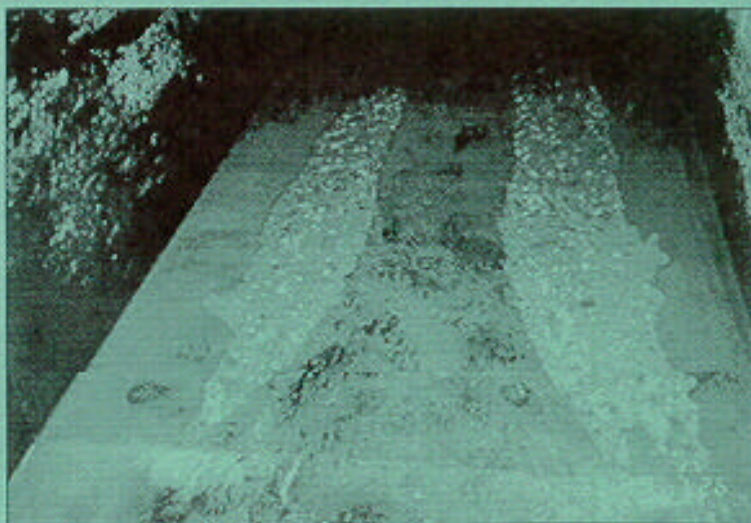


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UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

The ADFM Velocity Profilerä - A Report on Laboratory and Field Demonstrations Conducted for the Bureau of Reclamation

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Introduction

A new type of flow meter, the ADFM Velocity Profiler™ (Profiler) was demonstrated on March 3rd and 4th at the Bureau of Reclamation's Water Resources Research Laboratory in Denver, CO. The demonstration was organized by Tracy Vermeyen of the Bureau 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, CA, on March 14th. John Fields and Steve Melavic of the Bureau of Reclamation's Mid-Pacific Region 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 enables the calculation of the flow speed. A fifth ceramic mounted in the center of the transducer

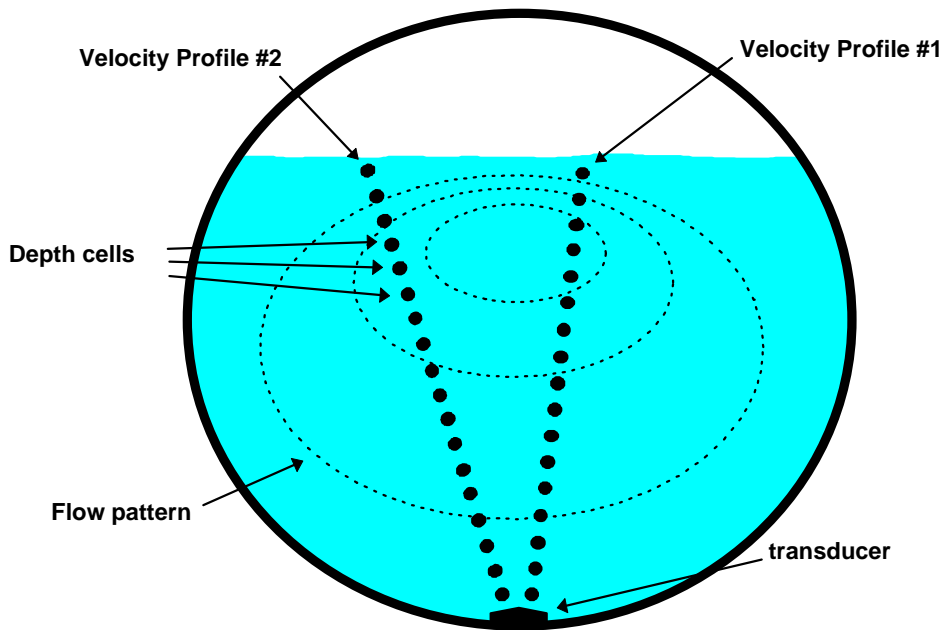


Figure 1. Profiler measurement technique. This figure shows the spatial relationship of the depth cells and the profiles relative to the transducer.

assembly, and aimed vertically, 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 represent 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 #1, and a beam pair on the opposite side of the transducer assembly generates Profile #2.

Since Doppler measurements are directional, only the component of velocity along the direction

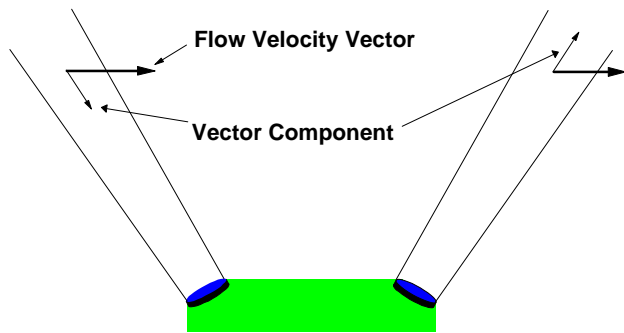


Figure 2. Profiler Beam Geometry

of transmit and receive is measured, as shown 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 insure that this measurement is accurate. Also, the range-gate times are short and the depth cells occupy a small volume - cylinders approximately 5 centimeters long and 5 centimeters in diameter. This insures that the velocity measurements are truly representative of

that portion of the flow. 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.

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 basis functions of a parametric model to the actual data. The result predicts flow velocities at all points throughout the flow. These results are integrated over the cross-sectional area to determine the discharge.

The key benefit to this approach is that the system will operate accurately under different 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 will adapt to the changes in hydraulics, and generate a flow pattern that is representative of the new hydraulic conditions, insuring an accurate estimate of flow rate.

Test Procedure

The Profiler was first tested in two sites at the Bureau of Reclamation's Water Resources Research laboratory in Denver - a 4 ft wide flume and a 12 ft 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 (the flow direction). No in-situ calibration or rating was performed.

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

The venturi meter flows were determined using a mercury manometer to measure the differential pressure across the venturi. This manometer was read several times during the above tests. Once set up, the flow was held constant through the control of an active feedback circuit. 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 flow measurement was within $\pm 0.8\%$ of the weigh tank measurements for flow rate.

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

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

The Profiler was placed on an aluminum strap about 44 ft in length. Hinges were placed on the strap so that the 8 ft. 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 ft.

Results

Figure 3 shows the test results from the 4 ft flume, with flow rate and depth plotted as a function of time. The round symbols are the Profiler flow data, the squares are the spot readings of the lab’s venturi meter, and the triangles are Profiler depth readings. The Profiler data correlates very well with the venturi meter readings.

At the beginning of the record, there is some scatter to the Profiler data, as the level in the flume had just been set and the depth of the system was still equilibrating. After the first few points, the flow rate readings (and depth readings, which are not shown) become steady. The Profiler average of flow rate during the initial depth of flow of 4 ft (after depth equilibration) is $6.86 \text{ ft}^3/\text{s}$, compared to $6.98 \text{ ft}^3/\text{s}$ for the manometer readings during the same time period; a difference of -1.72%.

We also see a change in the Profiler flow measurement after the level is increased to 7 ft at around 10:00 a.m. The Profiler is now over predicting the flow by around 5%. This is because one the beam is intersecting the wall of the flume at about 5.5 ft from the bottom. Consequently, the beam is reflected back towards the middle of the flow where the velocities are larger than they are near the wall. This falsely raises the average velocity of this beam pair, raising the estimate of flow rate.

The spacing on the x-axis is irregular as several sampling intervals were used. The intervals are different as some of the Profiler’s measurement parameters, such as bin size and the number of individual measurements within a sampling interval, were varied. The changes were selected so that they did not affect the overall accuracy of the flow rate measurement.

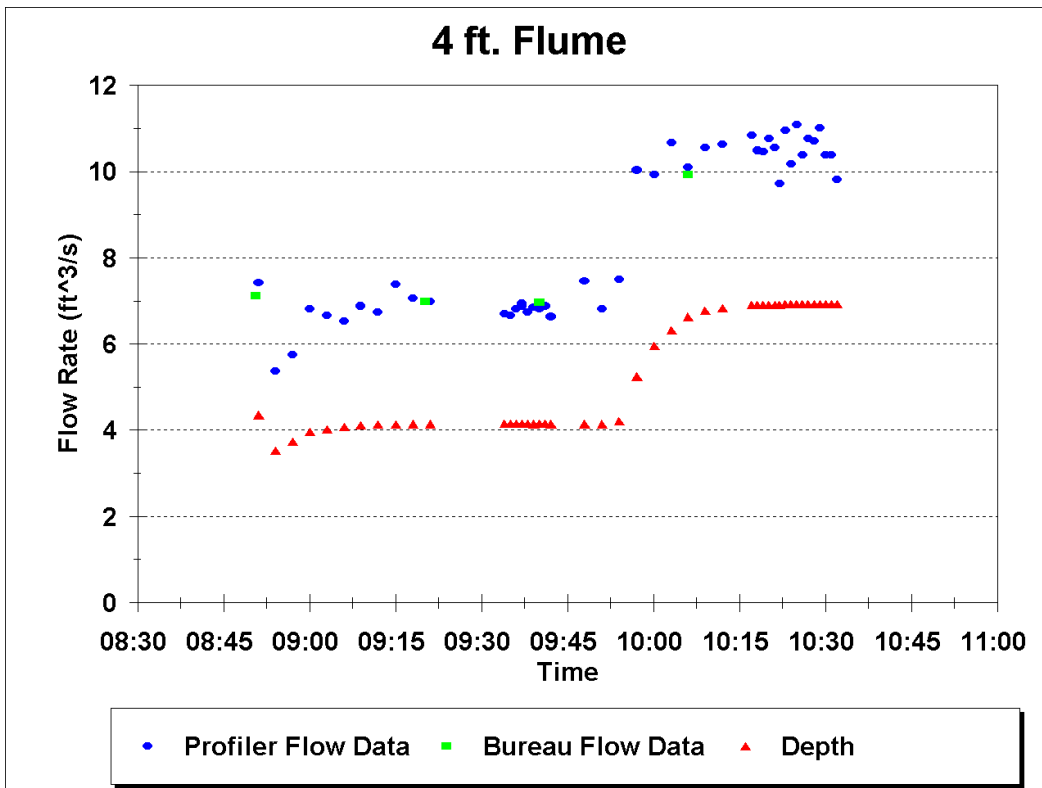


Figure 3. Flow rates measured in the 4 ft. flume plotted as a function of time. When the flume is filled to deeper than 5.5 ft, the Profiler over predicts flow by about 5% because one beam pair is intersecting the wall of the flume.

Figure 4 shows the results from several test runs in the 12 ft channel. The round symbols are the Profiler data, the squares are the spot readings of the lab's venturi meter, and the triangles are Profiler depth readings. Again, the Profiler data were averaged over different sampling intervals.

The first seven Profiler measurements were collected with an averaging interval of 1 minute. The average of these seven measurements is 10.48 ft³/s. The venturi reading was 10.26 ft³/s and this flow remained constant for the remainder of the test. The next five Profiler measurements were collected with an averaging interval of 5 minutes. The average of these five measurements is 10.29 ft³/s. The next six measurements were collected with an averaging interval of 2 minutes, and their average is 10.43 ft³/s.

This test demonstrates how the Profiler's measurements become more precise as the number of measurements averaged together is increased. The ability to average hundreds of individual flow measurements over a short period results in a very precise flow measurement. This is further illustrated by comparing the average of all eighteen Profiler measurements with the two venturi meter readings. The Profiler average was 0.97% different from the venturi meter average.

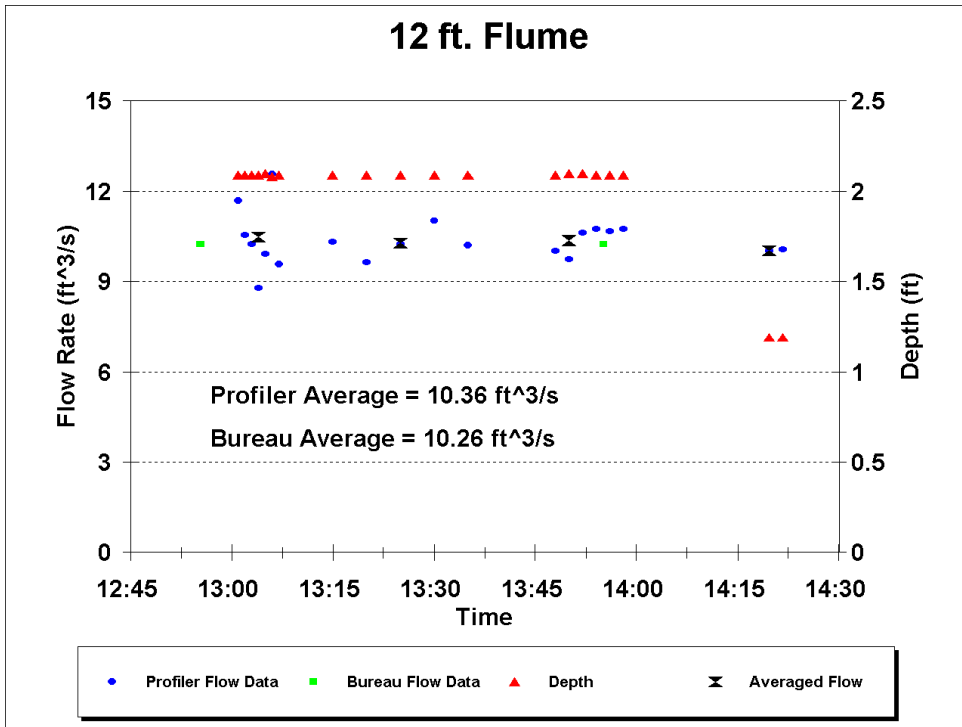


Figure 4. Flow rates measured in the 12 ft. channel plotted as a function of time. The addition of “Averaged Flow” is explained in the text.

The final Profiler reading on this plot was acquired at a depth of flow of 1.2 ft. This measurement was made with a width to depth aspect ratio of 10:1. This demonstrates the Profiler’s unique capability to measure flows in wide, shallow channels.

Figure 5 is a plot of the flow rate, depth, and average velocity measured in the San Luis Drain near Los Banos, CA. All three measured parameters were steady. 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 is 91.1 ft³/s. Flow rates of approximately 80 and 86 ft³/s were measured using the traditional method of stream gauging.

The first stream gauging value 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.

The second value 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 value for the section in order to compute a flow rate for the section. Again, section flow rates are summed to determine the total flow rate in the channel. Note: This velocity measurement should have been made at 0.6 of the depth as 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

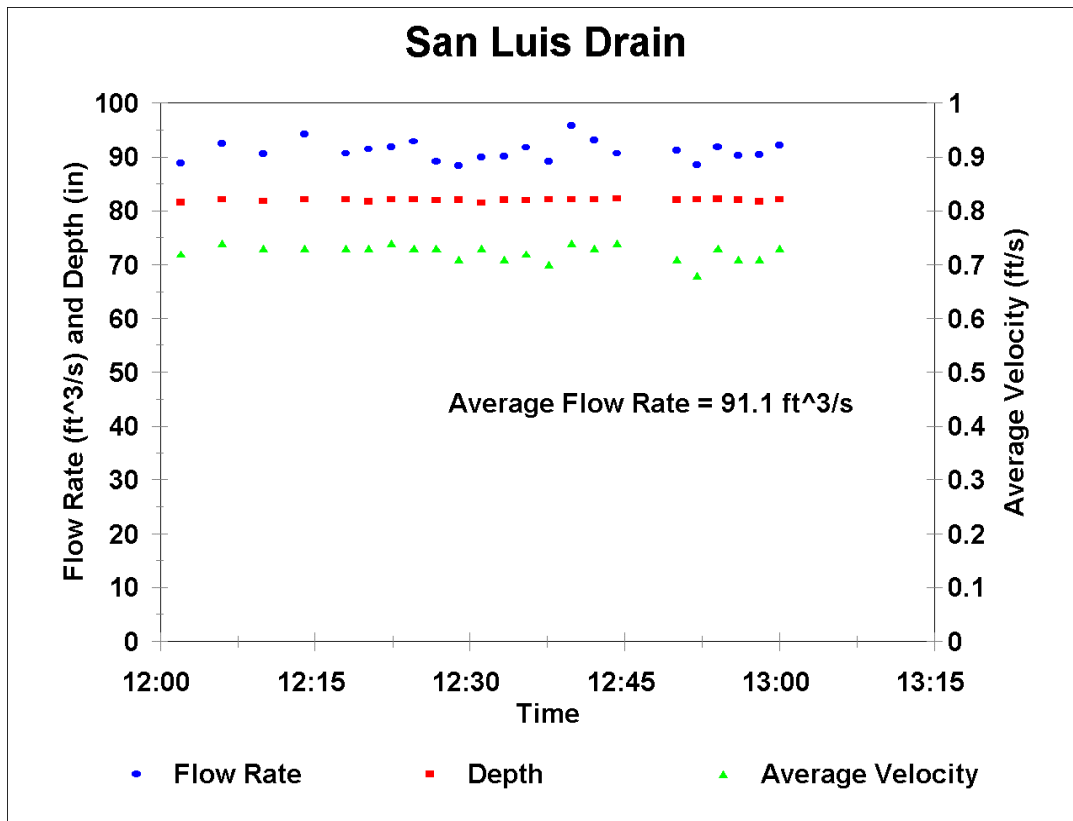


Figure 5. Flow rate, depth, and average velocity plotted as a function of time. The average flow rate was 91.1 ft³/s.

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

The Profiler measured flow rate with an accuracy of approximately 1.7% in the 4 ft. flume and 1.0% in the 12 ft. channel. The Profiler was able to accurately measure flow rate even with a width to depth aspect ratio of 10:1.

This test demonstrated a significant benefit of the Profiler; in situ calibration, or rating of the Profiler, was not required. 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% 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 in a variety of conditions and 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 could also be a valuable tool for calibrations of existing flow measurement structures and for research studies that require velocity profile measurements.