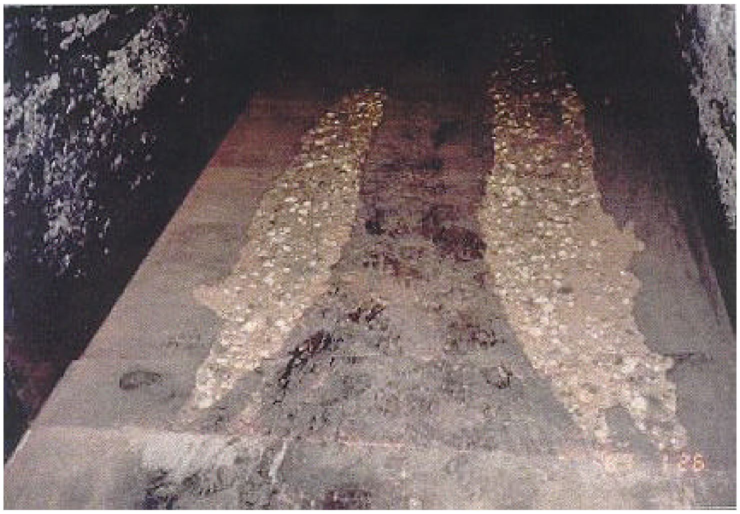
WATER OPERATION AND MAINTENANCE BULLETIN

No. 182

December 1997



IN THIS ISSUE. . .

- River Outlet Works Cavitation Damage
- The ADFM Velocity Profiler™—A Report on Laboratory and Field Demonstrations Conducted for the Bureau of Reclamation
- Cooling Off the Contra Costa Pumping Plants

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Reclamation personnel and water user groups in operating and maintaining project facilities.

Although every attempt is made to ensure high quality and accurate information, Reclamation cannot warrant nor be responsible for the use or misuse of information that is furnished in this bulletin.

Jerry Fischer, Managing Editor
Bureau of Reclamation
Operation and Structural Safety Group, Code D-8470
PO Box 25007, Denver CO 80225
Telephone: (303) 236-9000, extension 230
FAX: (303) 236-1070

Cover photograph: *Cavitation damage on the floor of river outlet No. 2 beginning at the liner. From this photo, it is evident that the cavitation damage begins on the floor of the outlet just downstream of the liner.*

WATER OPERATION AND MAINTENANCE BULLETIN
No. 182—December 1997

CONTENTS

RIVER OUTLET WORKS CAVITATION DAMAGE
Folsom Dam

by Steve Melavic, Mechanical Engineer, Division of Resources Management,
Mid-Pacific Regional Office, Sacramento, California

Folsom Dam was constructed by the Corps of Engineers (Corps) between 1949 and 1956. Operations and maintenance of the dam was transferred to the Bureau of Reclamation in 1956. Folsom Dam's river outlet works consists of eight 5-foot by 9-foot sluice conduits located through the spillway section of the dam, having a total maximum capacity of 28,600 cubic feet per second. There are two tiers of four outlet conduits, one tier at elevation 210 and the other at elevation 280. The lower tier is numbered 1 to 4 from the right side looking downstream, and the upper tier is likewise numbered 5 to 8. Each outlet has two hydraulically operated slide gates in series. The upstream gate is the guard gate, and the downstream gate is the service gate. Each conduit is lined with steel between the gates and extends about 9 feet downstream of the service gate. In the ceiling of each conduit immediately downstream of the service gate is an air vent. Air is required to minimize potential for cavitation.

An inspection in May 1997 revealed extensive cavitation damage inside river outlet No. 3 (photos 1 and 2). Subsequent inspections of the remaining outlets revealed similar damage in No. 4 (photo 3), minor damage in No. 2 (photo 4), and very little to no damage for the others. The severe damage in outlet Nos. 3 and 4 begins at the downstream edge of the liner and extends approximately 45 feet downstream. The damage essentially formed large caverns with the maximum dimensions on the order of 16 feet wide, 6 feet deep, and 5 feet above where the floor had been. The "hop-skip" pattern of minor damage in outlet No. 2 and the smaller cavern following a larger one in outlet No. 4 clearly indicated cavitation as initiating the damage. The steel liners of all outlets are in excellent condition with no loss of metal.

The most probable cause of the cavitation damage has to do with outlet Nos. 3 and 4 being the furthest away from the vent intake. The vent system consists of a 5-foot-diameter intake manifold at elevation 378. Each outlet is vented by a 30-inch-diameter riser connected to the manifold. The risers are approximately 163 feet in length for the lower tier outlets and approximately 93 feet in length for the upper tier outlets. Each vent riser attaches to an outlet tube immediately downstream of the service gate (photo 5 and figure 3). From observing the vent system on figures 1 and 2, it appears quite possible that outlet Nos. 3 and 4 are starving for air when multiple outlets are being operated simultaneously. The area of the 5-foot manifold is about half the combined areas of the 30-inch risers; therefore, the manifold is significantly under-sized when operating all outlets simultaneously.

Design information from the Corps indicates that the maximum air demand occurs when the gate is between one half to three-quarters open. Test data from Denver's Water Hydraulic's Laboratory concurs. Present flood operations at Folsom Dam require the gates to be dropped

Photograph 1.—Inside river outlet No. 3 looking downstream.

Photograph 2.—Inside river outlet No. 3 looking downstream from the metal liner. Cavitation damage begins at the end of the liner.

Photograph 3.—Gate 4 cavitation damage downstream of gate liner. Note second bowl-shaped damage downstream of smaller size which clearly indicates cavitation instead of strictly erosion.

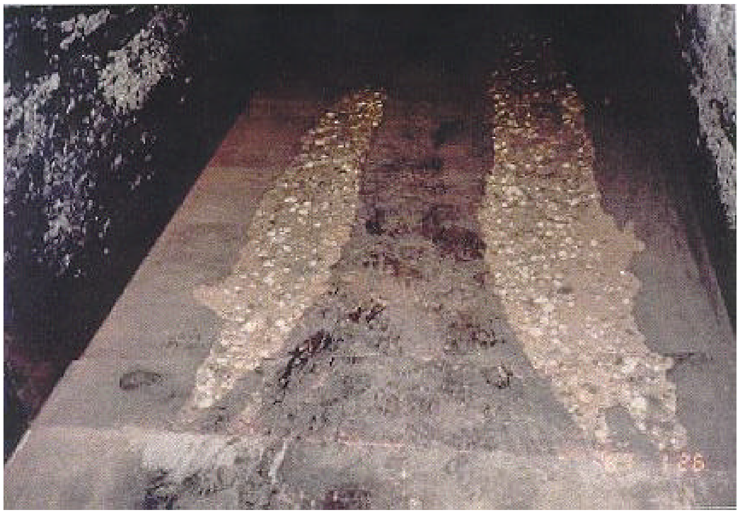
to 60-percent open before the radial gates can be operated in conjunction. Apparently, this operating criteria was set to prevent cavitation on the face of the dam in conjunction with a modification made almost 30 years ago to install "eyebrows" above each outlet on the face of the dam. Before this modification, flood operations did not permit releases from the spillway radial gates in conjunction with the river outlets. It is possible that the cavitation damage occurred when dropping the gates to 60-percent open, which requires more air.

Over the years, there had been concern that the outlet works cavitated when used. For that reason, operations of the outlet works was minimized and usually was not necessary. Reoperation of Folsom Dam for flood control resulted in the desire to make releases with the outlet works to minimize the peak release during flood operations. This explains why the design deficiency of the manifold went unnoticed until this year. During the storm in January 1997, all eight outlet works were operated simultaneously and then were dropped back to 60-percent open when the reservoir was high enough to release from the radial gates. It is possible that all of the damage occurred during these few days early in January. Previous to 1997, the outlet works conduits were last inspected in 1988. No significant damage was noted. Damage to the gates could have occurred over that length of time.

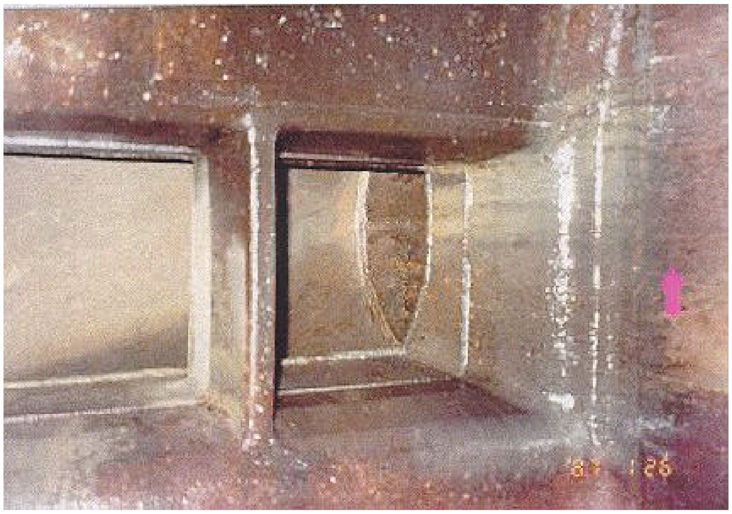
The following were possible modifications considered to prevent future cavitation:

A. Install a steel liner in the river outlet tube. This action protects the tube but does not prevent cavitation.

B. Modify the vent slot to provide air also to the bottom and sides of the tube. This approach has worked in other locations, but the problem appears to be insufficient air capacity in the vent manifold.



Photograph 4.—Cavitation damage on the floor of river outlet No. 2 beginning at the liner. From this photo, it is evident that the cavitation damage begins on the floor of the outlet just downstream of the liner.



Photograph 5.—Typical view of the air vent inside the river outlets. The arrow indicates the direction of flow. The vents are located on the tube's ceiling immediately downstream of the service gate.

C. Install an additional vent intake from the other side of the dam connecting to the same manifold.

D. Modify the sequence of gate operations. It may be possible to maximize air to gate Nos. 3 and 4 by opening them first.

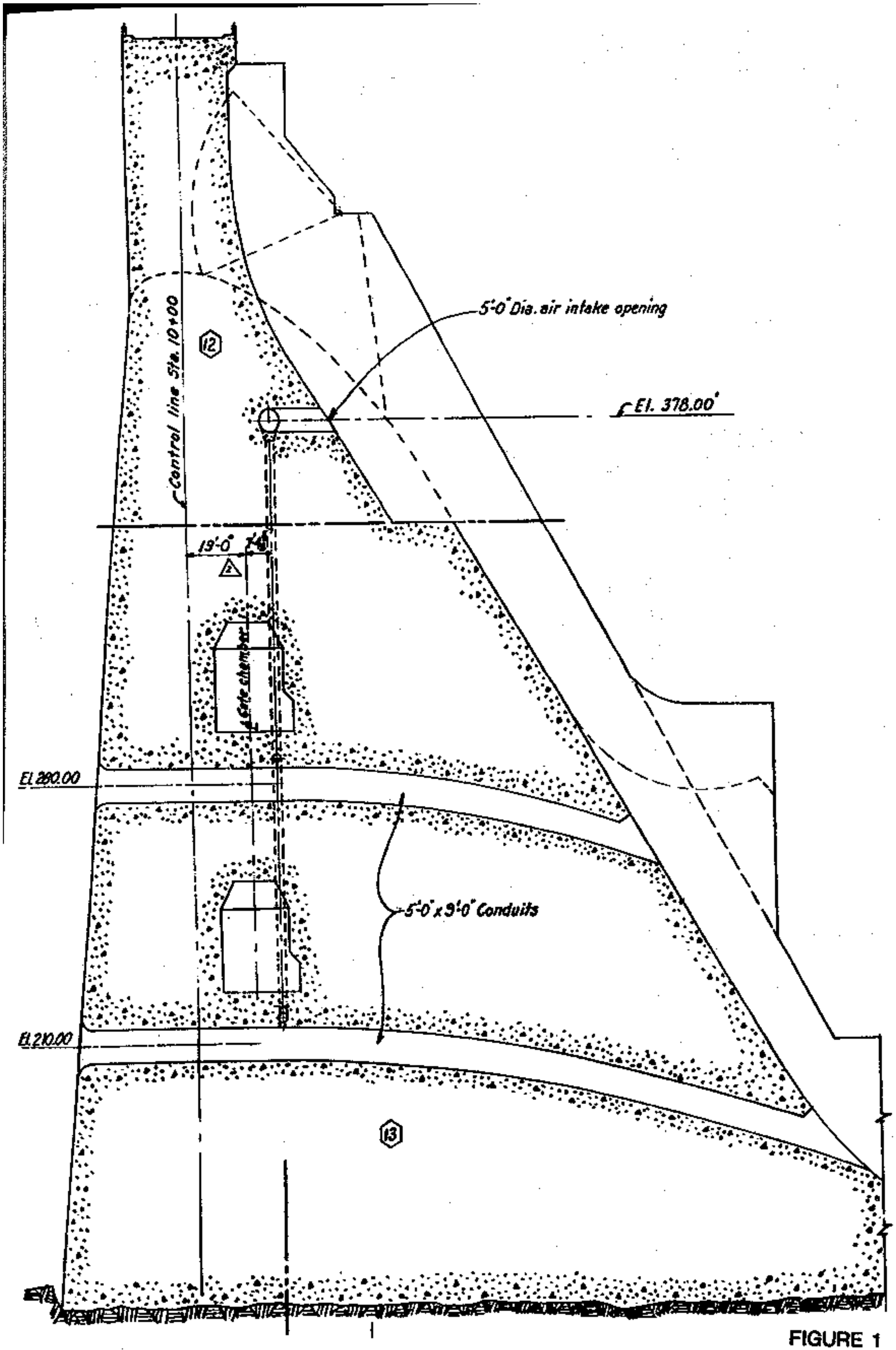
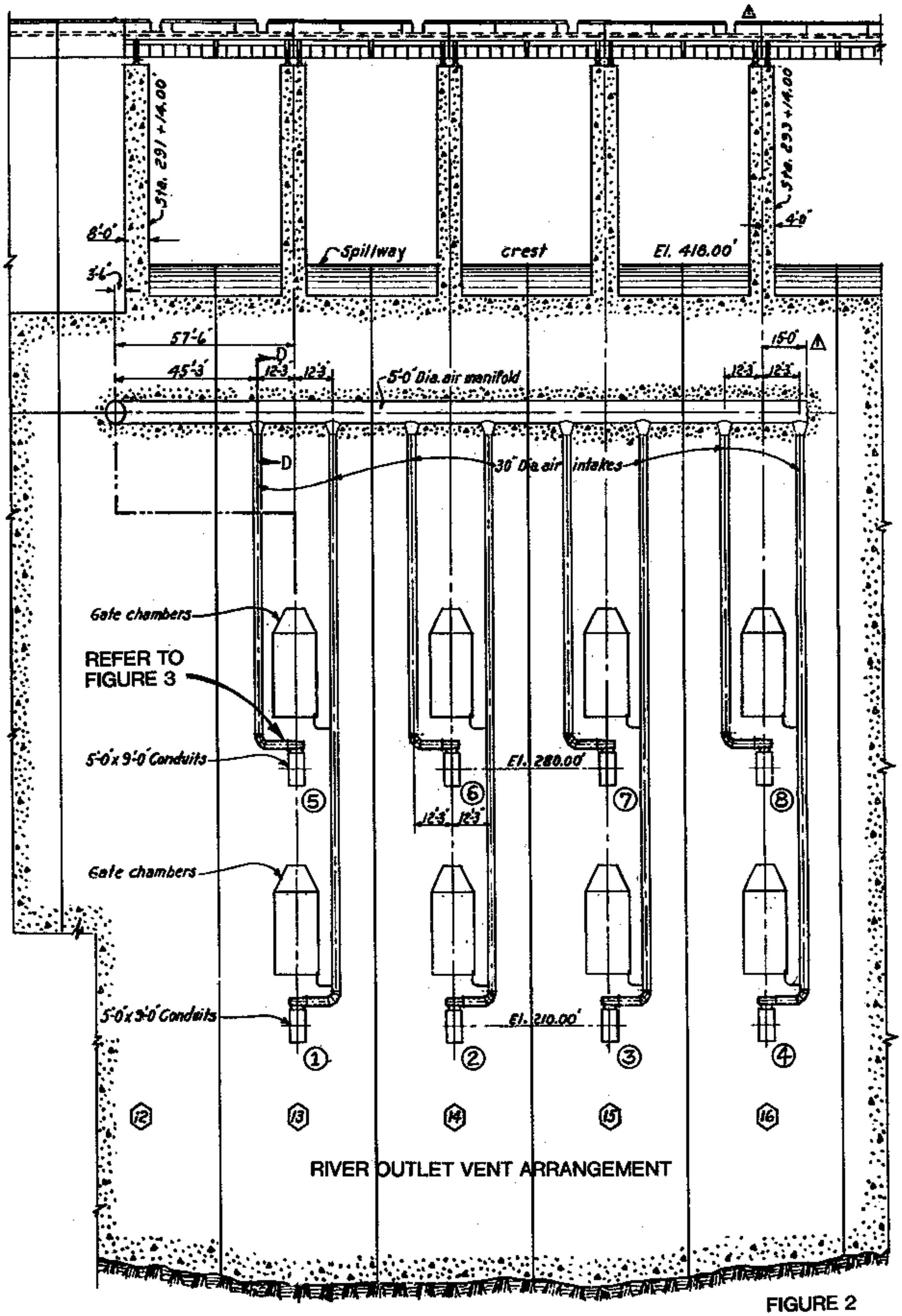
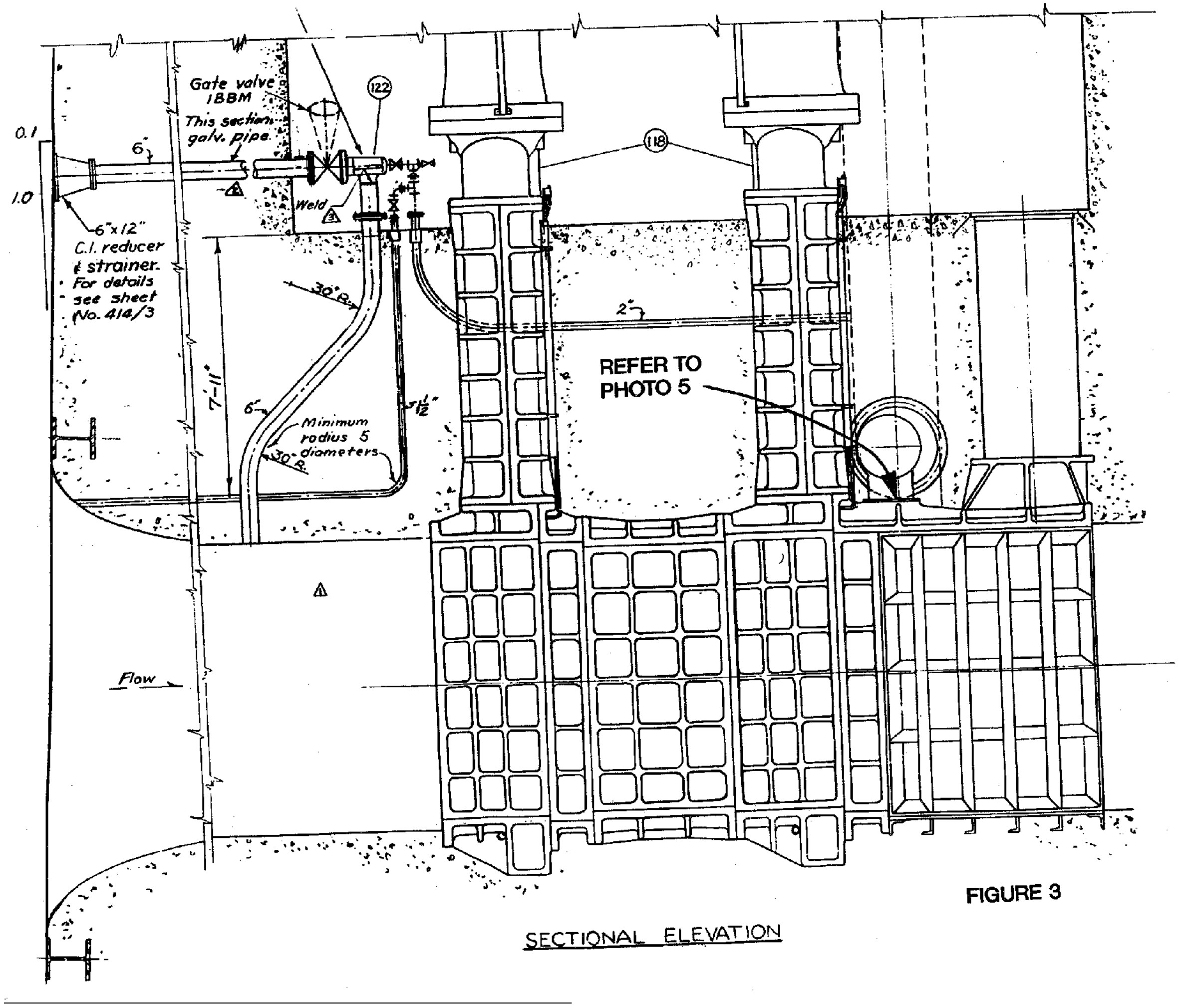

5'-0" Dia. air intake opening
℄ El. 378.00'
Control line Sta. 10+00
12
19'-0"
2
℄ Gate chamber
El 280.00
5'-0" x 9'-0" Conduits
El 210.00
13

FIGURE 1



RIVER OUTLET VENT ARRANGEMENT

FIGURE 2



SECTIONAL ELEVATION

FIGURE 3

E. Modify the allowable gate openings under flood operations. As previously stated, it may be possible to avoid cavitation by changing the allowable river outlet gate openings when releasing from the radial gates.

After reviewing the venting system, the Technical Service Center (TSC) decided that the manifold capacity was insufficient. To add additional capacity, the TSC designed a new intake supply from the left side of the spillway. This new intake will be a 5-foot-diameter tunnel of about 200 feet in length. Repairs are being made to bring the damaged outlets back to designed dimensions. All the work must be completed by the upcoming fall season to have the outlets available for the flood season.

The ADFM Velocity Profiler™—A Report on Laboratory and Field Demonstrations Conducted for the Bureau of Reclamation

by Mike Metcalf, MGD Technologies Inc.; Tracy Vermeyen, Bureau of Reclamation,
Water Resources Research Laboratory; and Steve Melavic and John Fields,
Bureau of Reclamation, Mid-Pacific Region

Introduction

A new type of flowmeter, the ADFM Velocity Profiler™ (Profiler), was demonstrated on March 3 and 4, 1997, at the Bureau of Reclamation's (Reclamation) Water Resources Research Laboratory in Denver, Colorado. The demonstration was organized by Tracy Vermeyen of Reclamation and Mike Metcalf of MGD Technologies, the manufacturer of the Profiler. A subsequent field test of the instrument was conducted in the San Luis Drain near Los Banos, California, on March 14, 1997. John Fields and Steve Melavic of Reclamation's Mid-Pacific Regional Office were responsible for organizing this test. This report documents the results of these tests.

The Instrument

Figure 1 shows a typical Profiler installation for measuring open channel flow in a pipe. A transducer assembly is mounted on the invert of a pipe or channel. Piezoelectric ceramics emit short pulses along narrow acoustic beams pointing in different directions. Echoes of these pulses are backscattered from material suspended in the flow. As this material has motion relative to the transducer, the echoes are Doppler shifted in frequency. Measurement of this frequency shift enables the calculation of the flow speed. A fifth transducer is mounted in the center of the transducer assembly and is used to measure the depth.

The Profiler divides the return signal into discrete regular intervals which correspond to different depths in the flow. Velocity is calculated from the frequency shift measured in each interval. The result is a profile, or linear distribution of velocities, along the direction of the beam. Each of the small black circles in figure 1 represents an individual velocity measurement in a small volume known as a depth cell.

The directions of the velocity profiles in figure 1 are based on the geometry of the Profiler's transducer assembly. Figure 2 shows a side view of the transducer assembly. The profiles shown in figure 1 are generated from velocity data measured by an upstream and downstream beam pair. The data from one beam pair are averaged to generate profile No. 1, and a beam pair on the opposite side of the transducer assembly generates profile No. 2.

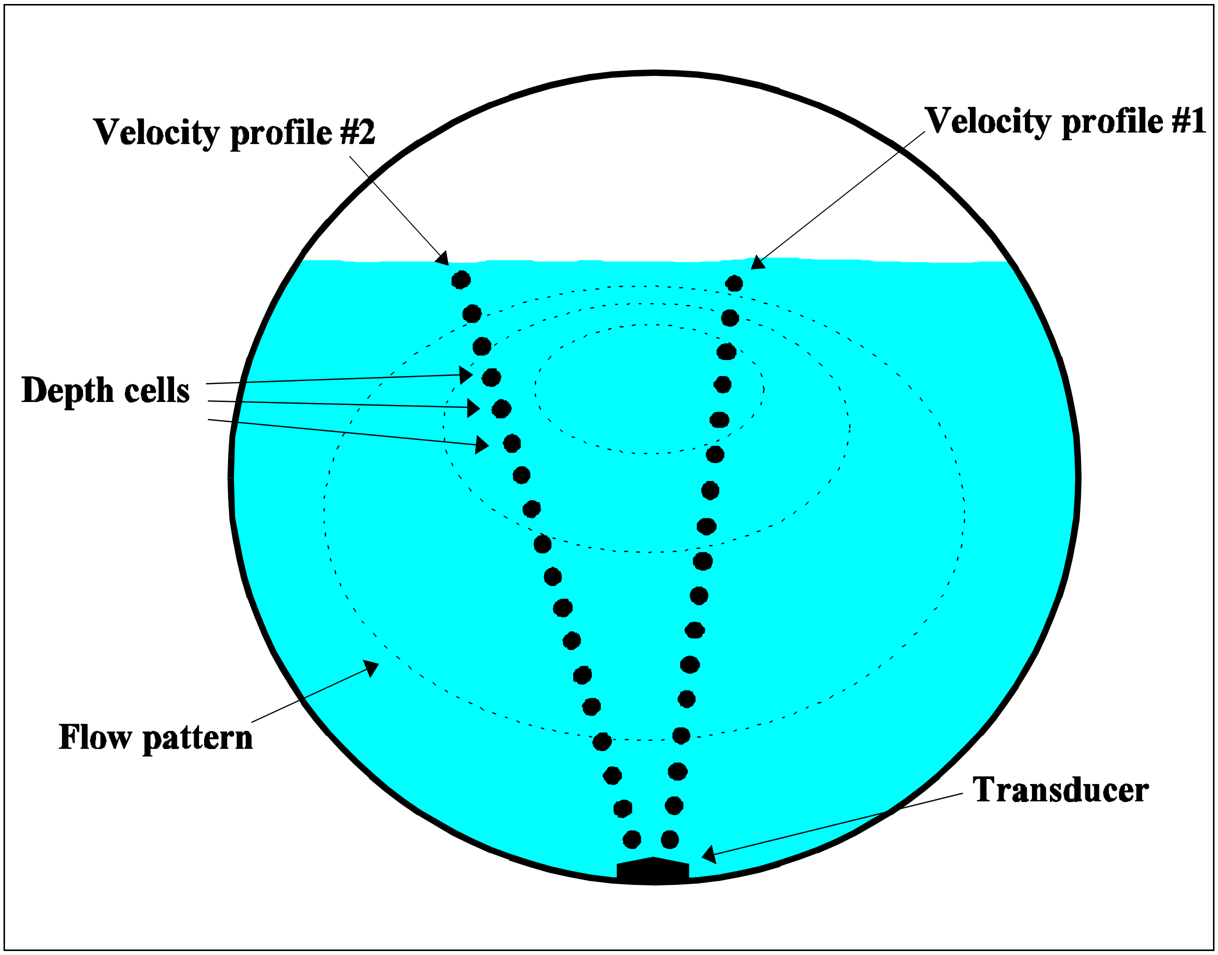


Figure 1.—Cross section view of typical Profiler application. This figure shows the spatial relationship of the depth cells and the profiles relative to the transducer housing.

Because Doppler measurements are directional, only the component of velocity along the direction of the transmit and receive signal is measured, as illustrated in figure 2. Narrow acoustic beams are required to accurately determine the horizontal velocity from the measured component. The narrow acoustic beams of the Profiler ensure that this measurement is accurate. Also, the range-gate times are short, and the depth cells occupy a small volume—cylinders approximately 5 centimeters (2 inches) long and 5 centimeters in diameter. These small sample volumes ensure that the velocity measurements are truly representative of that portion of the flow, and potential bias in the return energy spectrum due to range-dependent variables is avoided. The result is a very precise measurement of the vertical and transverse distribution of flow velocities.

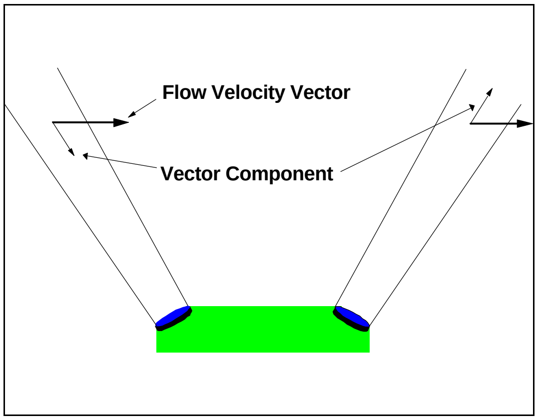


Figure 2.—Side view of the Profiler transducer assembly and its beam geometry.

The velocity data from the two profiles are entered into an algorithm to determine a mathematical description of the flow velocities throughout the entire cross-section of the flow. The algorithm fits the velocity data to the basis functions of a parametric model. The parametric model is used to predict flow velocities at points throughout the flow. The resulting velocity distribution is integrated over the cross-sectional area to determine the discharge.

The key benefit to this approach is that the system will operate accurately under variable hydraulic conditions. As hydraulic conditions change, the change will manifest itself in the distribution of velocity throughout the depth of flow. As the Profiler is measuring the velocity distribution directly, it can adapt to changes in the hydraulics and generate a flow pattern that is representative of the new hydraulic conditions, ensuring an accurate estimate of flow rate.

Test Procedure

The Profiler was first tested in two sites at Reclamation's Water Resources Research Laboratory in Denver using a 4-foot-wide flume and a 12-foot-wide rectangular channel. In both lab sites, the system was installed on the bottom of the flume, centered with the transducer's long axis aligned with the flume's axis (flow direction). No *in situ* calibration or rating was performed.

4-Foot Flume Tests

The test began with a flow depth of approximately 4 feet. The depth was increased after about 1 hour to around 7 feet. Profiler flow measurements were then compared with the venturi meter flows to check for accuracy and repeatability.

12-Foot Channel Tests

The test began with a depth of flow of approximately 2 feet. The depth was decreased after about 1 hour to 1.2 feet. Profiler flow measurements were then compared with the venturi meter flows to check for accuracy and repeatability.

The venturi meter flows were determined using a mercury manometer to measure the pressure differential across the venturi. This manometer was manually read several times during the tests. Once established, the flow was held constant as it was controlled by an active feedback control system. The laboratory venturi meter was calibrated prior to the Profiler demonstration. A weigh tank facility was used to calibrate the venturi meter, and the uncertainty in the venturi meter measurement was within ±0.8 percent of the weigh tank flow rate.

Following the laboratory tests, the Profiler was placed in a "live" channel—the San Luis Drain located near Los Banos, California. This channel is an irrigation drain for part of the San Joaquin Valley. The channel is trapezoidal in shape, with an 8-foot bottom width and 2:1 side slopes.

The Profiler was placed on an aluminum strap about 44 feet in length. Hinges were placed on the strap so that the 8-foot center piece would lay flat on the channel bottom and the rest of the strap would conform to the side slopes of the channel. The channel was in normal operation during the installation with a flow depth of approximately 7.2 feet.

Results

Figure 3 shows the results from the 4-foot flume tests. The round symbols represent the Profiler data, and the square symbols are the spot readings from the venturi meter. As shown in figure 3, the Profiler data agrees very well with the venturi meter readings.

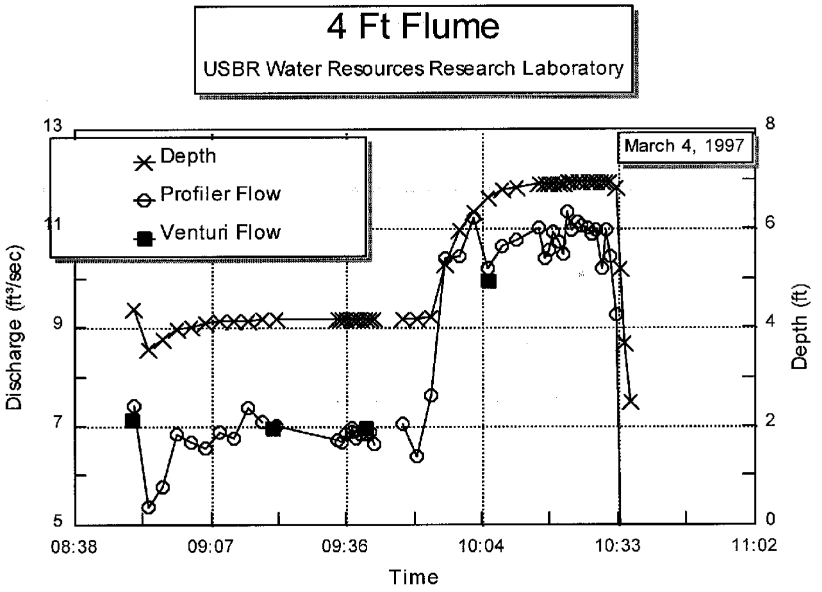


Figure 3.—Profiler and venturi flow rates measured in the 4-foot flume are plotted as a function of time. The Profiler's depth reading is also plotted to illustrate the effect of fluctuating water surface level on the discharge measurement accuracy.

At the beginning of the data record, there is some scatter to the Profiler data because the flow into the flume had just been set and the depth in the flume was still equilibrating. After the first few points, the flow rate readings and depth readings become steady. The Profiler measured an average flow rate of 6.86 cubic feet per second (ft^3/s) during the initial depth of flow of 4 feet (after depth equilibration), compared to 6.98 ft^3/s for the venturi readings during the same time period, a difference of -1.72 percent. We also see a change in the Profiler flow rate measurement after the level was increased to 7 feet at around 10:00 a.m. The Profiler overpredicts the flow because one pair of acoustic beams intersects the walls of the flume. Consequently, the average velocity is skewed higher because it is measured near the middle of the flume where velocities are larger than near the wall.

The spacing on the x-axis is irregular because several sampling schemes, in which parameters such as bin size and sampling interval, were varied. In most cases, changing these parameters did not affect the overall accuracy of the flow rate measurement.

Figure 4 shows the results from the 12-foot channel test. The round symbols are Profiler data, and the square symbols are spot readings from the venturi meter. For this test, the Profiler data were averaged over a variety of time periods. Figure 3 is a plot of "raw" flow data where each point corresponds to a individual measurement separated by an interval varying from 1 to 5 minutes. The first seven acoustic Doppler flow meter (ADFM) measurements were collected with a 1-minute averaging interval. The average of these seven measurements is 10.48 ft^3/s. The venturi meter reading was 10.26 ft^3/s, and this flow remained constant for the remainder of the test. The next five ADFM measurements were collected with an averaging interval of 5 minutes. The average of these five measurements is 10.29 ft^3/s. The next six ADFM measurements were collected with an averaging interval of 2 minutes. The average of these seven measurements is 10.43 ft^3/s. This test demonstrates how Profiler measurements become more precise as the number of measurements averaged together increases. The ability to average hundreds of flow measurements over a short period results in a very precise flow measurement. This is illustrated by comparing the average of the all 18 Profiler measurements with the 2 venturi meter readings. The Profiler average was +0.97 percent different from the venturi meter average. The last ADFM measurement was collected with an averaging interval of 2 minutes at a depth of 1.2 feet. The measured flow rate was 10.0 ft^3/s. This measurement was made with a 10:1 width to depth ratio. This demonstrates the Profiler's unique capability to measure flows in wide, shallow channels.

Figure 5 contains a plot of the flow rate, depth, and average velocity measured in the San Luis Drain near Los Banos, California, on March 14, 1997. All three measured parameters were steady over the test period. Variations in the flow rate correlate with variations in the average velocity, as the depth remains fairly constant. The average flow rate over the duration of the test was 91.1 ft^3/s. Flow rates of approximately 80 and 86 ft^3/s were measured using traditional stream gauging methods. Stream gauging velocities were measured with a Marsh-McBirney Flo-Mate, which is an electromagnetic velocity meter.

The first discharge measurement was obtained by manually measuring velocities at 0.2 and 0.8 of the depth measured from the water surface, at regular intervals across the channel. These velocities were used to compute an average velocity for a particular section of the channel. Multiplying this average velocity by the cross-sectional area of the individual section gives a flow rate for that section. The section flow rates are summed to determine the total flow rate for the channel.

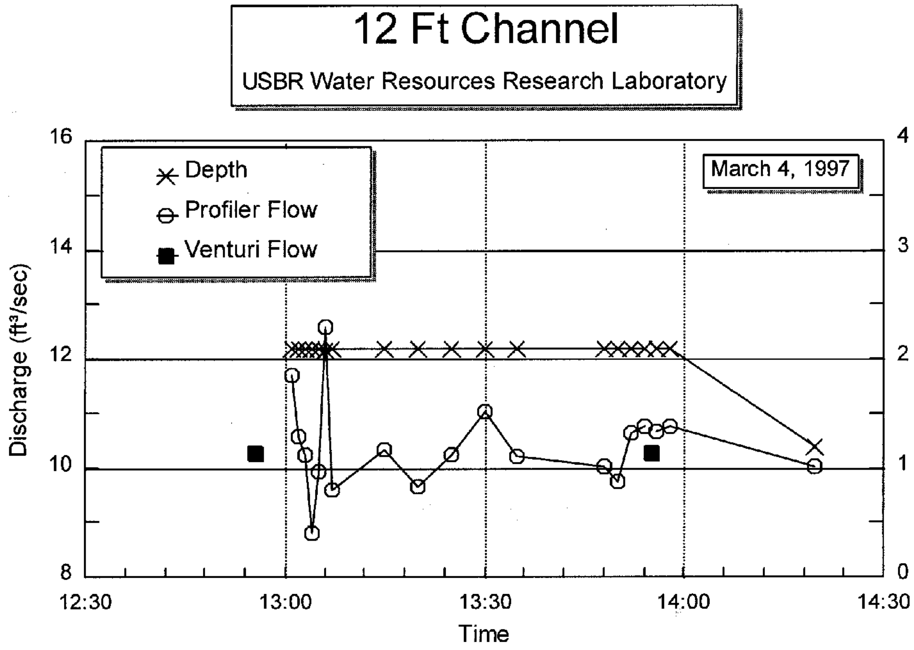


Figure 4.—Profiler and venturi flow rates measured in the 12-foot channel are plotted as a function of time. The Profiler's depth reading is also plotted. Initially, the Profiler's discharge measurements were variable but, with time, the accuracy improved to within 1 percent of the venturi-measured discharge.

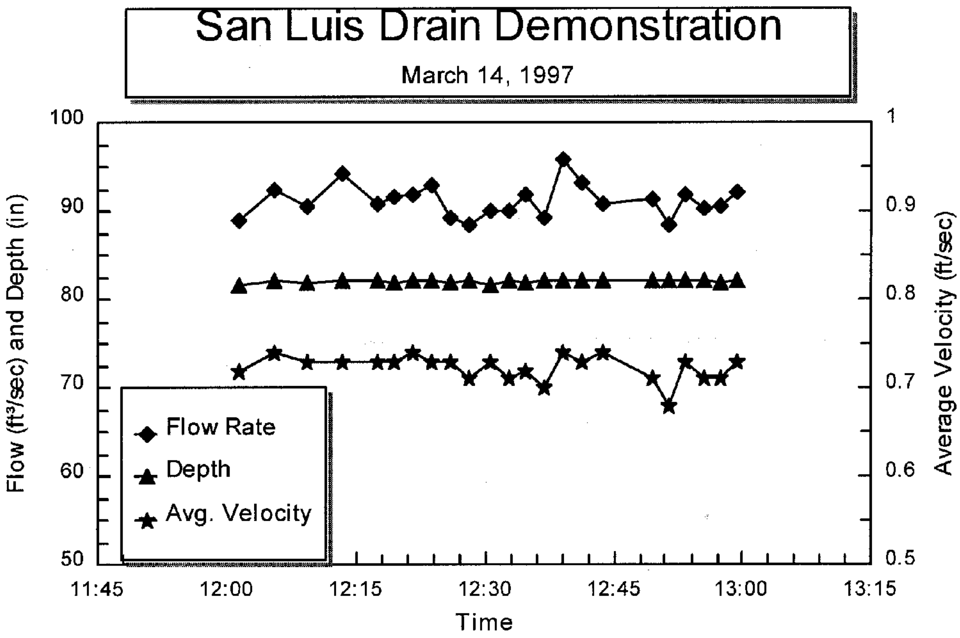


Figure 5.—Flow rate, depth, and average velocity plotted as a function of time. The average flow rate measured in the San Luis Drain was 9.1 ft^3/s with a standard deviation of 2.0 percent.

The second discharge measurement was obtained by making a single velocity measurement at a height above the bottom of 0.6 of full depth, at regular intervals across the channel. This value was used as the average velocity in that section to compute a flow rate for that section. Again, section flow rates are summed to determine the total flow rate in the channel. (Note: This velocity measurement should have been measured at 0.6 of the depth measured from the *surface*, not the bottom.)

It should be mentioned that there was some concern over the accuracy of the manual velocity measurements. The relationship between the velocities measured at the various depths was not as expected. In particular, the velocity value measured at a height above the bottom of 0.8 of full depth, in some cases, was lower than anticipated.

Conclusions

For laboratory tests, the Profiler measured flow rate with an accuracy of approximately 1.7 percent in the 4-foot flume and 1.0 percent in the 12-foot channel. The Profiler was able to accurately measure flow rate even with a width to depth aspect ratio of 10:1.

This test demonstrated that the Profiler does not require an *in situ* calibration or rating Profiler to make an accurate flow measurement. Accurate flow measurements were attained without any special consideration to the installation, aside from placing the Profiler in the middle of the flow and aligning it with the direction of flow.

The Profiler was successfully installed in a “live” channel, without interrupting the flow. Flow rates measured were repeatable and within roughly 10 percent of a traditional stream gauging measurement. However, there was some concern that the stream gauging measurement might not be accurate, as some velocities appeared lower than anticipated. This would lower the flow rate estimate generated by the stream gauging method.

This demonstration was useful in showing the ability of the ADFM Velocity Profiler to measure flow rates in a variety of conditions with a minimal amount of time required to install and setup the instrument. This new technology has the potential to provide flow measurement in areas where traditional discharge measurement devices are impractical. It also could be a valuable tool for calibrations of existing flow measurement structures and for research studies that require velocity profile measurements.

This instrument can accurately measure detailed velocity profiles in an open channel which can be used for engineering studies. For example, the ADFM can be used to measure velocity profiles which describe flow into and around structures such as fish screens or fish ladders.

COOLING OFF THE CONTRA COSTA PUMPING PLANTS

Construction on the Contra Costa Canal system was completed in 1948. The canal system, which is operated and maintained by the Contra Costa Water District, delivers water for industrial, municipal, and agricultural purposes to northeastern Contra Costa County, located east of Oakland, California. The canal removes water from the Rock Slough in the Sacramento-San Joaquin River delta. The water is lifted 127 feet by four pumping plants to the canal which terminates at Martinez Reservoir. Design flows range from 350 cubic feet per second (ft^3/s) at pumping plant No. 1 to 22 ft^3/s at Martinez Dam and Reservoir.

Contra Costa Pumping Plant Nos. 1, 2, 3, and 4 are located in series on the Contra Costa Canal. There are two levels in each pumping plant—the lowest contains the wet well intakes for the pumps, and the main level where the motors are mounted with electrical control equipment. Each of the four pumping plants was designed for six pumping units, with the initial installation of four pumping units at each plant. In 1972, two additional units were installed for each pumping plant. The pumping units were vertical-shaft, mixed-flow type, powered by a synchronous motor. Cooling of the motors for each pumping unit came from air taken in the vicinity of the motor. The fan blades on each motor's rotor discharged heated air upwards toward the ceiling vents. Still, during the summer months, operators complained that pumping plant temperatures remained well above 120 degrees.

In a Review of Operation and Maintenance examination of the canal system performed in 1994, recommendations were made to clean and repaint the roof vent metalwork and improve the access hatches to the pump bays at pumping plant No. 1. The district was planning on replacing their roof surfacing at each pumping plant, so they evaluated whether the roof vents at all plants also should be replaced. Inadequate air circulation through the plants was obvious when operators struggled to open doors drawn closed by fan operations.

The improvements to each pumping plant were recently completed. On the wet well level of each plant, air filters were attached with a frame to the inside of the louvers (photographs 1 and 2), which replaced the original windows, to remove dust and dirt from the air. To improve air flow around the motors on the main level, aluminum grating (photograph 3), with a larger net open area, was installed. The lighter gratings can be lifted easily by one operator. Finally, new roof vents with motors (photograph 4) were placed atop the plants. The improved air flows from the canal water surface through the filtered louvers, up from the wet well to the aluminum grating, past the cooling motors, toward the roof vent motors, and out the roof of each plant. Hot air from other electrical controls also is drawn out of each plant. The net result keeps interior plant temperatures in an acceptable operating range.

For more information on the pumping plant improvements, contact Elizabeth Partridge in Reclamation's Tracy Field Office at (209) 836-6278, or Werner Schmid, Assistant Superintendent-Operations and Maintenance, Contra Costa Water District, at (510) 625-6509.

Photograph 1.—Typical inlet area to each pumping plant.

Photograph 2.—Air filters attached to the inside of the louvers.

Photograph 3.—Aluminum grating over the floor openings adjacent to the motors.

Photograph 4—New roof vent motors atop the pumping plants.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

Jerry Fischer, Technical Service Center, ATTN: D-8470, PO Box 25007, Denver, Colorado 80225-0007; (303) 236-9000 ext. 230, FAX (303) 236-1070

Vicki Hoffman, Pacific Northwest Region, ATTN: PN-3234, 1150 North Curtis Road, Boise, Idaho 83706-1234; (208) 378-5335, FAX (208) 378-5305

Dena Uding, Mid-Pacific Region, ATTN: MP-430, 2800 Cottage Way, Sacramento, California 95825-1898; (916) 979-2422, FAX (916) 979-2505

Bob Sabouri, Lower Colorado Region, ATTN: LC-4844, PO Box 61470, Boulder City, Nevada 89006-1470; (702) 293-8116, FAX (702) 293-8042

Don Wintch, Upper Colorado Region, ATTN: UC-258, PO Box 11568, Salt Lake City, Utah 84147-0568; (801) 524-3307, FAX (801) 524-3034

Tim Flanagan, Great Plains Region, ATTN: GP-2400, PO Box 36900, Billings, Montana 59107-6900; (406) 247-7780, FAX (406) 247-7793