Discharge Measurements in Shallow Urban Streams Using a Hydroacoustic Current Meter

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Abstract

Hydroacoustic current-meter measurements were evaluated in small urban streams under a range of stages, velocities, and channel-bottom materials. Because flow in urban streams is often shallow, conventional mechanical current-meter measurements are difficult or impossible to make. The rotating-cup Price pygmy meter that is widely used by the U.S. Geological Survey and other agencies should not be used in depths below 0.20 ft and velocities less than 0.30 ft/s. The hydroacoustic device provides measurements at depths as shallow as 0.10 ft and velocities as low as 0.10 ft/s or less. Measurements using the hydroacoustic current meter were compared to conventional discharge measurements. Comparisons with Price-meter measurements were favorable within the range of flows for which the meters are rated. Based on laboratory and field tests, velocity measurements with the hydroacoustic cannot be validated below about 0.07 ft/s. However, the hydroacoustic meter provides valuable information on direction and magnitude of flow even at lower velocities, which otherwise could not be measured with conventional measurements.

Introduction

The U.S. Geological Survey (USGS) stream-gaging program provides streamflow data for a variety of purposes, including flood forecasting, water-resources planning and design, hydrologic research, and operation of water-resources projects (Wahl, Thomas, and Hirsh, 1995). Streamflow records are produced from more than 7,000 USGS stream-gaging stations across the Nation. The accuracy of streamflow records is dependant upon measurements of river and stream discharge made by USGS personnel. About 77 percent of all discharge measurements made annually by the USGS are made in river and stream depths that are shallow enough for personnel to wade.

In urban areas, extensive paving of pervious surfaces and channel modifications result in reduced baseflow and generally shallow streamflow. In many cases, the flow depths are at or below the recommended performance limits for conventional current meters. However, measurements of urban streamflow by USGS and others are very important for investigating water quality problems and for validating regulatory compliance.

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The U.S. Geological Survey (USGS) commonly uses the velocity-area method to measure discharge in streams and rivers (Wahl, Thomas, and Hirsh, 1995). The velocity-area method involves measuring the channel area and water velocities of a stream at a cross section that is perpendicular to the main flow of the channel. The channel is divided into a number of vertical "subsections." The area and mean velocity in each subsection is measured and the subsection discharge is computed. The total discharge within the stream is the sum of the individual subsection discharges. For wading discharge measurements, a tag line with marks at known distance increments is strung across the channel perpendicular to the flow. The tag-line distance marks are used to determine subsection widths. Depths are measured using a standard USGS top-setting wading rod (fig. 1). A top-setting rod has a main rod marked with 0.10-foot (ft) increments for measurement of depth. A current meter is attached to a second sliding rod that is attached to the main rod. "Top-setting" refers to the fact that the second rod can be slid up and down, and marks at the top of the rod allow a current meter to be set at .6, .2, or .8 of the water depth. The USGS has commonly used mechanical, rotating-cup Price current meters to measure water velocities.

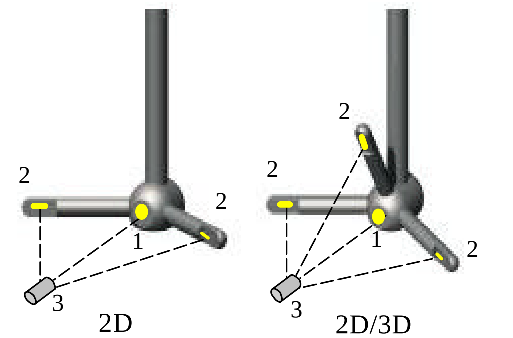
Figure 1. Top-setting wading rod: left, depth measurement at water surface; right, top of rod. (Nolan and Shields, 2000)

Price meters have limitations, including: 1) a shallow depth limit of 0.30 ft; 2) a low velocity threshold of 0.10 ft/s (feet per second); 3) extensive maintenance is required to maintain meter accuracy; 4) sensitivity to vertical velocities; and 5) disturbance of the flow measured by the meter. These limitations can hamper the usefulness of mechanical meters, particularly at very low flows when streams can be shallow and slow. An alternative to mechanical current meters for shallow-water discharge measurements is hydroacoustic current meters.

Hydroacoustic Current Meters

Hydroacoustic current meters use the Doppler principle applied to underwater sound to measure water velocities. Advantages of hydroacoustic current meters include: 1) no moving parts provides simple maintenance; 2) instrument calibration remains stable provided components are not damaged; 3) velocity accuracies of 0.01 ft/s are attainable; 4) high sample and data output rates; and 5) quality-assurance data not available for mechanical current meters can be collected. These advantages make hydroacoustic current meters an attractive alternative for discharge measurements in shallow rivers and streams. Disadvantages of hydroacoustic current meters include: 1) higher acquisition cost than mechanical meters; 2) damage or malfunctions cannot usually be repaired without return to the manufacturer; and 3) these instruments may function poorly or not at all in clear water.

A model of acoustic Doppler velocimeter (ADV), the FlowTracker, was designed by SonTek/YSI[3] to be used with the velocity-area discharge measurement method. The Flowtracker was designed for mounting to a standard USGS top-setting wading rod (fig. 1).



1. Transmitting transducer
2. Receiving transducer
3. Sample volume

Figure 2. ADV probe configurations showing components (courtesy SonTek/YSI corporation)

The FlowTracker probe configuration for this application is 2D or 2D/3D "side-looking" (fig. 2). To make discharge measurements, the probe is mounted so that the transmitting transducer acoustic beam is parallel to the tagline being used to measure subsection widths. The ADV computes velocities in XY (2D) or XYZ (3D) coordinates. The X-coordinate velocity is the velocity used as the measured velocity used to compute discharge and is therefore perpendicular to the tagline. The Y velocity component is the "across-stream" velocity parallel to the tagline. It is not used to compute discharge, but is used to quality assure the measurement (large Y-component velocities indicate large horizontal angles of flow with respect to the tagline; it is generally recommended that the instrument be used in flow angles of less than 20 degrees). The 2D/3D probe also provides a Z or vertical velocity that similarly can be used for quality assurance.

The FlowTracker probe is mounted at the same position on the wading rod as a mechanical current meter, and measures velocity in the same general location in the water (fig. 3). However, the ADV measures velocity in a very small volume (fig. 2) and is essentially a point measurement, whereas the response of the mechanical Price meter is to a composite of many point velocities on the front and rear of the meter's conical cups. Also, it is assumed when using the Price meter that all velocity is in the XY plane, or perpendicular to the axis of rotation of the meter. Up-down (Z) components of velocity cannot be detected with the Price meter, but may impact its performance. The 2D/3D FlowTracker probe provides information on velocity components in the XYZ directions.

[3] Use of trade or brand names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

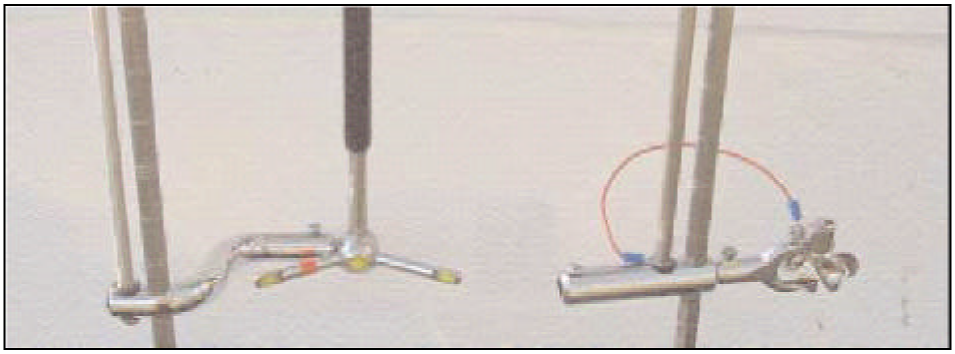


Figure 3. FlowTracker 2D probe (left) compared to Price pygmy current meter (right). (Photograph by Scott Kimball, U.S. Geological Survey.)

Morlock and Fisher (2002) summarize results of preliminary laboratory and field evaluations of the FlowTracker ADV. Tow-tank tests and informal field tests have produced generally favorable results, and more formal tests are ongoing. However, tow-tank tests are conducted under ideal conditions, and the slowest velocity tested was 0.15 ft/s. The field tests were done at discharges of 2.4 to 388 ft^3/s, which were generally greater than discharges anticipated in shallow urban streams.

Field Evaluation in Urban Streams

Flow in urban streams is often shallow; with depths less than the 0.2 ft that is the lowest recommended measurement depth for the Price pygmy current meter (Rantz, 1982). Because of reduced baseflow or channel modifications, stream widths may also be less, allowing fewer measurement subsections with the recommended minimum lateral spacing of 0.20-0.30 ft. Where widths are not reduced, velocities are likely to be below the minimum detectable by the mechanical meter, or about 0.06 ft/s. It is recommended that the Price AA and pygmy meter should not be used at velocities less than 0.30 ft/s, unless necessary. Channel modifications or accumulation of debris can introduce cross-sectional velocity distributions that are very different from natural streams. These differences violate many of the assumptions of smooth flow that are needed for discharge measurements using mechanical current meters, such as the flow being predominately in the XY plane. The vertical velocity distribution profile may be much different than the theoretical that is assumed. In some urban stream channels, there may be notable components of velocity in the Z direction. These up-down velocity vectors can cause Price current meters to spin faster and yield a higher measured discharge than that which is actually moving downstream.

Table 1 lists measurements that were made or attempted to evaluate application of the FlowTracker ADV to a range of flows and channel conditions. The largest flow measurement (No. 8) was done using the ADV and a Price AA current meter. The smallest measurement (No. 1) was done using a volumetric method only, where the full volume of flow is captured in a bucket while keeping time with a stopwatch. Measurement No. 3 was made using the ADV only. All other measurements were done using the ADV and a Price pygmy meter.

Table 1. Test measurements made or attempted.
[Discharge and mean velocity were determined using the FlowTracker ADV, except for No. 1 that was a direct volumetric measurement. Number of sections does not include end sections. ft^3/s = cubic feet per second; ft = feet; ft^2 = square feet; -- = no data.]

No.	Discharge (ft^3/s)	Width (ft)	Number of sections	Area (ft^2)	Mean Velocity (ft/s)	Minimum Depth (ft)	Channel materials
1	.006	--	--	--	--	--	Sand, silt, mud
2	.074	1.70	6	.539	.091	.10	Sand, gravel, rubble
3	.125	19.0	35	9.42	.008	.10	Sand
4	.245	3.4	15	1.01	.243	.22	Sand, gravel
5	.345	3.0	11	1.17	.295	.16	Sand, gravel
6	8.21	37.5	23	32.7	.251	.34	Sand, gravel
7	30.6	56.0	30	46.4	.660	.43	Sand, gravel
8	37.4	100.0	30	134.1	.279	.40	Sand, gravel

Comparisons between ADV and conventional discharge measurements are summarized in Table 2. At the three highest discharges (No. 6-8), streamflow conditions met the assumptions for a good Price-meter measurement, including minimum depth, and there was good agreement between the ADV and conventional measurements. Discharges were within the accuracy standard for a "good" quality measurement (5 percent), and maximum velocities were measured in about the same parts of the stream cross section.

Table 2. Comparison of discharge measurements made with FlowTracker acoustic velocity meter and conventional streamflow measurement techniques.
[Location is distance from right edge of water. ft^3/s = cubic feet per second; ft = feet; ft^2 = square feet; -- = no data.]

No.	Width (ft)	FlowTracker			Conventional Method			
		Discharge (ft^3/s)	Maximum Velocity (ft/s)	Location (ft)	Method	Discharge (ft^3/s)	Maximum Velocity (ft/s)	Location (ft)
1	--	--	--	--	Volumetric	.006	--	--
2	1.70	.074	.240	0.3	Pygmy	.097	.257	0.8
3	19.0	.125	.056	9.8	--	--	--	--
4	3.4	.245	.524	0.4	Pygmy	.361	.542	2.0
5	3.0	.345	1.042	1.8	Pygmy	.365	.408	1.8
6	37.5	8.21	.402	15.8	Pygmy	8.53	.374	15.8
7	56.0	30.6	1.26	25.6	Pygmy	30.5	1.15	27.6
8	100.0	37.4	.407	42.0	AA	37.2	.405	46.0

Comparisons were made at three discharges less than 1 ft^3/s (No. 2, 4, 5). ADV discharges were consistently less than those determined using conventional methods. There was general agreement between maximum velocities for measurements No. 2 and 4, but locations were different. Differences between maximum velocities and locations in the relatively shallow and narrow stream channels, including No. 5, can be attributed to measurement of a point by the ADV versus composite measurement of many points by the Price pygmy meter. Data provided by the ADV suggests that there is significant variation of velocities over small lateral and vertical distances in small urban channels.

ADV data also suggest that there are significant up-down (Z direction) components of velocity in small urban channels, particularly where debris is present in the channel. It is difficult for field hydrographers to detect these velocity components, which seem to produce extra spin in mechanical meters, resulting in larger computed discharges than from the ADV. Additional work is needed to evaluate these phenomena and their impact on discharge measurements.

Comparisons were not possible for two measurements. For measurement No. 3, stream velocities were too low to turn the cups of a Price pygmy meter. At the smallest discharge (No. 1), flow was not sufficient to submerge the ADV probe. Measurement No. 1 demonstrates that there is a lower limit for application of the FlowTracker device, probably below about 0.01 ft^3/s. Volumetric measurements are usually the best choice for very low streamflow, when practical.

Conclusions

The FlowTracker acoustic Doppler velocimeter provides a notable advantage over the mechanical Price pygmy meter for discharge measurements in shallow urban streams. The ADV can operate at shallower water depths, at slower velocities, and under flow conditions that are less than ideal for the mechanical meter. Preliminary results are encouraging, and continued and more rigorous testing should validate application of the ADV to shallow urban and other stream measurements.

Comparisons with Price-meter measurements were favorable within the range of flows for which the meters are rated. Based on laboratory and field tests, velocity measurements with the ADV cannot be validated below about 0.07 ft/s, the rated limit of the Price pygmy meter. However, the hydroacoustic meter provides valuable information on direction and magnitude of flow even at lower velocities, which otherwise could not be measured with conventional measurements.

The features of the ADV may provide important applications in addition to direct discharge measurements. As discussed, smooth streamflow is assumed for discharge measurements using a Price current meter. The ADV can be used to evaluate velocity distributions at established stream cross sections where Price-meter measurements are usually made. This may provide information that can be used to “fine tune” the conventional discharge measurements, or validate continued use of the cross section. Velocity distributions are also very important in the collection of water samples, where a representative sample of constituent flux is desired. Velocity distributions evaluated using the ADV could be used to select sampling locations in the cross section, or to locate an intake point for automatic sampling systems. Finally, velocities are important in studies of fluvial geomorphology, particularly in evaluating scour and deposition phenomena.

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