Measuring Sacramento River Diversions with ADFM Technology in the Glenn-Colusa Irrigation District

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Abstract

The ADFM Velocity Profiler™ (ADFM) is a variation of the well-known Acoustic Doppler Current Profiler (ADCP). Although the ADFM relies on the same BroadBand™ signal processing found in the RD Instruments ADCP, there is a fundamental difference between the two systems. An ADCP is designed to provide the user with profiles of the three vector components of water motion – the x, y and z components of a water current flow velocity vector. By comparison, the ADFM measures multiple x-velocity component profiles in order to derive a distribution of x-velocity components throughout the water column. This distribution is used to calculate the total downstream volumetric flow. In other words, an ADCP measures all velocity components to determine the three-dimensional velocity structure in a column of water. The ADFM measures a specific velocity component in order to calculate the total volumetric rate of flow of the column of water.

In April of this year, three (3) ADFMs were installed in the Stony Creek Siphon in the Glenn-Colusa Irrigation District (GCID). The purpose of the ADFM installations is to provide continuous monitoring of the volume of water diverted from the Sacramento River by the GCID. The installations were performed while the channel was "live" – there was no diversion or reduction in flow rate during the installation. The paper presents the methods of installation and initial flow data results from the ADFMs.

Introduction

The Glenn-Colusa Irrigation District (GCID) diverts flow from the Sacramento River for distribution to its customers and local wildlife refuges. Measuring the total flow rate of raw water discharged into the GCID system through a diversion canal is required by contract - the contract being between the Bureau of Reclamation, who is responsible for managing the flows in the Sacramento River, and the GCID. A typical diversion canal has an irregular or varying cross-section, making open channel flow measurements difficult. Using present day technology in such an open channel will degrade the quality of the flow data because of the unstable cross section. The obvious solution, relining an entire channel section, is a costly endeavor. Using a manual method for measuring the cross section and the flow rate is costly in both time and resources, and cannot be done continuously.

The Bureau of Reclamation was faced with the above challenge - the Bureau would have to reline a section of the diversion canal, at great cost, in order to install traditional travel time flow meters. Although the flow passes through a siphon underneath the Stony Creek, the siphon is always full, even when the flows are turned off at the end of the season. In order to use the same type of flow monitoring equipment described above, the siphon would either have to be drained or extensive diving operations would be required. Access to the meters for maintenance would be virtually impossible. An easy to install flow meter, that is still able to accurately measure flow rate in the siphon's large channels, is required.

The Bureau opted for the installation of the ADFM in the Stony Creek Siphon. The ADFM is an acoustic system, which utilizes the Doppler principle. However, it has a distinct advantage over other acoustic, and particularly Doppler, types of technology. The ADFM utilizes pulse coherent signal processing combined with signal range gating. The result is the ability to measure a velocity ***profile***, or a distribution of independent velocity measurements throughout the depth of flow. This is identical technology to that employed by ADCP instruments. Water level is also measured acoustically for use in open channel applications.

The key difference between and ADFM and a traditional ADCP lays in the transducer assembly geometry, and is reflected in the relative purpose of each instrument's measurement. An ADCP is concerned with measuring the three vector components of current velocity – x, y and z. By measuring profiles of these three components, a three-dimensional picture of the current structure can be generated. An ADFM is concerned only with measuring the downstream vector component of flow velocity – what we will call the x-component.

Figure 1 shows the ADFM measuring multiple x-component profiles in the depth of flow. Each one of the sections along the segmented lines, representing an acoustic beam, is a small volume in which the velocity is calculated. These segments are the same as the bins or depth cells of an ADCP. The vertical line represents the acoustic beam that is used to measure the

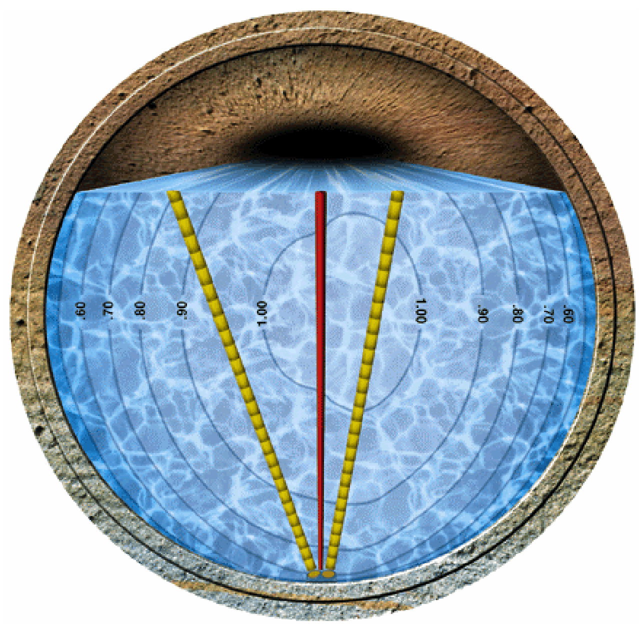

Figure 1. The ADFM measurement method in a circular pipe.

depth of flow. The x-component velocity data are entered into a data-adaptive algorithm that generates a mathematical description of the 2D-velocity structure. That is the distribution of x-component velocity throughout the depth of flow. Known hydraulic functions are fit to the real data to interpolate velocities throughout the entire depth of flow. The 2D-velocity distribution is integrated over the cross-sectional area to determine the flow rate. The contours in Figure 1 represent this velocity distribution.

Doppler technology applied in this way results in a flow meter that is less susceptible to measurement error for most flow conditions. It does not require site-specific calibration for accurate flow rate measurement. An accurate description of velocity distribution throughout a pipe or channel is computed directly from the distribution of discrete velocity measurements.

The Site

The Stony Creek Siphon is located approximately 3 miles south of Hamilton City, in Glenn County, California. The siphon conveys water in the GCID Canal underneath the Stony Creek. The siphon consists of three (3), side-by-side, rectangular channels that are 12' high and 14'. Figure 2 is a view of the effluent end of the siphon.

Figure 2. The Stony Creek Siphon channels, looking upstream towards the effluent end of the siphon.

As the water is unable to be drained from the siphon, divers were required to install the ADFM transducer assemblies; one assembly in each channel. Figure 3 shows the ADFM transducer assembly. It appears to differ from the "Janus" configuration of a standard ADCP, but the difference is not that large. The ADFM still uses the concept of opposing beams, one pointing upstream and the other downstream. However, both these beam pairs are designed to measure x-components of velocity. One pair creates the average beam that is represented by one of the segmented lines in Figure 1. The other beam pair creates the other segmented line.

Due to irrigation requirements downstream of the siphon, the flow through the siphon continued during the process of installations. Because of this, the diving team installed a handrail along the roof of each of the channels. This allowed the divers to maneuver down the channel against the flow of the current. Figure 4 shows a channel with the handrail just visible, and the diver making his way down the channel.

The actual installation of all three transducer assemblies took one and one-half days. Originally it was hoped that the siphon, although not drained, would at least have no live flow going through it. This was the cause of the extra half-day of diver time.

Figure 3. ADFM transducer assembly. Opposing beam pairs are situated on either side of the transducer (on the long axis). The depth detecting vertical transducer ceramic is in the middle of the assembly.

Figure 4. Diver descending into channel using the installed handrail.

The balance of the installation consisted of mounting the ADFM electronics and analog output modules in the gauge house. Figure 5 shows the ADFM electronics mounted on the wall to the right. The 4-20 mA current loop conversion modules are straight ahead, and are interfaced to the computer driven SCADA system located in the table. This system allows the GCID and the Bureau to receive real-time data from each of the three channels.

Figure 5. Electronics installation in the gauge house. This system provides real-time output of the data.

The Results

A key benefit of the ADFM is that no in-situ calibration is required. The system is up and acquiring accurate data immediately upon initiating data collection. Because of this, there is no regular maintenance of the system required. Therefore, the ADFMs began the data collection process as soon as the physical installation was complete.

Figure 6 is the first 24 hours of flow and velocity data from the Center Channel – the channels are referred to as the West Channel, Center Channel and East Channel. The only notable variation is the near zero reading at the beginning of the record. The diver was verifying channel dimensions one last time before exiting the water for good.

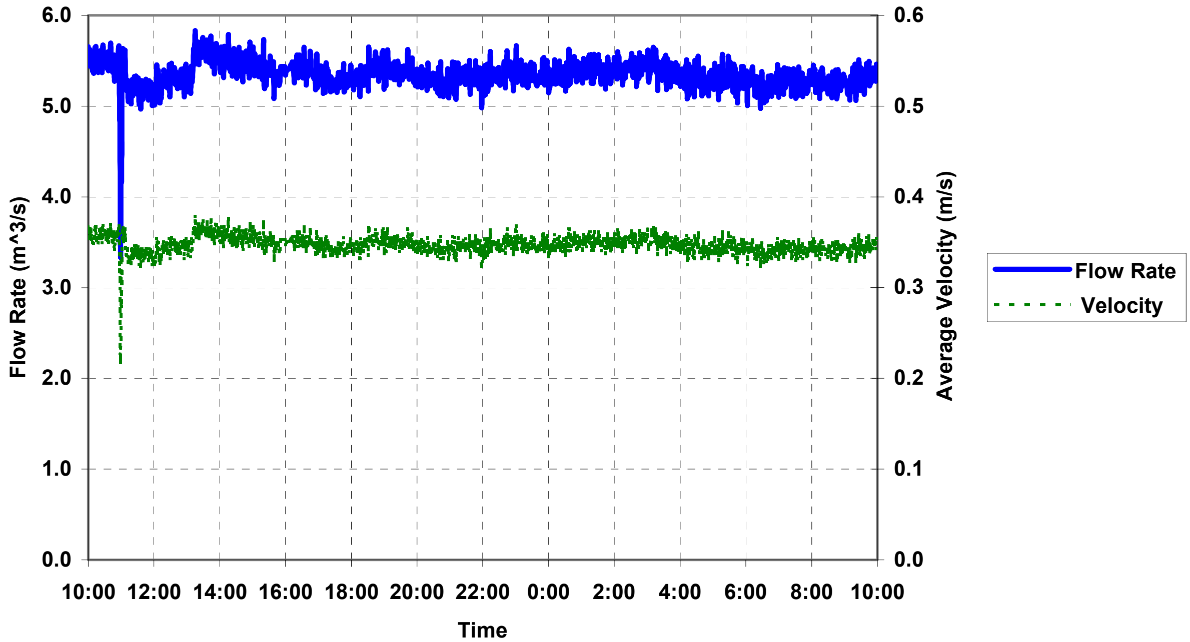

Figure 6. Flow rates and velocities measured in the Center Channel

Figure 7 shows the flow rates for all three channels, along with the totalized flow. You can see the presence of the diver moving from channel to channel at the beginning of the record.

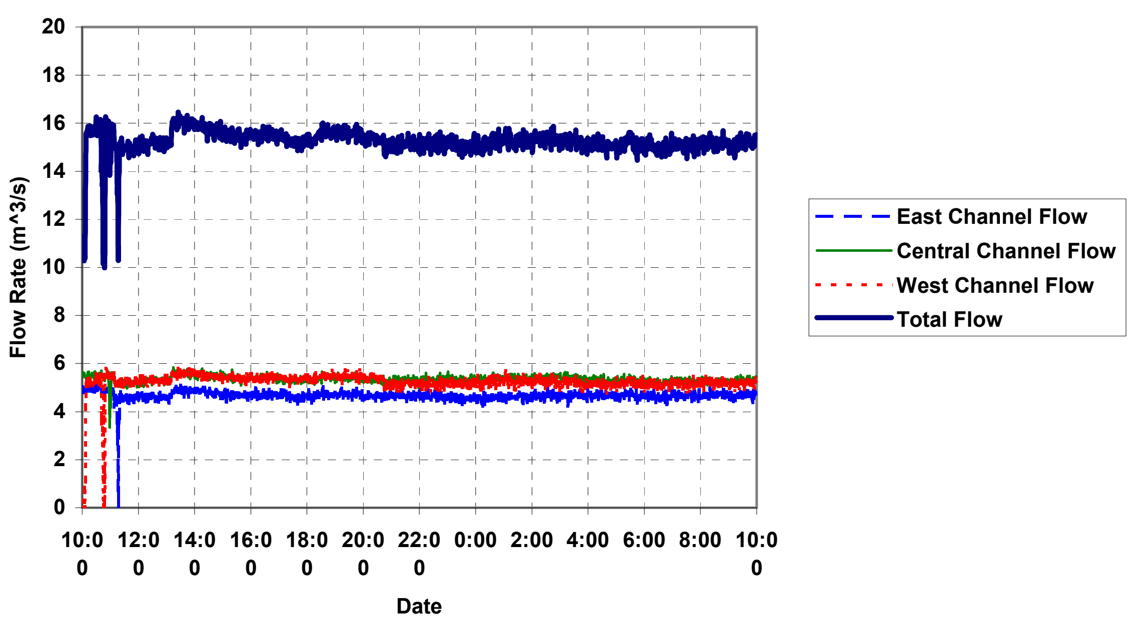

Figure 7. Measured flow rates for all three channels, along with a total flow rate.

The ability of the ADFM to measure flow rates very accurately comes from its ability to measure velocity profiles. The raw data of the ADFM is used to generate a model of what the flow velocity values are at all points in the depth of flow. Figures 8, 9 and 10 are flow profiles from the Center, East and West Channels respectively.

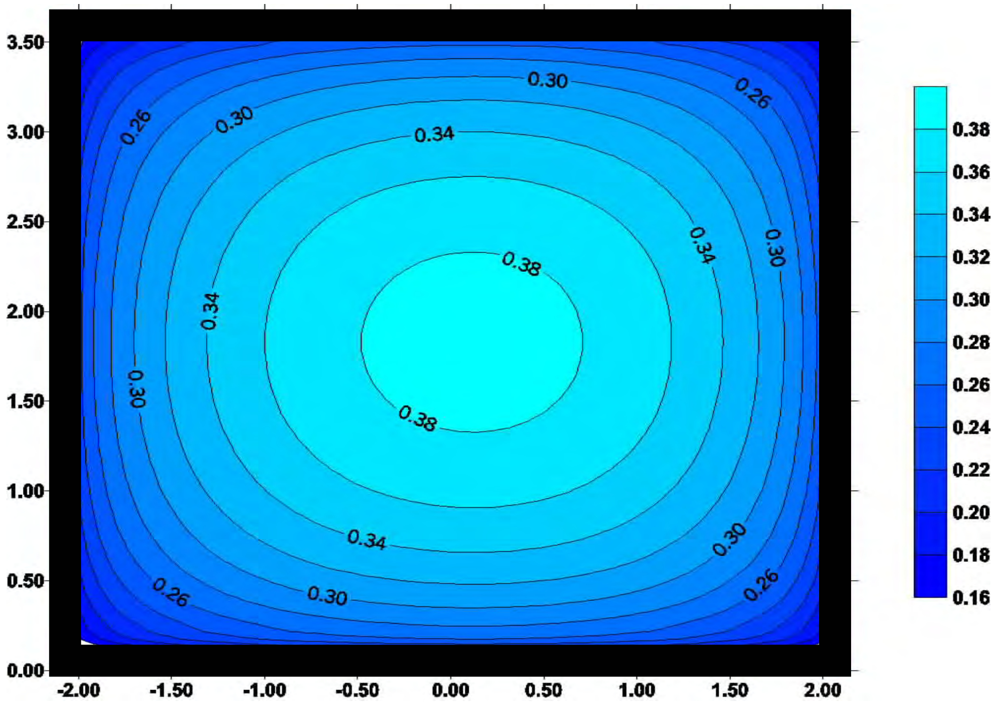

Figure 8. Flow profile from the Center Channel.

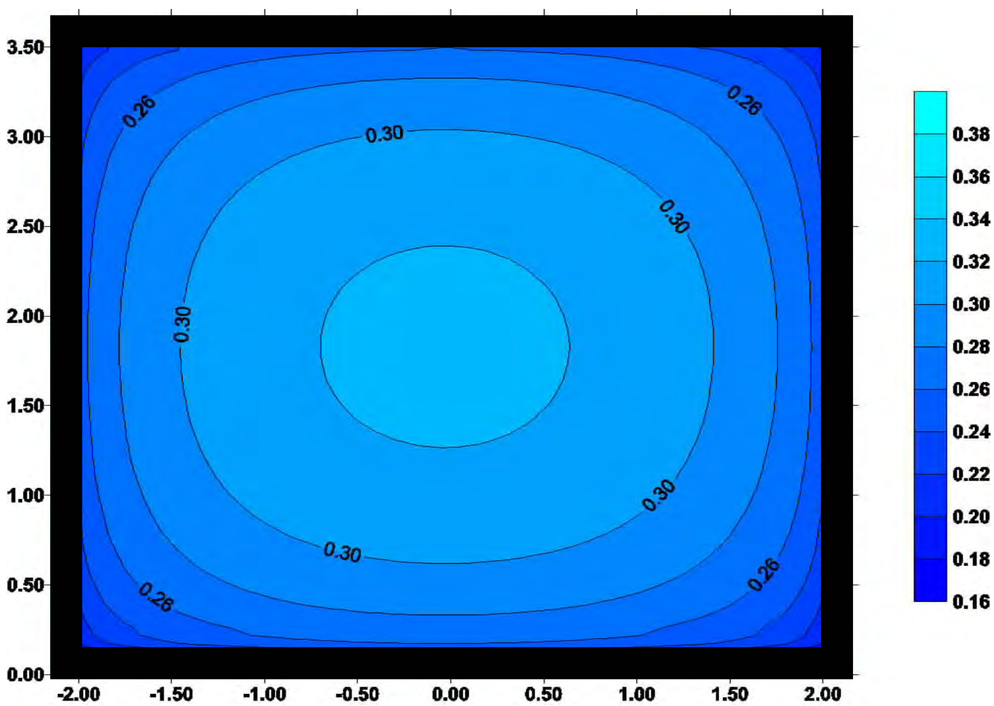

Figure 9. Flow profile from the East Channel.

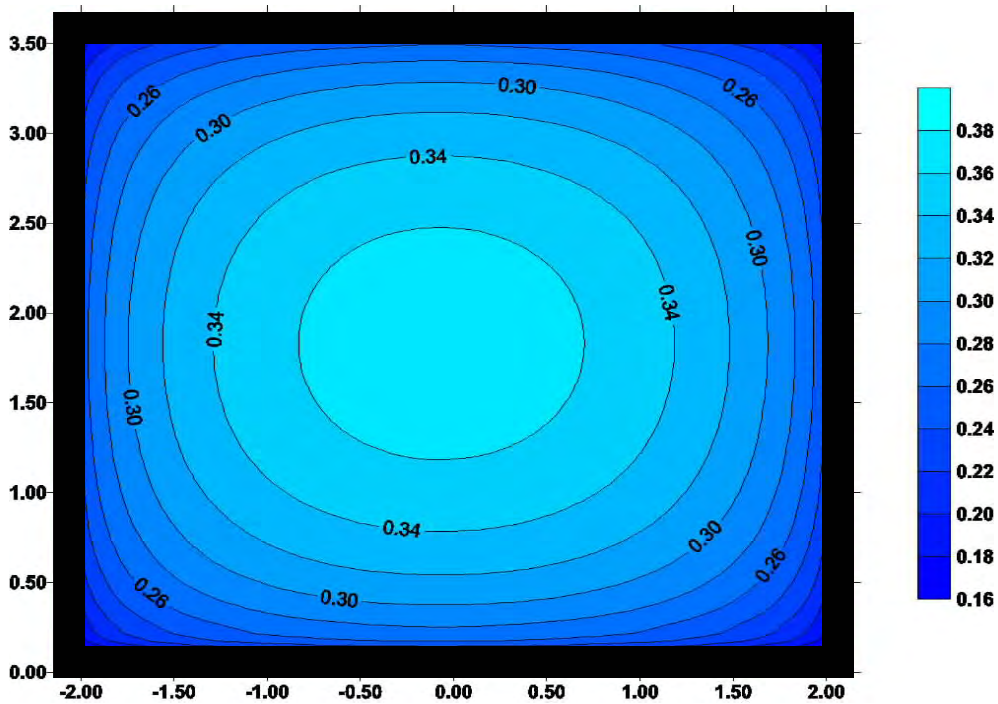

Figure 10. Flow Profile from the West Channel

From Figure 7, it is clear that the flow rates from the West and Center are approximately the same value. The flow rates in the East Channel are less than those of the other channels. This is due to the upstream configuration – the flow comes around an upstream bend, rebounds off the bank, and moves towards the Center and West Channels (observed in the field).

The lower flow rates in the East Channel can be seen as lower velocities in the profile of Figure 9. The maximum flow velocities are on the order of 0.32 m/s compared to 0.38 m/s in the Center Channel.

Another point to note is that although the West and Center Channels are approximately the same in magnitude, the Center Channel did exhibit slightly higher flows, and evidenced by the slightly higher maximum velocity in the center of the channel. What is interesting is that the profiles appear almost identical in the near wall region – within about 0.5-0.75 meters of any given wall. This indicates that a system that relied on point sampling in a near wall region, and extrapolating its measurement to a flow rate throughout the channel, would be in error for one of these two channels. The real difference in the flow profile is in the center of the channel. A full velocity profile is required for a truly accurate estimate of flow rate.

Conclusions

The ADFM provided an elegant solution to the problem of measuring flow rates in the Glenn-Colusa Irrigation District Channel. The flow rates measured matched expected values for the scheduled irrigation deliveries. Installation proceeded without interruption in water delivery.

The ADFM's transducer geometry and internal calculation ability allow it to accurately generate and output a flow rate. There is no need for post-processing a flow rate from an index velocity or depth measurement.

The ADFM also offers an accurate solution for the determination of index-velocity measurement when the channel being measured is wide and relatively shallow (a width to depth aspect ratio of greater than 15:1). Although the ADCP has been considered for such and applications, the ADFM may be more suitable as it supplies two average x-component profiles, rather than the one obtained from the ADCP. In addition, the ADFM's ability to calculate and output a flow rate directly will give an accurate flow rate where the water exhibits prismatic flow conditions.