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. These systems are often optimized for different sizes of open channels by using different acoustic frequencies, acoustic beam configurations as well as other factors, however, ADPs have been traditionally too expensive for flow monitoring in small channels. Traditional alternatives to ADP for measurements in small channels have used water level as a surrogate or continuous wave acoustic instruments. These two technologies, although inexpensive, do present problems to end users in the form of accuracy, which can be a major problem when making decisions or billing based on the collected data. Building on the success of ADPs in open channels and considering the increasing demand to quantify flows in very small channels due to the increasing scarcity of water, SonTek developed a shallow water flow meter – the SonTek IQ - for open channels ranging from 0.08 m to 5 meters in depth. The new flow meter uses multiple beams to measure water velocity and applies a vertical beam and pressure sensor to measure water level – these two types of data are used to calculate flow. In addition to the new design, the IQ 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. This paper describes the sensor configuration, preliminary specifications and theoretical flow models used to calculate open channel discharge. Preliminary testing in flow laboratories demonstrated good agreement when compared to independent measurements.

INTRODUCTION

Traditional flow monitoring in open channels has been done by monitoring water level (stage) 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 a 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 and 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, using a velocity to determine flow in 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 as 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 because velocity is measured only at a single depth and stratification of flow in open channels is vertical.

Considering these issues, the Argonaut-SW (SW for "Shallow Water") was developed. The Argonaut-SW is a bottom-mounted system that is intended for complex index velocity index 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 (ft) (30 centimeters (cm)) of water depth to measure to measure flow which is not convenient for measuring flow in irrigation applications. Thus small channels and irrigation turnouts have looked to measuring flow using other devices which 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). Continuous wave devices obtain an average velocity taken from sampling only a portion of the vertical water column, while profilers, like the SW collect water velocity data as a vertical profile as such are more accurate.

Considering the increasing demand for freshwater resources and the effects 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 United States Department of Agriculture (USDA). The goal of the project was to develop a Doppler-based instrument that would measure flow in small channels and irrigation turnouts with a minimum depth of 3-inches (in) 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 while still providing an accurate and reliable measurement.

MATERIALS AND METHODS

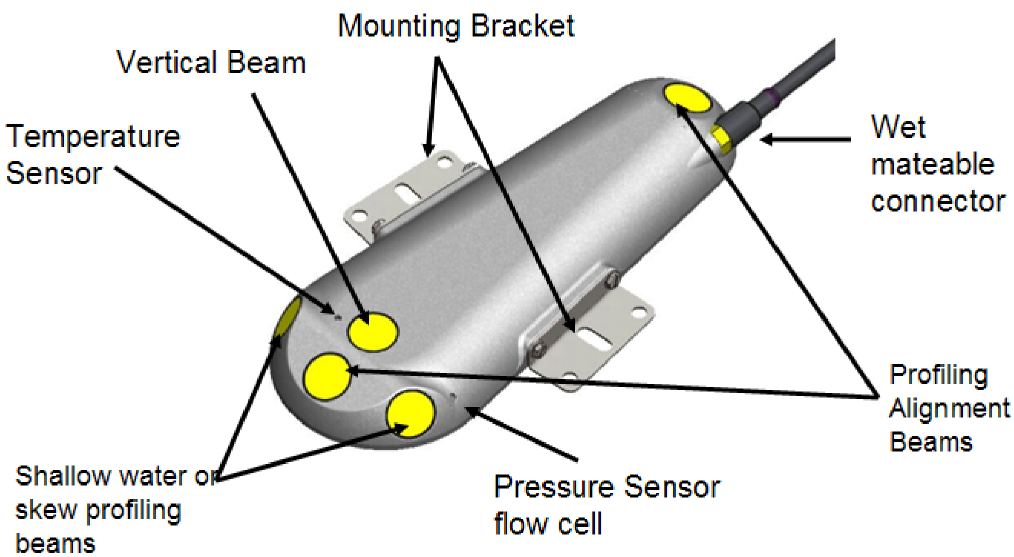
This paper presents flow comparison study from three irrigations canals using rating data from the USGS or data collected using the FlowTracker. Each canal represents a “typical” irrigation canal. The Overland canal is an earthen channel with vegetation found on the banks; the Overland canal is located in Fort Collins, Colorado. A FlowTracker measurement is used as the reference flow data for the Overland Canal. The Cocopah canal is located near Yuma, Arizona and is a concrete line canal. Reference flow was data collected from the USGS rated ramp flume as well as FlowTracker measurements. The Ypsilanti canal is also located near Yuma, Arizona and is a concrete lined trapezoidal canal that uses data from the FlowTracker and rating data from a broad-crested weir. Figure 1 presents a picture from the installation at the Cocopah canal.

Table 1. Summary of flow comparison sites

Site	Canal Type	Reference data
Overland	Natural canal, earthen lined	FlowTracker
Cocopah	Trapezoidal channel, concrete lined	Rating data and FlowTracker
Ypsilanti	Trapezoidal channel, concrete lined	Rating data and FlowTracker

Figure 1. Cocopah canal flow comparison site

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 measure flow in the horizontal direction. 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 drawing of the instrument is presented in Figure 2. 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 the cross sectional area rating. The cross-sectional area is multiplied by average velocity (taken from the averaging interval) to determine flow.



- **Figure 2. Features of the SonTek IQ**

Figure 3 presents a configuration of the IQ for data collection. In order to calculate flow the user has to enter the channel cross-section. System elevation or the elevation of the vertical beam referenced to channel bottom, for this configuration the system elevation is 0.31 ft (effectively the height of the instrument). Figure 4 presents how the instrument was configured using the IQ software. The software is divided into five sections with quality indicators to drive the user to deploy the sensor correctly.

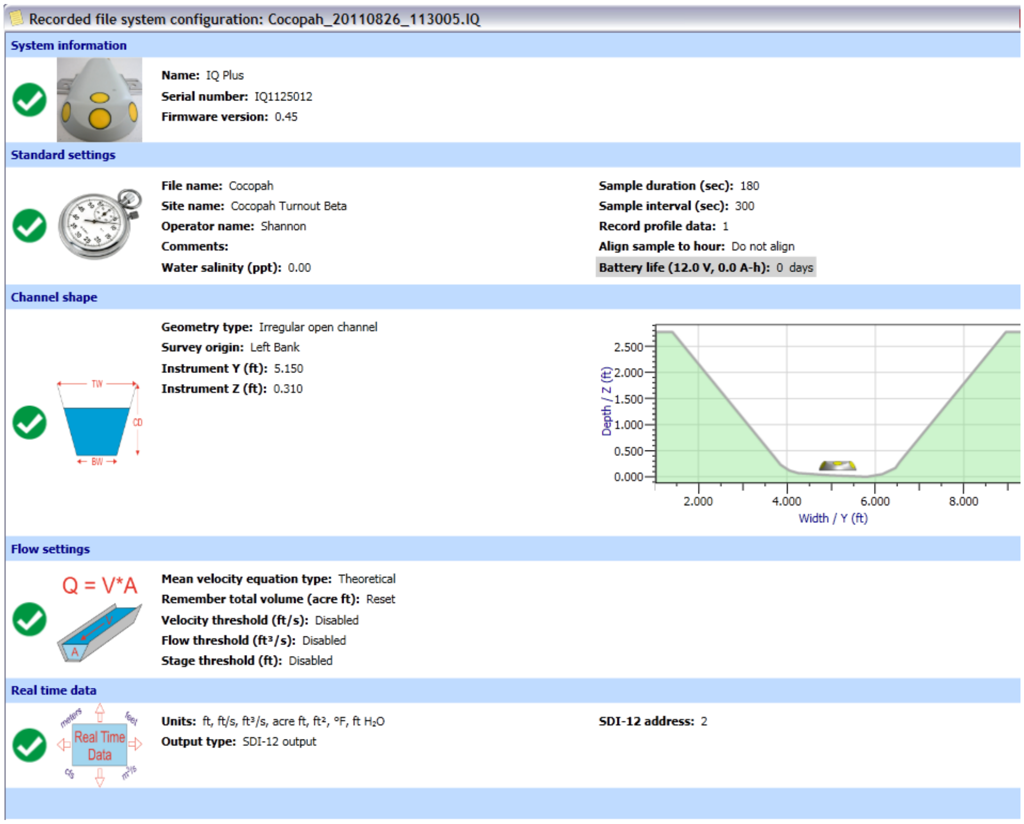


Figure 3. SonTek IQ example configuration

To configure the instrument, the user can define File Name, Site Name and Operator Name, while setting the Sample duration and interval are required. In order to calculate flow, a user defined cross-sectional area must be entered. Lastly, additional settings for managing velocity data and configuring the connection to a datalogger or Modbus system must be completed.

RESULTS

The results from the three tests at the sites are presented in Figures 4 - 6. Each figure presents Flow data in the first graph, water level in the second graph and velocity data in the third time series graph. The graph to the right is profile data collected by the instrument. Black vertical lines indicate where reference measurements were made. In the case of the Overland site, an average of the flow data collected with the IQ was compared to a FlowTracker measurement made over the same period (Figure 5).

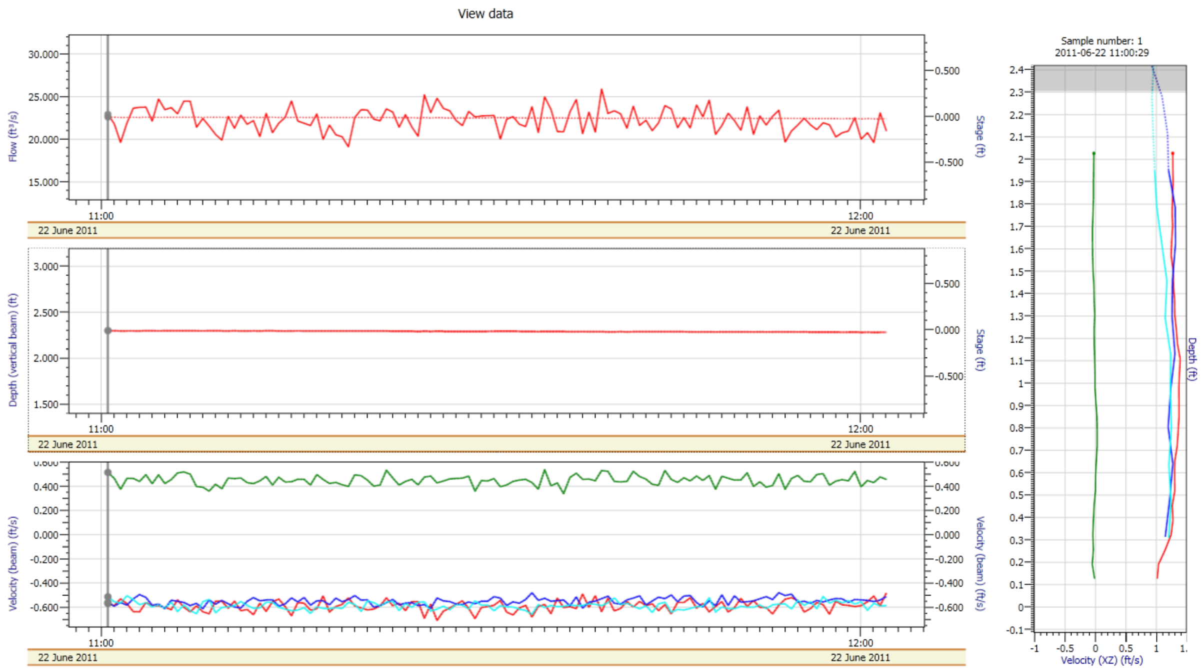


Figure 4. Overland test site with one reference measurement

Table 2 presents the comparison data in table format. The difference between the SonTek IQ flow data and reference data is 1.6%.

Table 2. Summary of comparison flow data at Overland

	Water Level (ft)	IQ Flow (cfs)	Reference (cfs)	% Error
Comparison 1	2.30	22.32	22.68	1.6

Figure 5 presents data collected at the Cocopah site. The site has three comparisons, using data from the FlowTracker and gauging information from the site. Overall, flow data compared well to the reference and data was representative for the site.

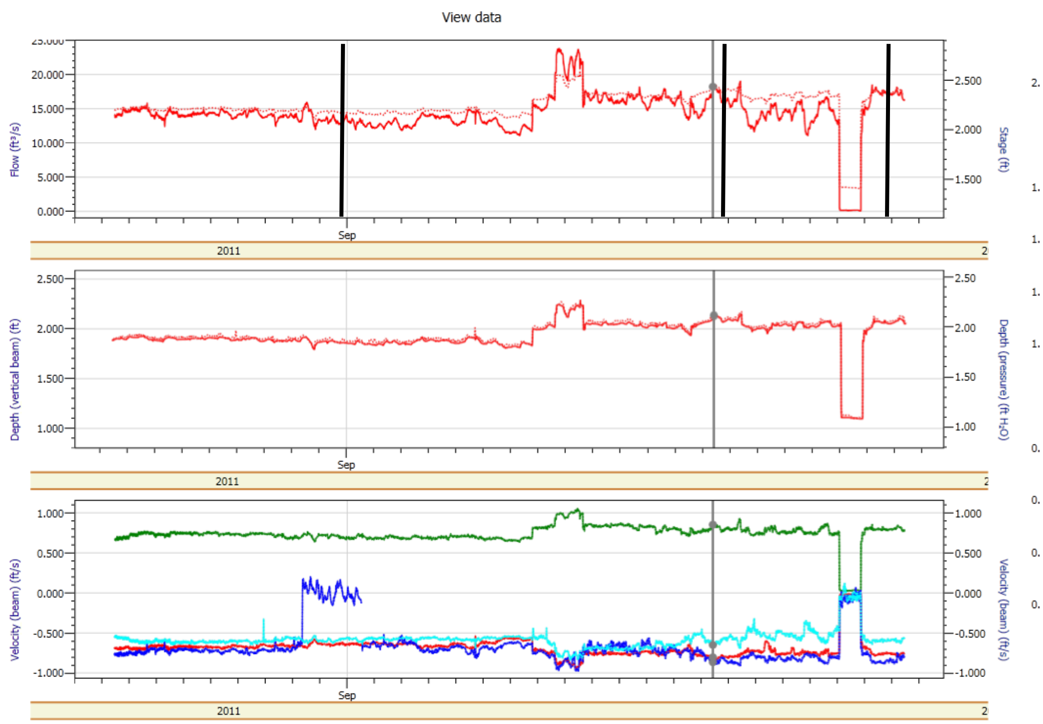


Figure 5. Cocopah test site with three reference measurements

Table 3 presents a summary of the data collected at Cocopah. Average error for the three reference measurements is 2.83%.

Table 3. Summary of comparison flow data at Cocopah

	Water Level (ft)	IQ Flow (cfs)	Reference (cfs)	% Error
Comparison 1	1.89	13.84	13.48†	2.6
Comparison 2	2.12	17.80	18.49*	-3.7
Comparison 3	2.06	16.48	16.85*	-2.2

† USGS Gauge data
*FlowTracker data

Figure 6 presents data from the Ypsilanti Site. Data from the site was very typical, with varying flow rates stepped up and down for water delivery to farmers. Four comparisons are presented three from gaging data and one from a FlowTracker measurement.

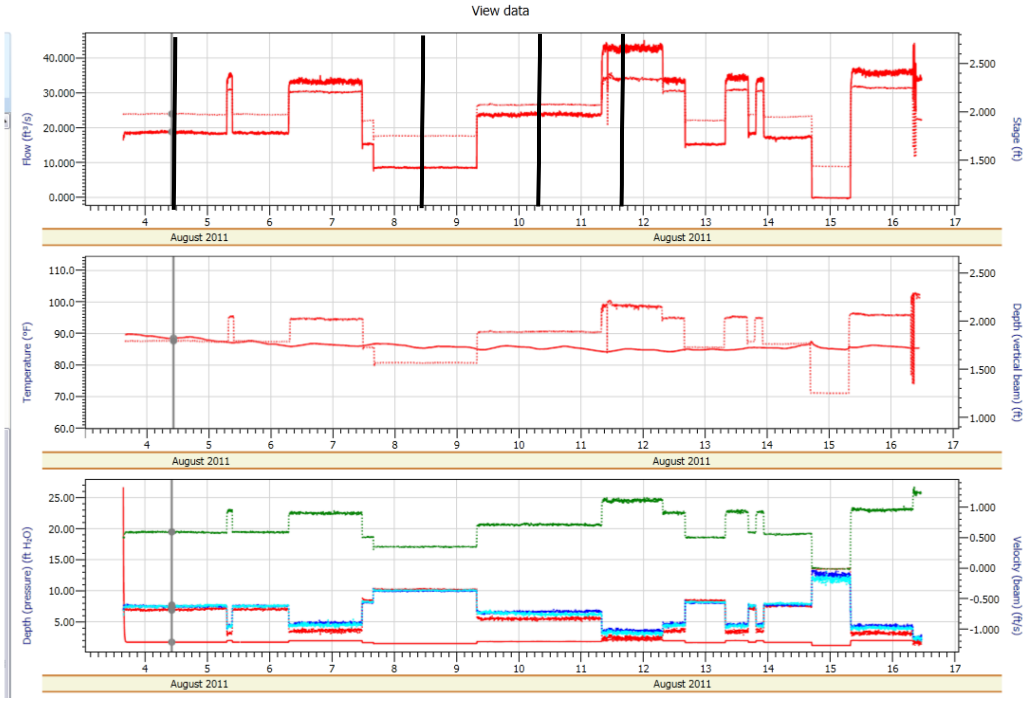


Figure 6. Ypsilanti test site with 3 reference measurements

Table 4 presents the comparison data in tabular form. Overall the data compared well to the reference measurements, with an average error of 1.28%.

Table 4. Summary of comparison flow data at Ypsilanti

	Water Level (ft)	IQ Flow (cfs)	Reference (cfs)	% Error
Comparison 1	1.81	18.73	19.01†	1.0
Comparison 2	1.58	8.36	8.45†	1.4
Comparison 3	1.90	23.85	24.33†	1.6
Comparison 4	2.19	43.70	43.25*	1.0

† USGS Gauge data
*FlowTracker data

CONCLUSIONS

Results are encouraging for the range of flow rates presented here (8-43 cfs) however additional tests should be conducted to verify the performance of the instrument in a wider range of flow conditions as well as verify the accuracy of the reference measurement. Based on these preliminary comparisons, the SonTek IQ measures within 3% of the reference flow measurements. The results were obtained simply by installing the instrument – no site specific calibrations were completed, thus resources were not only saved with the accuracy of the instrument but also for the time and resources to calibrate the instrument. Future tests will incorporate variations in water-level, flow velocity and the corresponding flow rate in conjunction with 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.

ACKNOWLEDGEMENTS
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