MODERNIZING IRRIGATION FACILITIES AT SUTTER MUTUAL WATER COMPANY: A CASE STUDY

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ABSTRACT

In 1999 Sutter Mutual Water Company (SMWC) began an effort to modernize its water-distribution system in an attempt to reduce operation and maintenance costs and conserve water and power resources. The primary technical support was provided by professionals from the Irrigation Training and Research Center (ITRC), California Polytechnic State University (Cal Poly), San Luis Obispo. Additional technical expertise was provided by Concepts in Controls of Visalia, California and Wilson Pumps of Woodland, California. This modernization project was partially funded by the United States Bureau of Reclamation (USBR), Mid-Pacific Region, Northern Area Office, through a Field Services Program Grant and technical support agreement with the ITRC.

The effort encompassed two projects within the company's service area located within the boundaries of California's largest reclamation district, Reclamation District 1500. The projects were (1) the automation of the pumping plant at Portuguese Bend with a new Variable Frequency Drive (VFD) pump and Supervisory Control and Data Acquisition (SCADA) system and (2) the demonstration of new SCADA-compatible electronic flow measurement technologies for both canals and pipelines.

The anticipated, and ultimately realized, benefits of the modernization effort was a savings to the company due to a reduction in the amount of water diverted,

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power consumed and number of personnel required to operate and maintain its system.

INTRODUCTION

Sutter-Mutual Water Company (SMWC), a farmer-owned, non-profit water company, decided in 1998 to begin modernizing its irrigation facilities in an attempt to reduce its increasing operation and maintenance costs while conserving water and power resources. The following paper is a 1999-2001 status report on what has become an ongoing effort.

The work completed to date has been possible due to a coordinated effort between company personnel and professional engineers from the Irrigation Training and Research Center (ITRC), California Polytechnic State University (Cal Poly), San Luis Obispo, Concepts in Controls, Visalia, California and Wilson Pumps, Woodland, California. This modernization project was partially funded by the United States Bureau of Reclamation (USBR), Mid-Pacific Region, Northern Area Office, through a Field Services Program Grant and technical support agreement with the ITRC.

Background

For over 80 years the company has operated and maintained its irrigation facilities, initially using mostly vintage technology, which has proven to be very reliable. In the 1960-1970s, three new pumping stations were built and more efficient turbine pumps were installed to help reduce power consumption and to increase water diversion efficiency. For economic and operational reasons, in 1999 it was decided to begin installing additional technology in some of the plants in order to take advantage of the substantial savings offered by such technology.

The first equipment chosen by the company was a Variable Frequency Drive (VFD) unit and a Supervisory Control and Data Acquisition (SCADA) system, which were installed in the Portuguese Bend plant during 1999-2001. While this project was being completed a second project was also initiated in order to measure flows in two different canals. Both of these projects are described below.

Description of Company

Formed in 1919, SMWC is one of the first water companies to be established in the state of California. The company's physical location (Figure 1) is approximately 45 miles northwest of Sacramento, California and is bordered in the north by the Tisdale Bypass, in the west by the Sacramento River and in the east by the Sutter Bypass. The southern boundary is located at the southern end of Sutter County near the Fremont Weir where the Sacramento River and Feather

River come together. The company's 46,746 irrigable acres (18,917 ha), which are part of the 67,850 (27,470 ha) gross service area that is maintained by Reclamation District 1500 flood control and drainage personnel, are served by approximately 400 turnouts. Approximately 200 miles (322 km) of canals and laterals in the distribution system convey water to the fields.

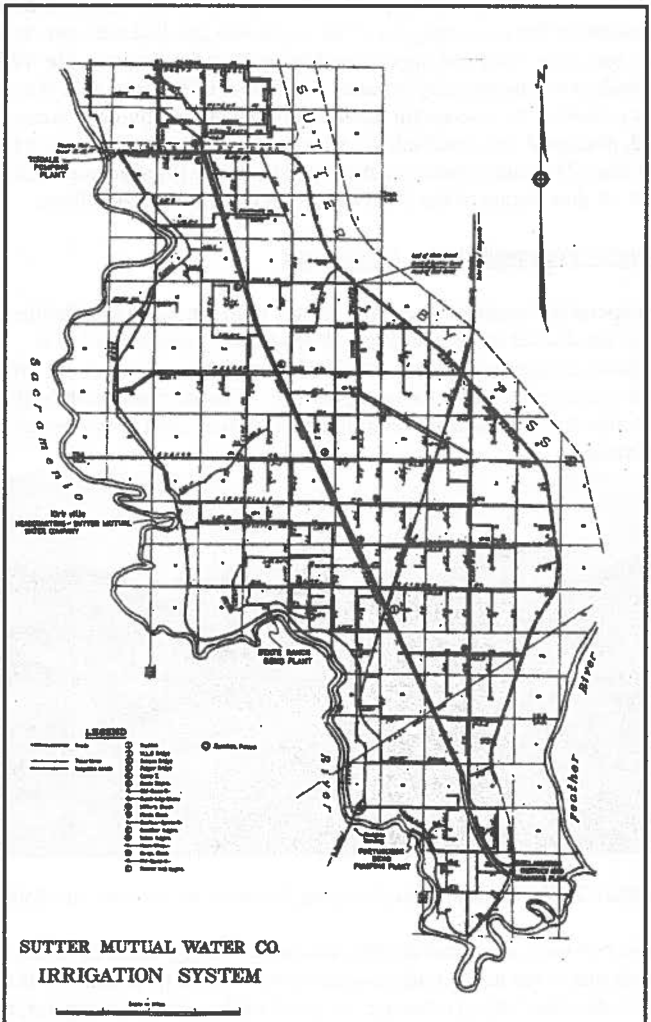

Figure 1. Map of Sutter Mutual Water Company service area

PROJECT #1: INSTALLING A VFD UNIT AND SCADA SYSTEM AT THE PORTURGUESE BEND PUMPING PLANT

In early 1999 the company decided to proceed with the installation of a Variable Frequency Drive (VFD) unit and a Supervisory Control and Data Acquisition (SCADA) system in the pumping plant at Portuguese Bend (Figure 2) following an explanation of the technology by ITRC staff who detailed the work to be done, the equipment to be used and the cost and benefits of the project. The VFD, in a manual mode, was successfully installed by the end of the year after three unique problems critical to the successful operation of the new technology were identified, evaluated and resolved: (1) an adequate radio signal between the office and field site, (2) proper siphon breaker operation, and (3) adequate cooling of the VFD unit. A description of the VFD and SCADA system is as follows.

The Variable Frequency Drive (VFD) Unit

Constant-speed AC motors drive many pumps used for water distribution and delivery at the district or grower level. When flow control is needed to accommodate changes in downstream demand, typically two methods are employed to control the flow rate and pressure: (i) a downstream throttling valve is used to alter the system curve, and (ii) some of the output is by-passed back into the intake.

Figure 2: Portuguese Bend Pumping Plant on the Sacramento River

With these two methods a considerable amount of energy could be wasted in doing work that is not needed just to achieve the desired flow rate. VFD units provide an effective way of reducing the speed of the pump drive motor, thereby allowing the flow rate or pressure to be adjusted to the desired level without the additional energy from throttling or by-passing. Basically the VFD is an electronic device that is used in conjunction with a constant-speed AC motor.

The VFD accepts the standard line voltage and frequency then converts the signal into a variable frequency and voltage output that allows the standard constant-speed AC motor to be varied in speed.

<u>Advantages of a VFD</u>: VFDs provide the potential for system automation of pumping plants such as Portuguese Bend. Water level sensors can be used as feedback into the controller to continuously adjust the VFD speed for varying downstream conditions. In general, this permits the ability to provide water deliveries to growers on-demand. In turn, growers are able to schedule irrigations to match the crop water requirements rather than district limitations. This type of VFD operation also offers the potential for labor savings over manual adjustment. The further advantages of VFD systems include the following:

- Softer starting: the device limits the current inrush to the motor providing for a smooth non-shocking acceleration of the pump shaft speed up to its operational RPM
- Elimination of pressure surge: bringing the system up to operating speed slowly removes the pressure surge caused by an almost instantaneous acceleration of the water to its operational flow rate
- Reduction of operating costs: by reducing the energy input over previous control methods (by-pass) operating costs can be reduced
- Reduction of motor stress: reduces mechanical stress on motor windings
- Reduction of peak demand charges: by reducing the energy loads the overall peak demand of the facility can be reduced

<u>Disadvantages of a VFD</u>: There are important issues to consider when VFD devices are being used, as follows:

- Increased motor stress: electrical stress increased due to the steep voltage wave that forms in the power supplied by the inverter. Older motors with inferior insulation may have problems. Typically the motor should be dipped and baked twice. Newer VFDs that include "soft switching output technology" can significantly reduce motor stress and interference from harmonics.
- Increased maintenance: while VFD units are very reliable they are an additional item requiring maintenance. In critical applications, it is essential to have spare parts and maintenance expertise or retain the ability to by-pass.
- Harmonics concern: with the increasing number of control systems going on-line, the line interference produced by some VFD units can cause problems.
- Environmental conditions: most units require relatively dust free enclosures with some type of temperature control. Most of the pumping VFD applications can utilize a simple water-to-air radiator type cooling system (simple and effective).

Energy Savings: VFD units usually reduce pumping costs by reducing the pump drive motor speed to match the desired operating conditions thereby reducing energy input. Without a VFD device this is typically accomplished by using either a by-pass set-up or a downstream throttling valve. The system layout for a typical by-pass installation consists of a pump and by-pass piped into a standtank. With this arrangement the by-pass maintains a constant head in the standtank regardless of flow, as there is less downstream demand. The excess flow is by-passed to the pump intake to maintain a constant head in the standtank or canal. Determining how a pump will operate in a given situation requires an understanding of the pump and system curve. The pump characteristic curve for a standard centrifugal pump shows that the pump, at a fixed speed, has a flow rate associated with a particular pressure; high flow, lower pressure vs. low flow, higher pressure. The intersection of the pump curve and the system curve shows the point of system operation.

If, instead, the pump speed is modified using a VFD device to control head just below the by-pass, flow and head are reduced together along the system curve. A comparison of the relative pump water horsepower with (i) VFD, and (ii) by-pass installations are shown by the shaded areas in Figure 3.

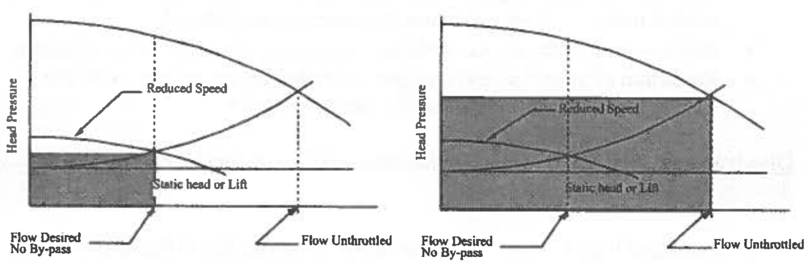

Figure 3. Water horsepower (shaded area) for pumping plant with (i) VFD and (ii) by-pass

However, the water horsepower differences above are only some of several factors to consider. To properly compare the actual cost savings of a VFD system, the overall plant pumping efficiencies with and without the VFD device also need to be considered. The major additional losses that must also be considered in determining the overall pumping plant efficiency are as follows:

- As the system curve changes or the pump speed is reduced, the operating efficiency of the pump changes. Therefore, for each operating point the pump efficiency must be checked.

- VFD units have some losses associated with the conversion process to the new operating frequencies. In general the units are relatively efficient, 95%. But, as the frequency is lowered, some units do become less efficient. The individual specifications for the VFD being considered should be obtained.
- Electric motors if sized properly near maximum loading, can be very efficient. With VFD units used in pumping, the motor loading is reduced as the speed is reduced. This reduction in motor loading can reduce its efficiency and drive motor losses will result.
- Drive friction losses can be reduced with VFD applications. As the speed is reduced the mechanical friction on drive shaft components is reduced.

In addition to the items above, it is important to consider the relative volume pumped each season. Small pumping volumes generally produce small savings and do not justify VFD installations.

Cost Savings Analysis: To determine the total savings due to the VFD unit, a detailed cost savings analysis was begun on the VFD installation on pump #1 (100 hp motor) at the Portuguese Bend pumping plant. Initial savings have already been realized with the reduction of one employee who was needed to constantly monitor and reset the plant's three pumps as dictated by flow requirements out of the plant's main canal. The main costs now under evaluation involve two other components as follows: (1) energy savings as a result of eliminating the by-pass practice (before meter) to control delivery flow, and (2) reduction of spilled water out of the canal, which reduces metered pumping of a purchased volume, plus the additional energy savings associated with the reduction in pumped volume. Both portions of the savings analysis do not take into consideration the specific time of use rates; they are based on the total monthly values. The reduction in canal spill and the associated energy savings are only achievable with the new SCADA system.

Table 1 shows the expected estimated annual energy savings based on the reduced pumping costs associated with a VFD unit. The cost savings analysis is based on an estimate of the average pumping costs before and after the installation of a VFD unit. In addition, an estimate of the average pumping cost with a VFD using a simple control algorithm is included to illustrate the expected additional cost savings during the first year operating with the new SCADA system. Table 2 shows the anticipated annual savings of approximately $2,000 to the company on Portuguese Bend's main canal due to the reduction in spilled water along the canal. Total cost savings from reducing both canal spill and from overall energy cost savings should be between $14,000 and $18,000 per year and will increase even more in the future as energy costs continue to increase.

Table 1. Average annual energy savings expected from VFD operations

Item	Pumping Cost $/AF	Annual Energy Savings based on 6,000 AF/ Season	Annual Energy Savings based on 8,000 AF/ Season
without VFD	4.7	---	---
with VFD	3.0	$10,200	$13,600
with VFD and simple algorithm	2.7	$12,100	$16,200

Table 2. Average annual savings anticipated from a reduction in Portuguese Bend canal spill with the new VFD and SCADA system

Description	Amount
Approximate annual spill at end of canal (acre-feet)	200
Possible reduction in spill with VFD (acre-feet)	120
Water value as missed opportunity to sell ($/acre-feet)	$12.00
Possible revenue from missed sales annually ($)	$1,440
Approximate pumping cost $/acre-feet (from pump test data)	$4.18
Energy savings from reduced pumped volume ($)	$502
Total Anticipated Canal Spill Savings	**$1,942**

The SCADA System

Overview: The basic objective of the automation at Portuguese Bend was to vary the pump flow rates from the pumping plant in order to maintain a target water level in the canal. This required the integration of a VFD unit at the pumping plant and a new SCADA system. Specifically, this involved the ability to remotely monitor the system (water levels, flow rates, pumps on/off, etc.), manually control operations from SMWC's administration office, and to eventually control the system automatically using the new VFD unit. This required the integration of data acquisition components (sensors for water level, electronic flow meters, etc.) with computerized controllers for implementing supervised commands. Monitoring and controlling operations at a remote site such as Portuguese Bend further required a two-way communications network between the remote office location and the control site. Such a system is often referred to as a Supervisory Control and Data Acquisition (SCADA) system.

SCADA is a tool that allows irrigation companies or districts to acquire real-time information and control operations at remote sites from a central location, usually in the main office or at an operations center. By having this real-time information available at the office, the system can also be managed on a real-time basis, thereby providing the ability to achieve maximum water conservation and operational flexibility.

In the water industry, the SCADA systems installed just a few years ago were one-of-a-kind systems custom designed for a specific job. As a result, these systems were not in most cases industrially hardened. Their relatively short-term design efforts did not address all of the day-to-day conditions the components would be subjected to. Consequently, system reliability was low. In addition, the communications protocols were all unique within these proprietary systems; therefore, no interchangeability between components and different vendors was possible. The overall communication systems used also added to the unreliability of early SCADA systems. The older systems typically used lower frequency voice radios for data transmission that were prone to many outside disturbances.

Current SCADA systems are now being designed under a term called "open architecture". This new approach uses off-the-shelf industrially hardened components, which can be linked together using common communication protocols. One such protocol currently adopted by the industry is Modbus. The current systems configuration assembles individual components, called Remote Terminal Units (RTU's), to control or monitor at each site independently. These standard components are then configured (programmed) for the specific task. The site RTU information is then linked back to the central location via radio communication. The open architecture and industrially hardened components have allowed increased scalability and reliability.

Radio communication for the SCADA systems has also improved. Equipment and FCC regulations have allowed the operation frequencies to increase, thereby improving reliability. One notable advance in radio communication has been the FCC approval of a technology known as Spread Spectrum radio. This is an unlicensed 900 Mhz frequency 'hopping' technique that provides reliable communication within about a 15-mile range. The range can be extended with a repeater configuration.

<u>Project Phases</u>: Due to the complex nature of installing a SCADA system into an irrigated area, successful implementation is best accomplished in phases. Initiating change in the routine operation of key facilities and altering the day-to-day activities of company or district personnel can create significant uncertainty. It is therefore necessary that this uncertainty is addressed during each step of the process and a level of confidence is gradually built-up in the participants. Achieving this critical "buy-in" from the people who will actually use the system is essential for the success of modernization projects. This phased approach has the important benefits including maximizing reliability while allowing an irrigation company or district to prioritize critical modernization needs and implement components on a site-by-site basis. Styles et al. (1999) outline further advantages of the phased approach based on experience in modernization projects

in irrigation districts. The Project Phases used for installing a SCADA system for SMWC were as follows:

Phase 1 (Completed in April 2001): The first phase of the SCADA part of the project was to install, test and calibrate a new water level sensor in the head of the main canal at Portuguese Bend. The new sensor located in a stilled area at the start of the canal was connected to the RTU/PLC at the Portuguese Bend pumping plant. The new sensor installation was setup so that water levels in the canal were measured once per second and transmitted via radio to the RTU/PLC, where it was stored in a data table and averaged over a one-minute time interval. Upon completion of this task, the Lookout® screens at the district office included information on the canal water levels at two locations, the river stage, the status of each pump (on/off and speed) and target depth (water level setpoint). In addition, the Lookout® screens were configured so that the target depth could be remotely changed from the office (for future automatic control), and so that up to 15 coefficients used for the distributed automatic control could be remotely changed from the office. However, the ability to change these coefficients were "hidden" so that only authorized personnel will be able to change the values.

Phase 2 (Completed in June 2001): This was the first step toward automating the site but nothing automatic was introduced at this stage. The VFD pump was tested on-site in manual mode with occasional remote manual operation. Manual VFD operation means the operator sets the motor speed control using the percent speed control located in the pumping plant. This phase facilitated testing of the new communications equipment, sensors, VFD controls, connection to the office computer, a new air/vacuum relief valve, etc.

Phase 3 (Completed in October 2001): This was the second step toward automating the site. There was a continuation of the remote manual mode of operation, but it was expanded to include a new flow meter. Rather than using only water levels as feedback, the operators now had information on specific flow rates at the pumping plant. A new electronic flow measurement device (Panametrics acoustic meter) was installed on one of the three pumping units and the flow rate was available to the operator. The digital display screens for the new Panametrics meters are shown in Figure 4. This did not mean that operators were expected to make hourly changes from the remote office location. This step required at least two months of operational testing extending into the peak irrigation season.

Phase 4 (Completed in December 2001): This was the third and final step of automating the Portuguese Bend pumping plant. A Proportional-Integral-Filtered (PIF) algorithm for control of the site was programmed into the RTU/PLC and implemented. The control algorithm was a PIF algorithm supplied by the ITRC and not the internal Proportional-Integral (PI) equation supplied by the VFD's manufacturer.

The Lookout® screens in the office necessary to support this automation were already in-place. The ladder logic and additional site programming were completed during this stage. At this time the effect of fluctuations in the Sacramento River level was factored in and added to the ladder logic programming, allowing the minimum VFD speed to shift with the river level. The Lookout® screens were modified to allow a person in the remote office location the ability to shift the pumps to automatic or manual control. In the case of remote manual control, this meant the ability to control the speed of the VFD and the number of pumps operating from the office. This final step allowed for the fullest possible (or desirable) automation of the site.

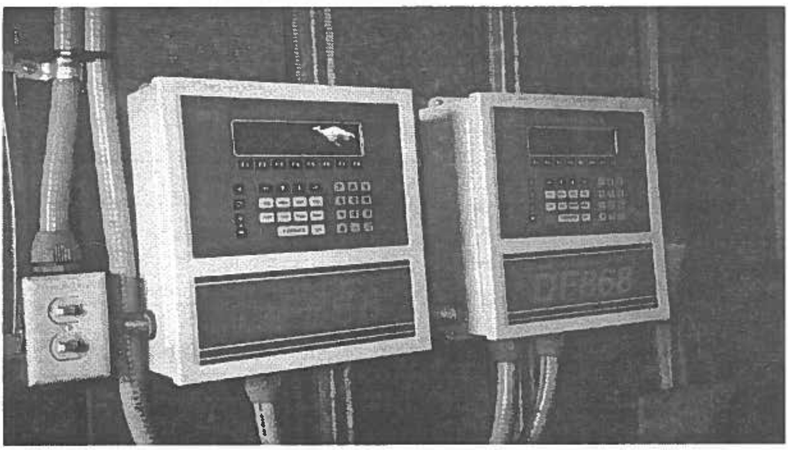

Figure 4. Digital display screens for new Panametrics flow meters inside the Portuguese Bend pumping plant

<u>CANALCAD Modeling</u>: During the modernization effort, the ITRC completed several unsteady flow hydraulic simulations of the first pool of the Portuguese Bend canal were conducted to determine the optimum control scheme for the new VFD unit. The algorithm uses PIF control logic based on water depth measurements 1,800 feet downstream of the Portuguese Bend pumping plant. The algorithm controls that water depth using the VFD and single stage pumps in the pumping plant.

The following is the control logic with optimized algorithm parameters:

VFD pump speed change: DS =1.3 * Round (DQ, 3)
Required flow rate change: DQ=35.315*[KP*(FE1-FE2)+(KI*FE1)]

with: FE1 =fc*FE2+(1-fc)*ENOW
FE2 = FE1 of previous step.
KP = -6.50
KI = - 0.18
fc = 0.84

Simulation Results: Figure 5 summarizes the best modeling results and algorithm for controlling the water depth about three-quarters of the way downstream from the Portuguese Bend canal.

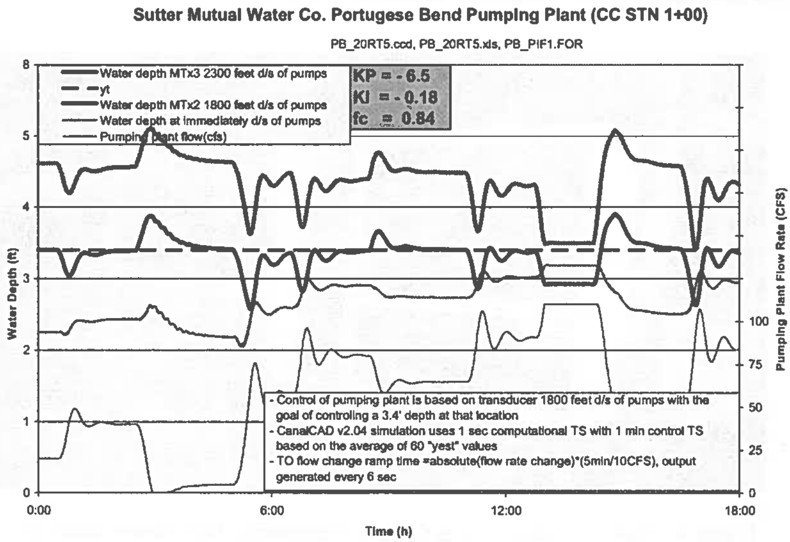

Figure 5. Water level control results when turnout flow changes occur at a rate of 5 minutes for every 10 cfs change

The control action occurs once a minute based on the average of at least 60 measurements of water depth. The graph presents the control results for nine simulated end-of-canal turnout flow changes that range from 5 to 110 cfs and that occur over an 18-hour period. The turnout flow changes occurred based on five minutes per every 10 cfs change in flow.

The graph shows the following information:

- Water depth immediately downstream of the pumping plant,
- Target water level of 3.4 ft at 1,800 ft downstream of the pumping plant,
- Water depth at 1,800 ft downstream of the pumping plant,

- Water depth at 2,300 ft (end of the pool), and
- Pumping plant flow rate

Figure 5 demonstrates satisfactory water level control with frequent flow rate changes over a relatively short period of time using the ITRC selected control algorithm. The target water level to maintain is 3.4[6] ft and the control location is 1,800 ft downstream of the pumping plant. This is the location of two transducers for measuring water depth[7].

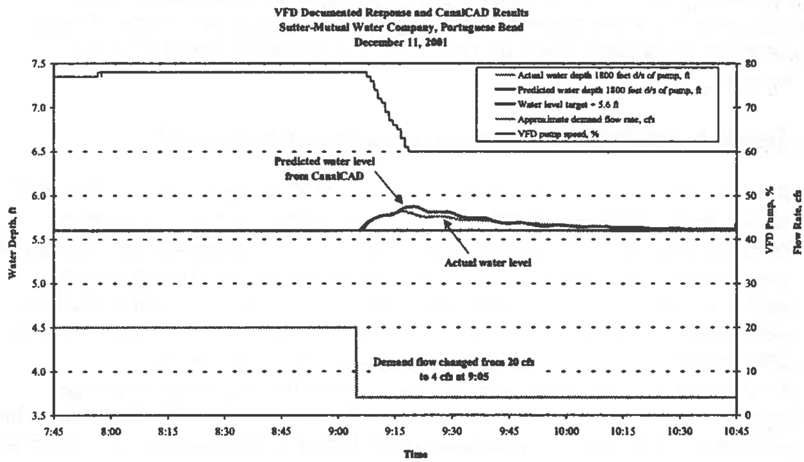

Figure 6. Documented VFD response, water level control results and predicted water depth with an 80% change in demand flow

<u>Documented VFD Response</u>: The documented response of the Portuguese Bend pumping plant from field tests conducted in December 2001 is shown above in Figure 6. During the final evaluation, the demand flow was varied with multiple flow rate changes to test the response time, stability and robustness of the VFD and SCADA systems. The flow changes were made manually by the operator adding or removing weir boards and opening or closing the gate at the check structure located at the downstream end of the first pool of the Portuguese Bend canal.

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[6] The target water level was later changed to 5.6 ft after the canal was de-silted and the sensor height adjusted.

[7] A redundant measurement (Y2) is used to check the integrity of the (Y1) measurement, which is used in the control logic.

PROJECT #2: ELECTRONIC WATER FLOW MEASUREMENT

The second project of the modernization program at the SMWC was the successful utilization of advanced flow measurement technologies. Accurate flow measurement is an integral part of the scientific management of water and energy resources. New electronic flow measurement devices provide a cost-effective and practical means to precisely measure flows at critical locations such as the pumping plant at Portuguese Bend. Panametrics, SonTek Argonaut™ SL and Unidata Starflow ultrasonic flow meters were used to determine flow rates and volumetric flow in the discharge pipeline and canal at Portuguese Bend in conjunction with the evaluation of the new VFD and SCADA system. A brief overview of the deployment of these devices is presented in the following sections.

Testing in the Portuguese Bend Pumping Plant's Main Canal

The new VFD pump permits excellent control of the water level in the first pool of the canal by allowing an unlimited flow rate range. However, in order to correctly program the RTU/PLC of the VFD, the relationship between "change in pump speed" and "change in flow rate" must be known. In practice, this is neither a constant nor a precisely known value. The ITRC used ultrasonic flow measurement equipment on the VFD pump discharge pipeline and pump affinity laws to estimate the relationship between pump speed and flow rate. A Panametrics acoustic flow meter was installed on the VFD pump discharge pipeline in order to integrate real-time flow data into the new SCADA system, in addition to providing flow rate via a digital display in the pumping plant (refer to Figure 4).

Testing in the Tisdale Pumping Plant's Main Canal at the Tisdale Bridge

A SonTek Argonaut™ SL Doppler current meter (Figure 7) was deployed in the Tisdale main canal near Tisdale Bridge from April 18 to July 31, 2001. The canal flow rate was measured in 10-minute intervals and the daily flow volume was calculated. The daily flow volume measured by the SonTek Argonaut™ SL was compared to data provided by SMWC. Drawings of the canal cross-sections at the deployment location were prepared and used in the calculation of volumetric flows. The Tisdale Bridge location is shown in Figure 7 below.

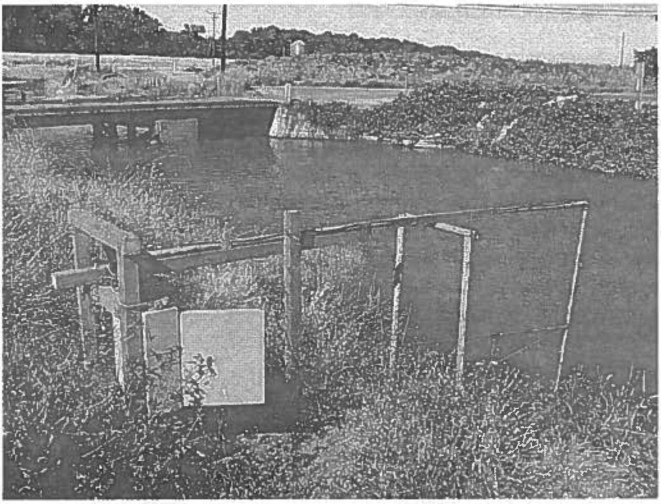

Figure 7. SonTek Argonaut™ SL Doppler current meter at Tisdale Bridge

The percent difference in the measured volume of delivered water ranged from 1.4 to 2.6% per month while the percent difference in total delivered volumes during the four months was less than one percent (–0.9%) as shown in Figure 8. In both monthly and total volumes, the meter registered the slightly higher amount.

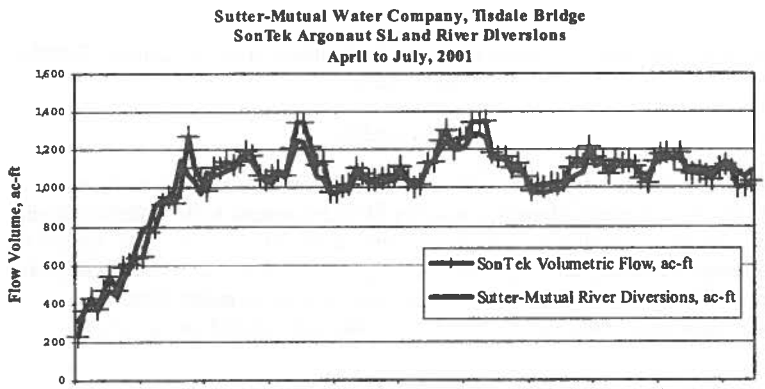

Figure 8. Comparison of Sutter Mutual Water Company and the SonTek Argonaut SL volumetric flows at Tisdale Bridge

Testing at Portuguese Bend Canal

To facilitate the final evaluation testing of the VFD and SCADA system at Portuguese Bend, a Unidata Starflow acoustic Doppler flow meter (Figure 9) was installed in the canal approximately 200 ft downstream of the pumping plant. The Unidata Starflow ultrasonic flow meter provided the total flow rate from the pumping plant during the test period. This was necessary because the new Panametrics meter had not yet been installed on pump #3 (single stage) at the pumping plant. The Unidata Starflow meter was field calibrated using the Panametrics flow meter on pump #1.

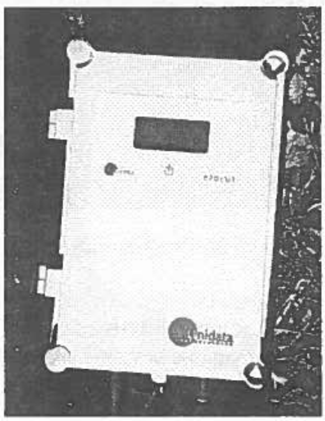

Figure 9. Digital display LCD screen on the Unidata Starflow acoustic Doppler flow meter

SUMMARY

In summary, the modernization effort at SMWC is still continuing in the year 2002 when the company hopes to install a SCADA system in its Tisdale pumping plant. Savings resulting from the installation of the VFD and SCADA system at the Portuguese Bend pumping plant are being closely monitored and already have shown important benefits to the water company and reclamation district as a whole, especially in the area of conserved water and reduced energy costs.

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