PUTAH SOUTH CANAL REMOTE ACOUSTIC WATER LEVEL MONITORING AND FLOW MEASUREMENT

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ABSTRACT

The Putah South Canal (PSC) was constructed as a part of the Solano Project by the U. S. Bureau of Reclamation for the conveyance of water to the agricultural and urban member units of the Solano County Water Agency in California. The Solano Irrigation District (SID) operates the PSC for the member units. Average annual deliveries are approximately 200,000 acre feet.

The PSC has 12 manually operated radial gate check structures which are used to control the flow in the canal throughout its 33 mile length. Prior to the installation of the monitoring equipment, SID did not have the ability to instantaneously monitor the PSC flow status. When unanticipated delivery changes occurred, increases or decreases in the PSC flows often went unnoticed for several hours. The flow monitoring system installed during the winter of 1991-92 includes acoustic water level monitoring and radio telemetry equipment at each of the PSC check structures. The equipment measures the upstream and downstream water levels and then based on the measured head loss, gate opening, and radial gate parameters, calculates the flow through each of the radial gates. The flow and water depth data are continuously transmitted to the District office. This information provides the District with the ability to more efficiently monitor and manage the delivery of water in Solano County.

SOLANO IRRIGATION DISTRICT HISTORY

The Solano Irrigation District was organized in 1948 in accordance with the provisions of the California Water Code. The District, shown in Fig. 1, is located midway between Sacramento and San Francisco and comprises approximately 56,000 irrigable acres in Solano County.

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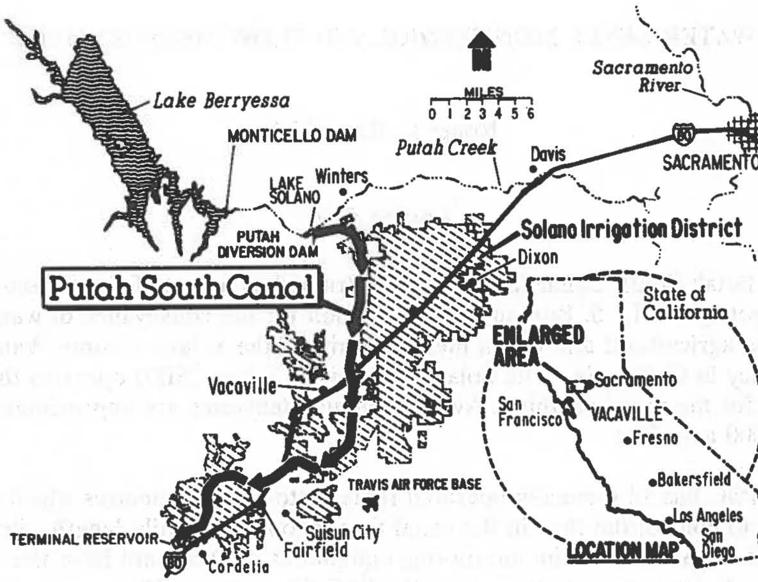

Fig. 1 Solano Irrigation District Location Map

Principal crops are corn, wheat, sugar beets, tomatoes, fruits, nuts and irrigated pasture. The District's water supply is obtained from Putah Creek by the Solano Project, constructed by the U.S. Bureau of Reclamation in the late 1950's. The project's principal facilities are Monticello Dam and its reservoir, Lake Berryessa, the Putah Diversion Dam 6 miles below Monticello Dam, and the Putah South Canal which conveys water to the agricultural and urban member units of the Solano County Water Agency. The Solano Project was initially conceived, developed and brought to fruition through the efforts of the District and Solano County. Average annual deliveries from the project are approximately 200,000 acre feet. The District annually receives approximately 151,000 acre feet from the Solano Project. The remaining member units of the Solano County Water Agency are urban entities. The majority of their municipal and industrial water supply is conveyed by the PSC.

The District's distribution system, designed and constructed in the same time period as the Solano Project, consists of approximately 115 miles of open canal, 185 miles of pipeline, and approximately 70 miles of open drainage channels. Summers Engineering, Inc. has been engineer for the Solano Irrigation District for nearly 30 years.

PUTAH SOUTH CANAL OPERATION

The PSC, depicted on the District Map in Fig. 1, is the water conveyance facility of the Solano Project. The PSC is approximately 33 miles in length from its headworks at the Putah Diversion Dam to its end at the Terminal Reservoir near Cordelia. The PSC is a concrete lined canal. The canal has 5 distinct reaches from its headworks to the terminus. The maximum capacity of the first reach is 950 cubic feet per second decreasing to a capacity of 180 cubic feet per second at its terminus. The PSC was constructed with 12 radial gate check structures along its alinement. The checks (Fig. 2) are manually operated to maintain the necessary flow in the canal and to provide the required water surface for upstream diversions.

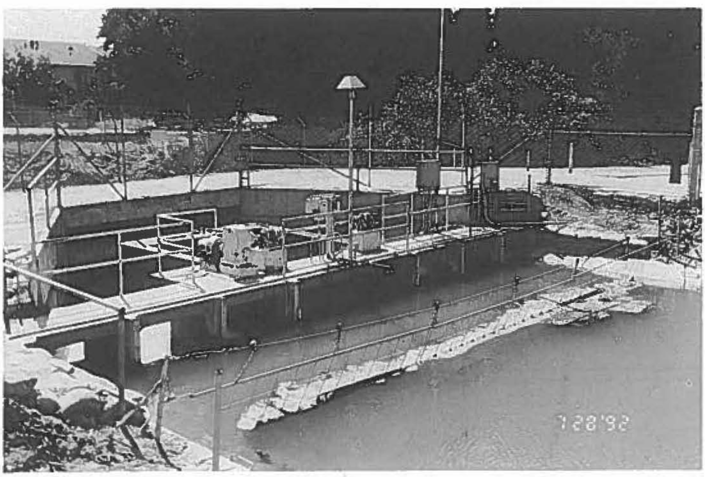

Fig. 2 Typical PSC Check Structure

Since completion of the Solano Projection, the District, under contract with the Solano County Water Agency, has been responsible for the daily maintenance and operation of the PSC. The canal was designed as a manually operated water delivery system. Water orders by farmers or urban agencies must be placed by 2:00 p.m. of the day prior to delivery. Each morning the Putah Diversion Dam operator changes the gates at the PSC headworks to meet the flow requirements for the day. The PSC Water Tender begins early each morning driving to the various check structures along the canal alinement, checking for problems, measuring the flow and changing the radial gate openings to accommodate the day's flow requirements. It takes approximately one half of the work day to drive to all the check structures, measure the flow and make the necessary changes. The Water Tender then retraces his steps in the afternoon, double checking the operation of the various check structures, and verifying that everything is operating properly.

Shortly after construction of the PSC, flow charts were developed for the various radial gates to give the operators the ability to measure the approximate flow through each check structure. The flow charts developed were based on the Orifice Equation.

$$Q = C\, G_0\, W \sqrt{64.4\ (H_1 - H_2)}$$

C = Coefficient of 0.7

W = Radial Gate Width

Figure 3 displays the other parameters used in the Orifice Equation.

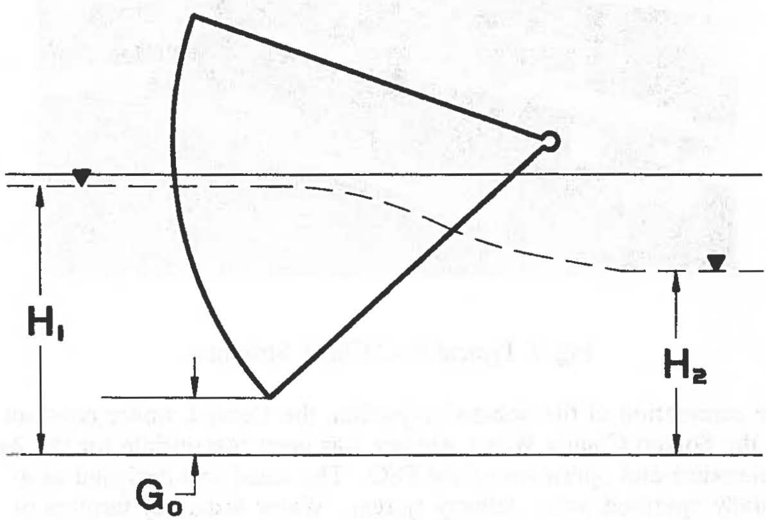

Fig. 3 Parameters Used for Orifice Equation

Staff gauges were installed at each check to allow the operator to read the upstream and downstream water levels. Markings were inscribed on the sidewalls of each radial gate as well as on the radial gate hoist mechanism to allow the operator to measure the gate opening. Based on the water level differential and the gate opening, the operator estimated the flow through the check structure using the flow charts. The flow charts have been used to manage and operate the flows through the PSC for the past 33 years.

The PSC has three side spills along its alinement. When unanticipated flow changes or emergencies increase the flow of water in the canal above the side spill elevations, excess water is spilled down wasteways that flow into existing creeks. Minor operational fluctuations continue down the PSC and are stored in the downstream canal reaches. As a manually operated system, unanticipated delivery changes, emergencies, vandalism, or miscellaneous operational errors may occur at any given time. Although the Water Tender and the PSC maintenance staff drive the canal daily, there are periods of time when changes in the flow regime may go unnoticed for several hours, allowing water to be lost from the Solano Project and also creating circumstances where possible damage may occur to the PSC.

The District realized their flow monitoring limitations and in 1987 constructed a test installation which included acoustic water level measuring sensors on the upstream and downstream side of one radial gate check structure. The sensors measured the water levels in the canal and transmitted the data to a radio telemetry unit which at regular intervals transmitted the water level data to the District Office. The data was downloaded to a computer programmed to calculate the flow at the check structure using the Orifice Equation. While the test installation did have some minor problems in operation, the District was pleased with the continual flow monitoring possibilities it could provide for the PSC and felt similar measuring equipment along with a high and low water level alarm system should be installed at all of the check structures to improve the efficiency of operating the PSC. What the District was lacking, however, was a funding source for such a project.

WATER CONSERVATION

During 1988 Solano Irrigation District applied to the Department of Water Resources for a loan under the Water Conservation and Water Quality Bond Law of 1986, to fund the installation of acoustic water level monitoring equipment, radio telemetry transmitters and the necessary software to provide a system which would continually monitor the flows of the PSC at the various check structures. The loan was approved based on the determination that the ability to continually monitor the actual water storage and flows in the various PSC reaches would provide the District the ability to quickly respond to operational changes or emergencies and thus minimize water losses. It was estimated from historic data on water losses and the operation of the PSC, that the proposed project had the potential of conserving approximately 2,400 acre feet per year.

PROJECT FORMULATION

The loan under the Water Conservation and Water Quality Bond Law of 1986 was finally approved in late 1989. While reviewing the proposed project requirements, it was recommended that the water monitoring system be configured as a two way talk through communications network with a central station computer capable of monitoring and accessing each remote field station. The test installation installed and operated by the District in 1987 was a one directional type of system. Data could only be sent from the check structure to the District office. The District office did not have the ability to access the monitoring equipment at the check structure to verify water levels or any of the measured parameters. The rapid improvement in radio telemetry, computer equipment, and software created a situation where the District thought it would be better to design a system that would not only receive the measurement data but one which could communicate with each remote site to verify its status. A system designed in this manner would have the potential of being expanded in the future to not only monitor but also remotely control the radial gates at each check structure. The PSC water level monitoring and radio telemetry equipment has the capability of being expanded in this manner.

A predominant goal in developing the project was to provide a system which would accurately monitor the water levels and flows in the Putah South Canal, sending alarms when the radial gate or equipment were tampered with or any predetermined water levels were exceeded. A system with this capability or with these characteristics would provide the District Watermaster with the ability to more efficiently operate the PSC. He would instantaneously know all flows, water levels, and approximate water storage quantities for each reach along the PSC.

Accurate flow measurement calculations at each check structure were a necessity for the project. As mentioned, charts developed from the Orifice Equation were the basis for the present flow measurement and operation of the PSC. A review was made of existing studies which analyzed the flow through radial (tainter) gates. One of the most useful analyses on radial gate flow characteristics was by Arthur Toch[1]. Toch expanded previous work on developing discharge coefficient data for radial gates for free flow and submerged flow conditions. The analysis presented by Toch provides the basis for using the geometric parameters of a radial gate to calculate its respective discharge coefficient and flow.

The radial gate check structures along the Putah South Canal operate in a submerged condition in the majority of all operating situations. By making a few minor modifications to Toch's submerged flow equation, the following Modified Toch Equation was developed to calculate the flow at each PSC check structure:

$$Q_S = FH_2W\sqrt{\frac{64.4(H_1-H_2)}{\psi+1-(\frac{H_2}{H_1})^2}}$$

The parameters and variables used in this equation are defined below and in Fig. 4

$$\psi = (\frac{1}{\beta})^2 - 1 + \frac{\gamma^2\,(\beta-1)}{\gamma\beta - 2(\alpha-1) - \sqrt{[2(\alpha-1) - \gamma\beta]^2 - \gamma^2(\beta^2-1)}}$$

$$\alpha = \frac{H_2}{D\,G_0} \qquad \beta = \frac{H_1}{H_2} \qquad \gamma = (\frac{H_2}{C_c\,G_o})^2 - (\frac{1}{\beta})^2$$

$$C_c = 0.76 + [(\frac{\theta-40}{50})\,(-0.14)]$$

$$\theta = \cos^{-1}(\frac{A-G_0}{R})$$

[1] Discharge Characteristics of Tainter Gates by Arthur Toch, Paper No. 2730 ASCE Transactions October 1953

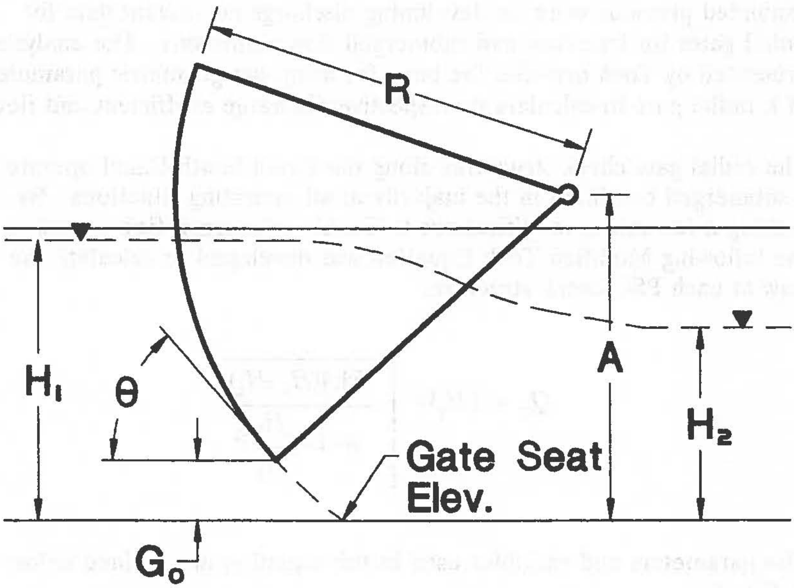

Fig. 4 Parameters Used for Modified Toch Equation

Variables Measured by Flow Monitoring Equipment:

H_1 = Upstream Water Depth (Ft.)

H_2 = Downstream Water Depth (Ft.)

G_o = Gate Opening (Ft.)

Operator Defined Variables

F = Correction Factor (Enter as 1.0 at present)

D = Alpha Denominator Correction Factor

A = Height of Gate Axis above Gate Seat (Ft.)

R = Gate Radius (Ft.)

W = Gate Width (Ft.)

A comparison of the calculated flows through a radial gate using the Orifice Equation and the Modified Toch Equation for equivalent upstream and downstream water levels and varying gate openings is plotted in Fig. 5.

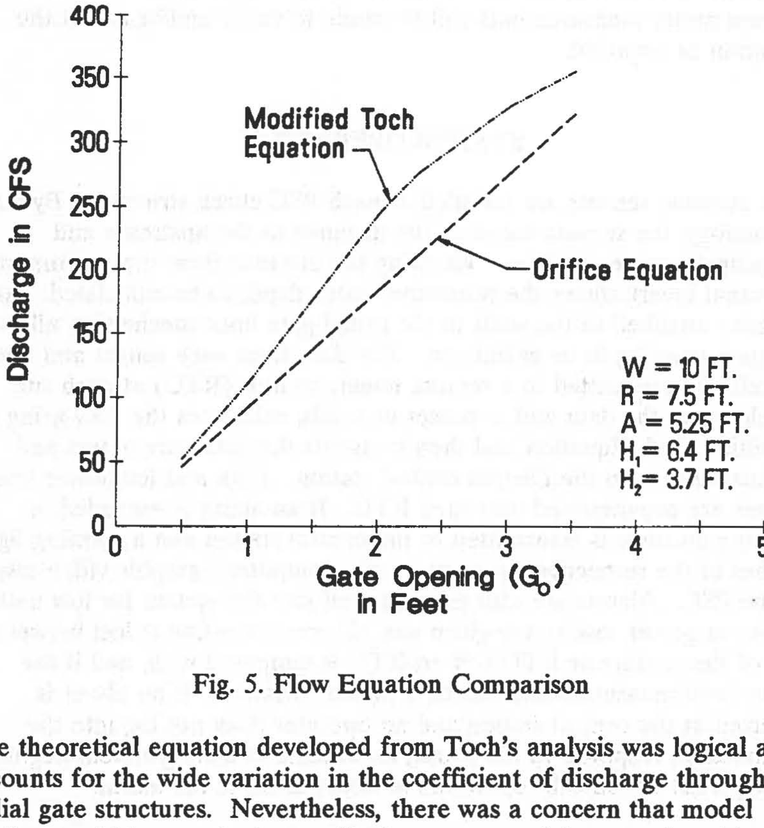

Fig. 5. Flow Equation Comparison

The theoretical equation developed from Toch's analysis was logical and accounts for the wide variation in the coefficient of discharge through radial gate structures. Nevertheless, there was a concern that model studies would be required to verify the accuracy of the equation. During the early 1980's the U.S. Bureau of Reclamation made an in-depth analysis of discharge algorithms for canal radial gates.[2] The Bureau's work included numerous field investigations and flow measurements at existing radial gate structures in California. At each site, current meter measurements were made to determine the flow under varying head and gate openings. Using the site specific geometric parameters provided in the Bureau's report, the Modified Toch Equation was used to

[2] Discharge Algorithms For Canal Radial Gates by Clark P. Buyalski, U.S. Department of the Interior, Bureau of Reclamation Engineering and Research Center, December 1983

independently recalculate the flow at the various test locations. The results indicated the Modified Toch Equation was more accurate in estimating the flow than the Orifice Equation. The flow using the Modified Toch Equation was within 5% to 10% of the actual current meter measurements. Once the District's new system is fully operable, current meter measurements will be made to verify and/or adjust the equation as required.

SYSTEM OPERATION

Two acoustic sensors are installed at each PSC check structure. By echo technology, the sensors measure the distance to the upstream and downstream water surfaces. Knowing the distance from the sensors to the canal invert allows the respective water depth to be calculated. An encoder attached to the shaft of the radial gate hoist mechanism allows the gate opening to be calculated. The data from each sensor and the encoder is transmitted to a remote telemetry unit (RTU) at each site which stores the data and at preset intervals, calculates the flow using the Modified Toch Equation and then transmits the gate parameters and calculated flow to the District central station. High and low water level alarms are programmed into each RTU. If an alarm is exceeded, a warning message is transmitted to the central station and a warning light flashes at the respective structure on the computer's graphic video display of the PSC. Alarms are also programmed into the system for low battery power or power loss at any given site, if communication is lost between any of the sensors or RTU's, if an RTU is tampered with, and if the water level measurements exceed a preset variation. If an alarm is received at the central station and an operator does not log into the computer in response to the alarm, an automatic dialing system begins calling a list of "on-call" operators to notify them of the alarm.

The operating system software maintains and continually updates a data base of all water level and flow measurements. Graphs and/or charts summarizing the flow measurements for any period of record can quickly be developed. The software also includes an area capacity curve for each canal reach upstream of a check structure. This provides the Watermaster with the capability of quickly determining the amount of water in storage in the PSC.

CONCLUSION

The District installed the acoustic water level monitoring equipment, radial telemetry equipment and the central station computer during the winter of 1991-92 for a cost of approximately $200,000. Some installation problems and software debugging are still taking place. Changes and modifications to the system will probably be required in the future as the District becomes familiar with operating its automatic water level and flow monitoring system. The system was not fully operable during the summer of 1992 and at this time it is too early to analyze the benefits of the system in helping the District more efficiently operate the Putah South Canal. The Watermaster and District Water Operations Supervisor are convinced, however, that the new system will improve operations by giving the District the ability to instantaneously monitor the flow throughout the 33 mile length of the Putah South Canal, and automatically provide warnings if operational changes or vandalism affect the flow and require immediate attention. Daily driving of the canal is still required, but continual monitoring of the flow at the existing check structures on a 24 hour a day basis provides the District with an even better ability to more efficiently manage and conserve the waters of the Solano Project.