IMPROVED WATER RESOURCE MANAGEMENT USING AN ACOUSTIC PULSED DOPPLER SENSOR IN A SHALLOW OPEN CHANNEL

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Abstract. *Over the years acoustic Doppler profilers (ADP) have become a standard for flow measurement in large open channels. In most cases, pulsed Doppler systems measure the water velocity profile either from the side of the channel or from a bottom mounted system. Having a velocity profile is critical in providing accurate flow measurements and provides important information about the structure of the velocities in the flow. A SonTek IQ flow meter uses multiple beams to measure water velocity and applies a vertical beam and pressure senor to measure water level – these two types of data are used to calculate flow. In addition to the new design, the flow meter provides improved performance for theoretical flow calculations, which are important in smaller channels, such as ditches and turnouts where an index calibration may not be practical when considering cost.*

Keywords. Doppler profiler, water management, flow rate, total volume, water velocity, agricultural flow monitoring

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INTRODUCTION

Traditional flow monitoring in open channels has been done by monitoring water level as a surrogate. For this method, a rating curve is developed by comparing various water levels to the corresponding flows, which are determined by discharge measurements or gagings over the range of water levels and time at the site. Using this method, periodic discharge measurements are required to validate the stage-discharge relationship. For some sites, such as tidal rivers, locations with variable backwater like irrigation gate control systems, no reliable stage-discharge relationship is developed. At these sites, a velocity index relationship is typically used. For a velocity index, a channel cross-section survey provides a relationship between stage and cross sectional area. A velocity sensor is installed and a relationship is developed between the velocity of the permanently installed sensor and the mean measured velocity in the channel (via gaging). The combination of the stage-area and measured-mean velocity relationships provides the ability to continuously monitor discharge. Like the stage-discharge method, this velocity indexing also requires periodic discharge measurements at the site in order to maintain a viable index, however complex hydrologic conditions are more accurately monitored.

Side-looking Doppler velocity sensors (such as the SonTek Argonaut-SL) have become a preferred method for monitoring velocity at index rated sites in larger channels. The sensor is mounted on a vertical structure and measures a horizontal velocity profile and a programmable cell some distance into the river. Simple installation, low maintenance requirements and the ability to monitor velocity away from flow interference generated by underwater structures are advantages of these sensors. Side-looking instruments do have some limitations; for instance, the relationship between Doppler velocity (measured at one depth) and mean channel velocity can be difficult to determine in situations of highly variable water level. In addition, sites with highly stratified flow can require permanent installations at more than one depth. Lastly, from a resource standpoint, it is not always practical to make the measurements required to develop an index rating. For side-looking systems, this theoretical relationship is less robust since velocity is measured only at a single depth and stratification of flow in open channels is vertical.

Considering this, the Argonaut-SW (SW for "Shallow Water") was developed. The Argonaut-SW is a bottom-mounted system that is intended for complex index velocity sites (those with large stage variation or stratified flow) and for sites where purely theoretical discharge calculations are desired. Although very accurate and precise in regular open channels, the SW requires 1-foot (30 cm) of water to measure flow. Thus small channels and irrigation turnouts are limited to determining discharge with techniques that are not accurate or repeatable (measure flow based on water level or determine flow using low cost continuous wave Doppler instruments that do not have a high degree of accuracy or precision).

Considering the increasing demand for freshwater resources and the affects of climate change there is an increased need to quantify flow in smaller and smaller channels, such as irrigations turnouts. In 2007, SonTek was awarded a Small Business Innovation Research (SBIR) grant from the USDA. The aim of the project was to develop a Doppler-based instrument that would measure in small channels (such as irrigation turnouts with a minimum depth of 3-inches or 8-cm) with a high degree of accuracy – thus end-users are not required to perform a velocity index or calibrate the instrument to the site and still provide an accurate and reliable measurement.

MATERIALS AND METHODS

Preliminary flow comparison study was conducted at the Irrigation training and Research Center (ITRC) at the California Polytechnic State University, San Luis Obispo (Cal Poly). Figure 1 displays an aerial photo of the testing facility. The testing facility has a 280 ft long hydraulic flume with dimensions of 4.0 ft × 4.0 ft. A variable speed pump, capable of delivering up to 30 cfs, delivers water through a pipeline to a buffer pond at the upstream end of the flume. A magnetic meter (magmeter) is located in the pipeline, with large air vents located upstream of the magnetic meter. Since a constant flow rate was desired, the pump was set at a constant speed and the water passed into and out of the buffer pond with no change in position of any of the downstream control structures over time. Measurements were taken after the flow rate stabilized in the flume test section, typically after 30 minutes. Water depths in the flume were controlled by flashboards or gates at the downstream end of the flume for the three tests presented here; water level was varied for each flow rate.

Figure 1. California Polytechnic State University - Irrigation and Training and Research Center

Reference measurements were made using a McCrometer® UltraMag model #UM06-30, 76 cm (30”) meter (magmeter) which samples data multiple times per second and averages over a 2 second period. The magnetic meter’s data is output using the meter’s standard 4-20ma signal converter. A Control MicroSystems SCADAPack32 was used to convert the analog data to a digital number and recorded every 2 seconds. The SonTek IQ was installed approximately 180 ft from the inlet of the flume in order to avoid turbulence and to allow flow to homogenize. The IQ was installed in the bottom of the flume using two 5/16” stainless steel screws with the power and communications cable point downstream. Figure 2 displays a picture of the IQ installation at ITRC.

Figure 2. SonTek IQ installation at ITRC flume

The SonTek IQ was designed to provide highly accurate and precise flow measurement in shallow channels. A built in pressure sensor and vertical acoustic beam are used in tandem to determine water level, while four velocity profiling transducers, two that measure velocities along the channel flow axis while two skew beams. The skew profiling beams measure velocities at 60° off the vertical axis and 60° center axis of flow, while the along axis profiling beams are 25° off of the vertical axis. A rendering of the instrument is presented in Figure 3. The housing of the sensor has screws pre-set in the mounting brackets all of which were designed for an easy install. The instrument was configured to collect data every 30 seconds and average data for 30 seconds – effectively measuring flow continuously. Flow is determined by using a combination of the water level data that are converted into cross-sectional area using – cross sectional area rating. Cross-sectional area is multiplied by average velocity (taken from the averaging interval) to determine flow.

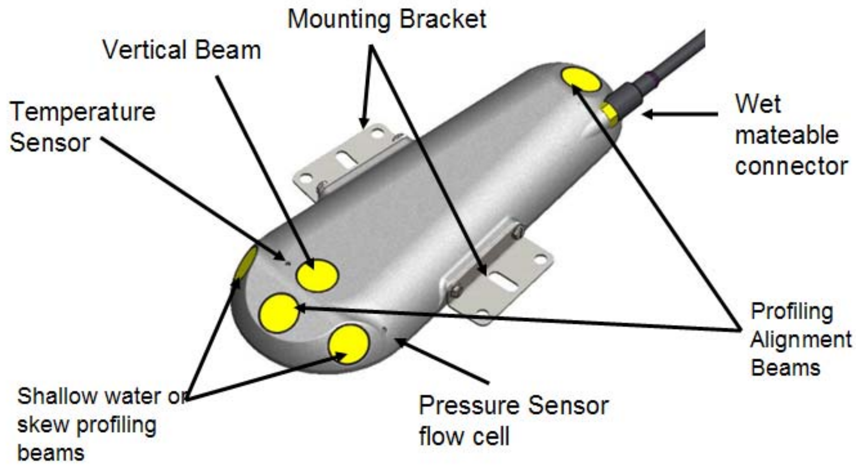

Figure 3. Drawing highlighting the attributes of the SonTek IQ

Figure 4 presents the configuration of the SonTek IQ for data collection. In order to calculate flow the use has to enter the channel cross-section. System elevation, or the elevation of the vertical beam referenced to channel bottom, was 0.09 ft (effectively the height of the instrument). Figure 4 presents how the instrument was configured using the IQ software.

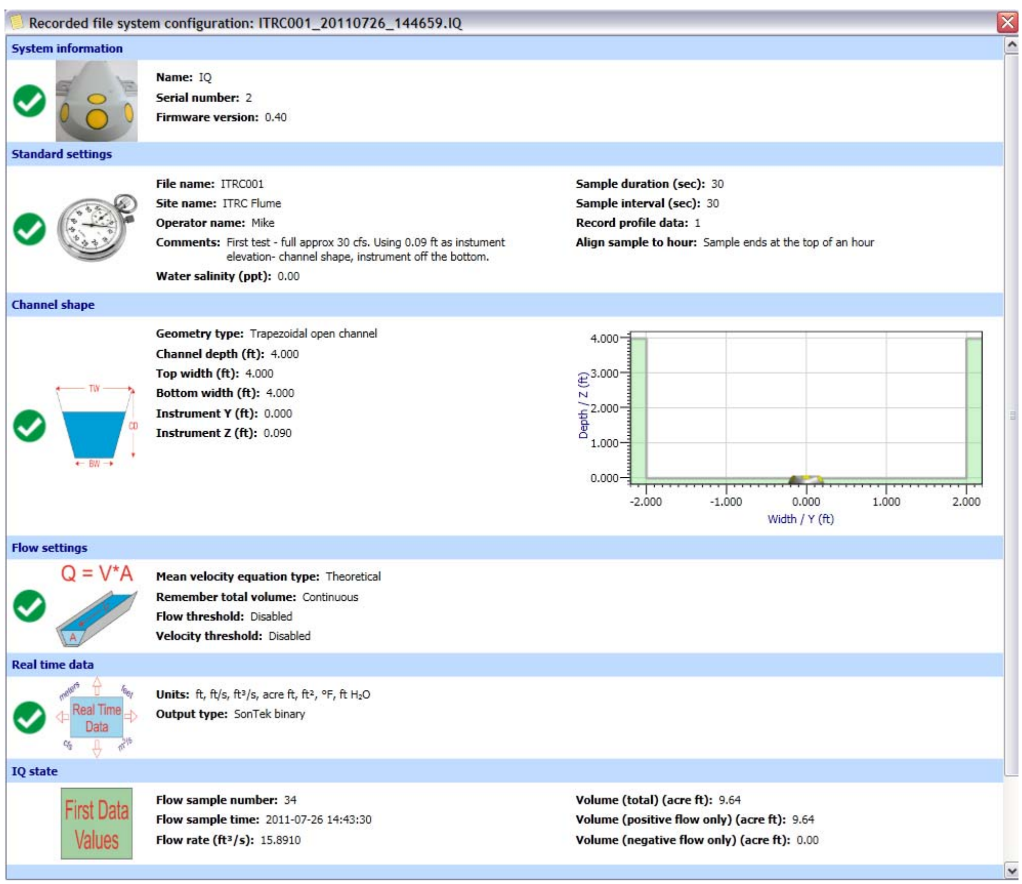

Figure 4. SonTek IQ configuration for ITRC testing

RESULTS

The results from three tests at the site are presented in Figures 5-7. The blue line displays a trace for the flow measured by the magnetic meter, while the red line represents data from the IQ. Since the flow meters are not installed in the same place flow rates were allowed to stabilize for 30 minutes in order to make data comparisons and the pumping rate and hydraulic head were maintained the same throughout the tests. All tests we performed for approximately 30 minutes.

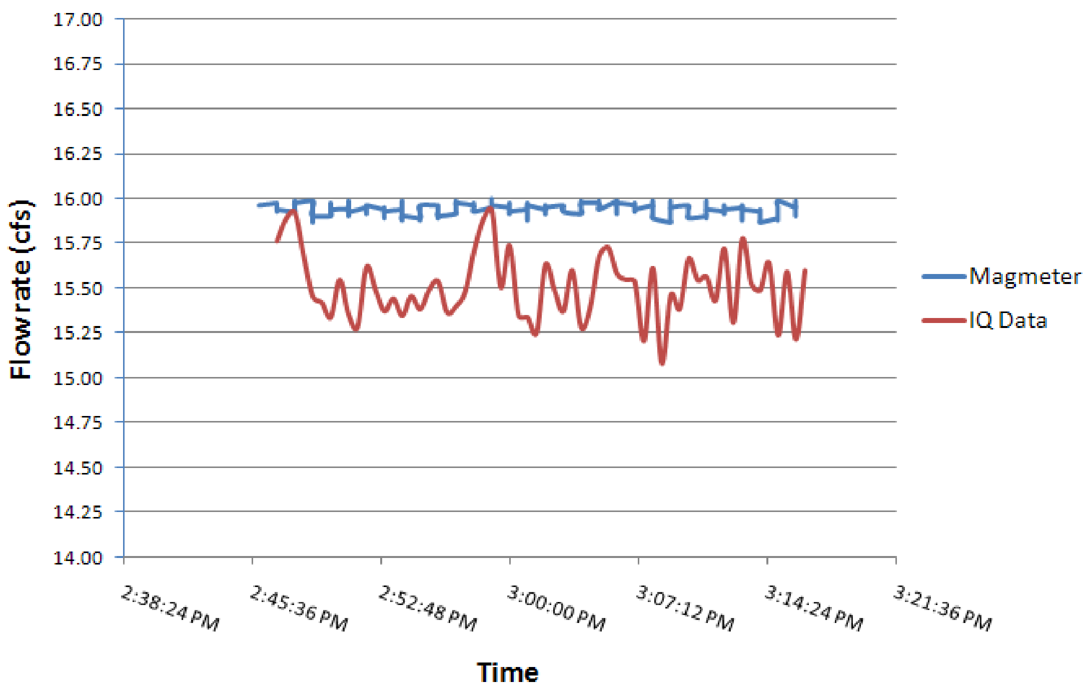

Figure 5. Flow data comparison at a reference flow of 15.94 cfs

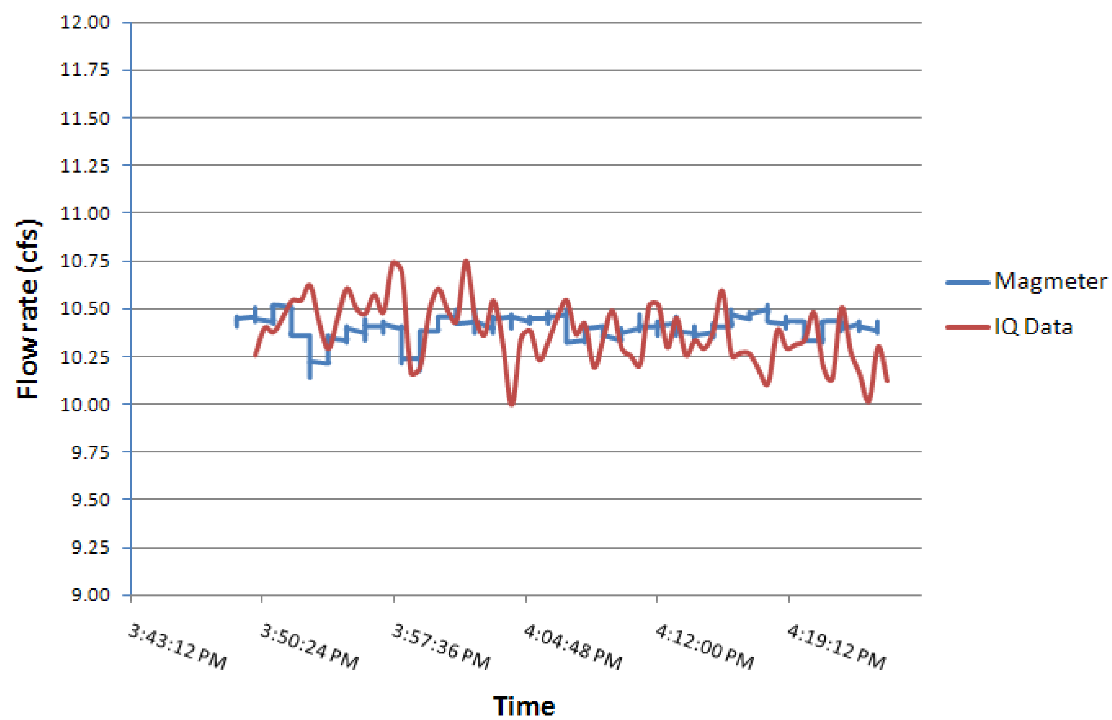

Figure 6. Flow data comparison at a reference flow of 10.42 cfs

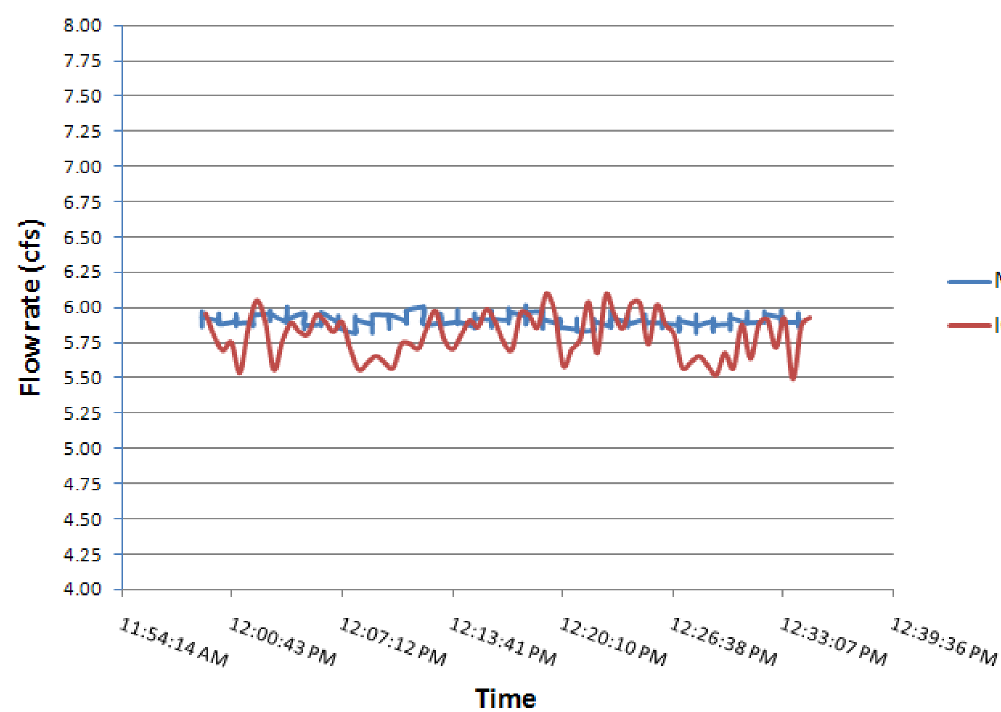

Figure 7. Flow data comparison at a reference flow of 5.80 cfs

Table 2 summarizes the results from the flow testing. The simple data analysis compares flow rate from the Magmeter and SonTek IQ. In general, there is good agreement between technologies with the average difference -1.68% for flow rate.

Table 2. Summary of the flow data comparing Magmeter and SonTek IQ

	MAGMETER (CFS)	SONTEK IQ (CFS)	% Diff. Flow Rate (cfs)
Test 1	15.94	15.51	-2.69%
Test 2	10.42	10.38	-0.36%
Test 3	5.92	5.80	-2.00%

Over the period of the tests, the SonTek IQ collects additional data at the site. Table 3 presents average values for flow (cfs), velocity (ft/s) and stage (ft).

Table 3. Summary of average values collected by SonTek IQ

	FLOW RATE(CFS)	VELOCITY (FT/S)	STAGE (FT)
Test 1	15.51	1.67	2.32
Test 2	10.38	1.80	1.43
Test 3	5.80	0.84	1.73

CONCLUSIONS

Based on the preliminary tests the SonTek IQ compares on average 1.68% lower than the reference measurement done using a magmeter. Graph indicate that the variability of the data from the SonTek IQ is greater than the magmeter, however the measurement devices are installed in two different environments – the magmeter in a pipe and the SonTek IQ in an open channel. The open channel environment for measuring flow is much more complex as flow patterns or velocity fields can be highly variable, where as in pipe conditions flow lines are streamlined and thus easier to measure. For accurate flow monitoring in open channels, it is necessary to sample a large portion of the water column as flow can be distributed unevenly, as such the SonTek IQ measures velocity horizontally and vertically by using the along axis beams as well as the skew beams. The SonTek IQ configuration and the corresponding algorithms have been specifically designed using data from agricultural canals to more accurately monitor flow in open channel.

Preliminary results are encouraging when considering the flow ranges evaluated (5.8 - 15.5 cfs) as well as velocities (0.84 -1.80 ft/s) and stage (1.43 ft – 2.32 ft), however additional tests should be conducted to verify the performance of the instrument in a wider range of flow conditions. Future tests will incorporate not only variations in water-level, velocity and the corresponding flow rate but field testing as well. Field testing for flow rate will be verified by comparing flow rates to reference flows or by making spot measurements using instruments in the field.

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