal operational requirements vary from one canal to another depending on the type of inlet and outlet facilities, the size, and the nature of the service demands. Recognition of the more critical operational requirements peculiar to each canal system prompted developments which led to the installation of either

remote control or on-site automatic devices. The more troublesome problems have been reduced and the canal delivery capability has been improved.

Limitations of operating in the conventional manner has stimulated the Bureau of Reclamation to adapt remote and automatic modes of operation to main canal systems. The program is an imaginative one directed towards modernizing and upgrading the conventional mode of operation. The objective is to realize the benefits associated with remote and automatic control systems, such as (a) reduction in operating costs; (b) more efficient use of water; and (c) better service to the water users.

The experience gained in this on-going program is expected to have an influence on the design of future projects. Recognition of the advantages and the flexibility of modern control concepts in the early planning stages could result in the addition of significant benefits to a new project. Particularly attractive are the benefits of offpeak pump operation made possible by such concepts.