Field Evaluation of Shallow-Water Acoustic Doppler Current Profiler Discharge Measurements

Michael S. Rehmel

U.S. Geological Survey Indiana Water Science Center, 5957 Lakeside Blvd., Indianapolis, IN 46278; phone: (317) 290-3333; email: msrehmel@usgs.gov

Abstract

In 2004, the U.S. Geological Survey (USGS) Office of Surface Water staff and USGS Water Science employees began testing the StreamPro, an acoustic Doppler current profiler (ADCP) for shallow-water discharge measurements. Teledyne RD Instruments introduced the StreamPro in December of 2003. The StreamPro is designed to make a "moving boat" discharge measurement in streams with depths between 0.15 and 2 m. If the StreamPro works reliably in these conditions, it will allow for use of ADCPs in a greater number of streams than previously possible.

Evaluation sites were chosen to test the StreamPro over a range of conditions. Simultaneous discharge measurements with mechanical and other acoustic meters, along with stable rating curves at established USGS streamflow-gaging stations, were used for comparisons. The StreamPro measurements ranged in mean velocity from 0.076 to 1.04 m/s and in discharge from 0.083 m^3/s to 43.4 m^3/s.

Tests indicate that discharges measured with the StreamPro compare favorably to the discharges measured with the other meters when the mean channel velocity is greater than 0.25 m/s. When the mean channel velocity is less than 0.25 m/s, the StreamPro discharge measurements for individual transects have greater variability than those StreamPro measurements where the mean channel velocity is greater than 0.25 m/s. Despite this greater variation in individual transects, there is no indication that the StreamPro measured discharges (the mean discharge for all transects) are biased, provided that enough transects are used to determine the mean discharge.

The use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Introduction

Acoustic Doppler current profilers (ADCPs) have been in widespread use by the U.S. Geological Survey (USGS) for measuring discharge since the late 1990s (Oberg, 2005). The USGS has evaluated 1,200- and 600-kHz versions of those instruments manufactured by Teledyne RD Instruments (TRDI) and 1,500- and 3,000-kHz versions manufactured by SonTek/YSI (Morlock, 1996; Mueller, 2002).

In December 2003, TRDI introduced a new ADCP, called StreamPro, for shallow-water discharge measurements. The StreamPro is a 2,000-kHz ADCP with a small (0.035-m diameter) transducer head. The unit is deployed from a specially designed tethered boat (Figure 1). Bluetooth radio telemetry is used for communication between the StreamPro and a hand-held computer equipped with the Pocket PC operating system. Software on the hand-held computer saves the data transmitted by the StreamPro and computes the discharge. The data can be viewed and reprocessed on a computer using WinRiver software. The StreamPro is designed to make a "moving boat" discharge measurement in streams with depths between 0.15 and 2 m. The majority of discharge measurements made by the USGS are in streams with mean depths of less than 1 meter (Fulford, 1992). If the StreamPro can work reliably in these conditions, it will allow for use of ADCPs in a much greater number of streams than previously possible.

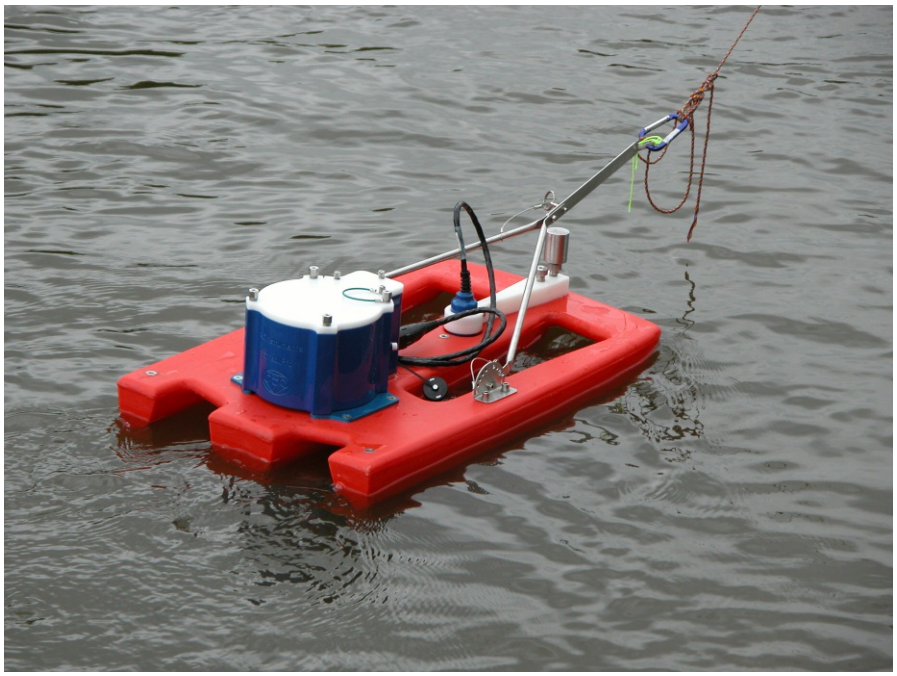


Figure 1. Side view of StreamPro at Fox River at Montgomery, IL.

In 2004, USGS Office of Surface Water staff and USGS Water Science employees began testing the StreamPro. The standard measurement scheme used by the StreamPro is water mode 12 (WM12). WM12 is intended to be robust general purpose mode for use over a wide range of conditions. In October 2005, TRDI released a low-noise profiling mode called water mode 13 (WM13) for use in StreamPro discharge measurements with maximum water velocities less than .25 m/s. This version of WM13 was not available for data collection during these field evaluations.

Site Descriptions

For evaluation of the StreamPro over a range of conditions, 23 StreamPro measurements were made at 20 sites with various depths, widths, and velocities. The evaluation sites along with their measurement conditions are summarized in Table 1.

Table 1. Location and characteristics of evaluation sites.
[m, meter; m/s, meter/second]

USGS Gaging-Station Name	USGS Gaging-Station Number	Mean Depth (m)	Mean Width (m)	Mean Velocity (m/s)
Big Creek near Wadesville, IN	03378550	0.50	8.8	0.29
Boneyard Creek at Urbana, IL	03337000	0.35	4.2	0.07
Buck Creek at Acton, IN	03361850	0.20	16.3	0.19
Cicero Creek at Arcadia, IN	03349510	0.26	10.8	0.08
Clifty Creek at Hartsville, IN	03364500	0.32	15.3	0.39
Eagle Creek at Indianapolis, IN	03353200	0.45	25.3	0.34
Eagle Creek at Indianapolis, IN	03353200	0.31	12	0.19
Eagle Creek at Indianapolis, IN	03353200	0.60	13	0.11
Eagle Creek at Zionsville, IN	03353200	0.47	20.7	0.09
Eel River at North Manchester, IN	03328000	0.46	33.5	0.56
Eel River near Logansport, IN	03328500	0.63	46.8	0.56
Fall Creek near Fortville, IN	03351500	0.43	20.7	0.30
Fox River at Algonquin, IL	05550000	0.93	38.6	1.04
Fox River at Montgomery, IL	05551540	1.02	71	0.60
Jacks Fork at Alley Spring, MO	07064533	0.33	13.2	0.72
Jacks Fork at Eminence, MO	07066000	0.60	20.7	0.55
Kokomo Creek near Kokomo, IN	03333600	0.51	5.8	0.19
Kokomo Creek near Kokomo, IN	03333600	0.54	5.9	0.43
Salt Fork near St. Joseph, IL	03336900	0.60	14.3	0.27
St. Francis River at Fisk, MO	07040000	1.23	15.7	0.56
West Canada Creek near Wilmurt, NY	01343060	0.96	33.6	0.36
White River at Noblesville, IN	03349000	0.56	53	0.26
Wildcat Creek near Jerome, IN	03333450	0.63	17.5	0.47

Data-Collection Methods

A detailed plan for testing was developed and followed. This plan included methods for collecting StreamPro and comparison measurement data. Efforts were made to perform the StreamPro measurement and comparison measurement under the same flow conditions, which included making simultaneous measurements under steady flow conditions when possible.

Standard USGS ADCP measurement techniques were used for collecting the StreamPro data. These include performing a moving-bed test, minimizing erratic boat motion during transects, measuring edge distances accurately, and keeping boat speed less than or equal to water speed (Oberg, 2005). Whenever feasible, a temporary bank-operated cableway or rope-and-pulley system was used to move the StreamPro back and forth across the stream during discharge measurements (Figure 2). Bank-operated cableways or rope-and-pulley systems allow for more-uniform boat motion and help reduce variability in measured discharges. The elapsed time for a single transect was 3 minutes or more, whenever possible.

Figure 2. StreamPro measurement using rope-and-pulley system at Buck Creek at Acton, IN

Comparing measurements of discharge to an absolute standard is not easily accomplished. For many years the USGS standard for discharge measurements has been a Price AA or Pygmy mechanical meter used in accordance with USGS policies and guidelines (Rantz, 1982). For the StreamPro evaluations, USGS policies and guidelines were followed for the additional discharge measurements made with mechanical and other acoustic meters used for the comparison discharge, along with stable rating curves at established USGS gaging stations. The acoustic meters used for the comparisons include a 1,200-kHz TRDI RioGrande ADCP and SonTek FlowTracker acoustic Doppler velocimeter.

Processing Procedures

Following standard USGS measurement policy for ADCPs (Oberg 2005), the mean of four or more transects was used to obtain the measured StreamPro discharge. Although a discharge is reported on the hand-held computer as the measurements are made, the collected discharge-measurement data were loaded into TRDI WinRiver software version 10.06. Each StreamPro discharge measurement then was reviewed for quality-assurance purposes. This quality-assurance process included the review of the edge distances, types, and discharges; velocity-profile extrapolations used to compute discharge in the unmeasured top and bottom zones of the transect; and boat speed versus water speed. To review the data in WinRiver, the StreamPro configuration file was converted to the WinRiver configuration format, using the StreamPro Configuration File Utility (INI2XML).

Discussion of Results

Analysis of the test measurements indicate that discharges measured using the StreamPro compare favorably to the discharges measured with the other meters when the mean channel velocity is greater than 0.25 m/s. Of the 16 measurements where the mean channel velocity was greater than 0.25 m/s, 13 of the StreamPro-measured discharges were within 5 percent of the comparison discharge and all 16 were within 6 percent of the comparison discharge (Table 2 and Figure 3).

The discharge coefficient of variation was high for the seven measurements made with a mean velocity less than 0.25 m/s. Even with this large variation, the mean of the transects tends to compare favorably with the other measurement methods, if enough transects are averaged together. In low-velocity conditions, the amount of data that needs to be collected may not make the discharge measurement practical because of time constraints. Even if a large amount of data is collected, the widely varying discharges may place the quality of the measurement in doubt. While no consistent bias was detected when enough transects were included in the average discharge, more testing is needed in low-velocity conditions to determine if accurate discharge can be made and, if so, how many transects are needed to make an accurate measurement. The new low-noise water mode (WM13), released since these data were collected, was designed by TRDI to limit transect-to-transect variation of discharge measurements made in low-velocity conditions.

The five measurements with departures of 6 percent or greater from the comparison discharge also had a range/mean percentage greater than 10 (Figure 4). For the collected data, the range/mean seems to be a better indication than the coefficient of variation that there could be a data quality issue. The coefficient of variation was as low as 4 percent for measurements with departures of 6 percent or greater from the comparison discharge.

Table 2. Summary of StreamPro evaluation measurements. [m/s, meter per second; m^3/s cubic meter per second; Q, discharge; COV, coefficient of variation; %, percent]

Station Name	Mean Velocity (m/s)	Number Transects	StreamPro Q (m^3/s)	Discharge COV (%)	Range/ mean (%)	Comparison Q (m^3/s)	Comparison Type	Departure from Comparison (%)
Boneyard Creek at Urbana, IL	0.07	8	0.083	9	25.3	0.0785	FlowTracker	5.73
Buck Creek at Acton, IN	0.19	8	0.624	5	11.1	0.685	pygmy	-8.9
Cicero Creek at Arcadia, IN	0.08	8	0.211	20	59.8	0.203	pygmy	3.9
Eagle Creek at Indianapolis, IN	0.19	8	0.725	4	11.3	0.639	AA	13.5
Eagle Creek at Indianapolis, IN	0.11	12	0.688	10	38.2	0.639	AA	7.7
Eagle Creek at Zionsville, IN	0.09	8	0.882	7	22.5	0.949	FlowTracker	-7.1
Kokomo Creek near Kokomo, IN	0.19	8	0.551	5	15.1	0.553	FlowTracker	-0.4
Average				**9**	**26.2**			**2.1**
Big Creek near Wadesville, IN	0.29	12	1.272	6	23.7	1.243	FlowTracker	2.4
Clifty Creek at Hartsville, IN	0.39	8	1.924	3	9.3	1.972	FlowTracker	-2.4
Eagle Creek at Indianapolis, IN	0.34	4	3.940	2	5.8	4.000	FlowTracker	-1.5
Eel River at North Manchester, IN	0.56	4	8.476	1	2.7	8.492	FlowTracker	-0.2
Eel River near Loagansport, IN	0.56	4	16.476	2	3.8	16.082	FlowTracker	2.4
Fall Creek near Fortville, IN	0.30	12	2.636	2	5	2.559	FlowTracker	3.0
Fox River at Algonquin, IL	1.04	12	37.384	1	4	37.378	Rating	0.0
Fox River at Montgomery, IL	0.60	12	43.436	1	2.4	41.626	RioGrande	4.3
Jacks Fork at Alley Spring, MO	0.72	12	3.180	5	19.9	3.000	AA	6
Jacks Fork at Eminence, MO	0.55	12	6.773	10	5.6	6.853	AA	-1.7
Kokomo Creek near Kokomo, IN	0.43	8	1.380	4	14.1	1.376	FlowTracker	0.3
Salt Fork near St. Joseph, IL	0.27	8	1.317	5	17.5	1.250	pygmy	5.4
St. Francis River at Fisk, MO	0.56	12	10.800	2	7.8	10.560	Rio Grande	2.3
West Canada Creek near Wilmurt, NY	0.36	6	7.200	4	8.7	7.400	FlowTracker	-2.7
White River at Noblesville, IN	0.26	8	7.590	1	3.2	7.386	FlowTracker	2.77
Wildcat Creek near Jerome, IN	0.47	4	5.215	2	3.7	4.930	FlowTracker	5.83
Average				**3.2**	**8.7**			**1.7**

Figure 3. Mean channel velocity and departure of StreamPro discharges from comparison discharges, in percent.

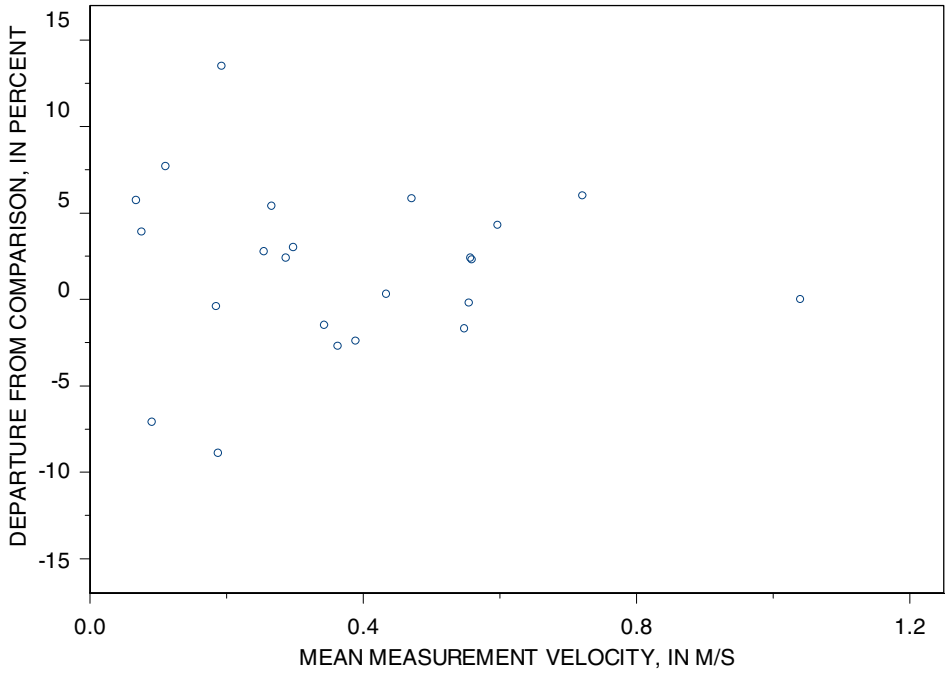
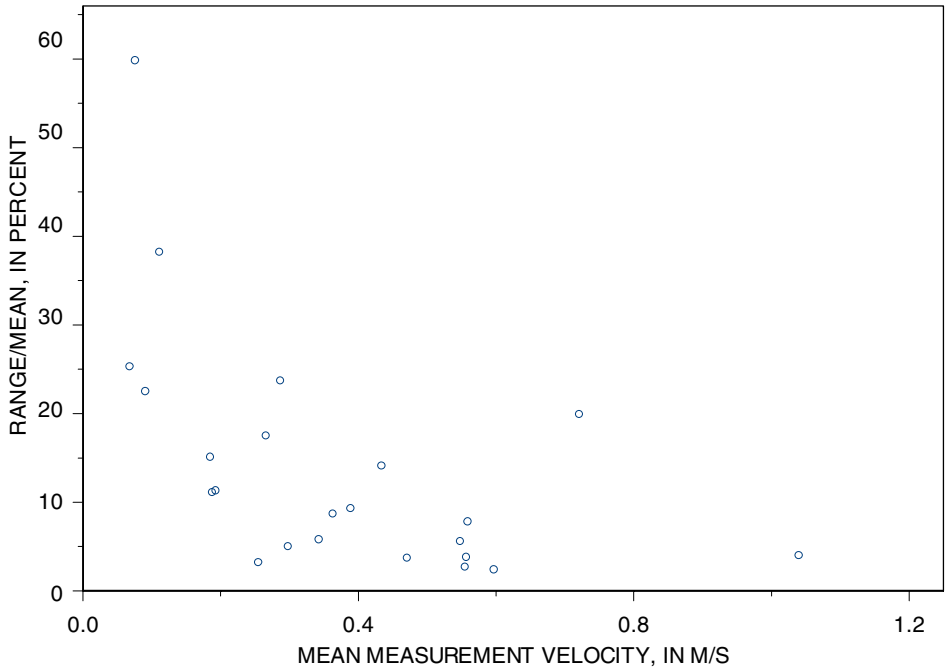


Figure 4. Mean channel velocity and transect discharge range divided by mean, in percent.



Summary and Conclusions

The USGS has conducted field evaluations of the StreamPro ADCP for use in shallow-water discharge measurements. The field evaluations were conducted at sites ranging in mean depth from 0.20 to 1.23 m, mean velocity from 0.076 to 1.04 m/s, and in discharge from 0.083 m^3/s to 43.4 m^3/s. On average, the StreamPro has proven capable of measuring discharge within 5 percent of standard USGS data-collection methods. For the measurements with mean velocities below 0.25 m/s, however, the discharge measurement of individual transects varies substantially. The results of evaluation showed that the variation can be so great that even if eight or more transects are collected (per standard USGS methods) the measurement quality may be affected. While no consistent bias was detected, this result means that using the StreamPro to make discharge measurements under these low-velocity flow conditions may not be practical because of the time required to obtain additional transects. More testing is needed to determine how many transects are needed in low-velocity conditions to make an accurate discharge measurement.

References

1. Oberg, K.A., Morlock S.E., and Caldwell, W.S., 2005 Quality-assurance plan for discharge measurements using acoustic Doppler current profilers: U.S. Geological Survey Scientific Investigations Report 2005-5183, 35 p.
2. Morlock, S.E., 1996, Evaluation of acoustic Doppler current profiler measurements of river discharge: U.S. Geological Survey Water-Resources Investigations Report 95-4218, 37 p.
3. Mueller, D.S., 2002, Field assessment of acoustic-Doppler based discharge measurements *in* Hydraulic Measurements and Experimental Methods 2002, T.L. Wahl, C.A. Pugh, K.A. Oberg, and T.B. Vermeyen, eds.: Proceedings of Hydraulic Measurements and Experimental Methods 2002, Estes Park, Colo., ASCE
4. Fulford, J.M., 1992, Characteristics of U.S. Geological Survey discharge measurements for Water Year 1990: U.S. Geological Survey Open-File Report 92-493, 79 p.
5. Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 2 v., 631 p.