In Reply Refer To: June 2, 2004
Mail Stop 415

OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2004.04

SUBJECT: Policy on the use of the FlowTracker for discharge measurements.

The purpose of this memorandum is to provide information and guidance regarding the use of SonTek/YSI's FlowTracker for making wading discharge measurements. More than 100 FlowTrackers have been purchased for use by the U.S. Geological Survey (USGS) as of October 2003. Although the Office of Surface Water (OSW) continues to conduct laboratory tests of these instruments, we can state that the FlowTracker performs well in many stream environments. Guidance on the general use of FlowTrackers is important, especially for their use in low-backscatter environments and with boundaries, such as rocks, logs, or large stream bedforms.

Background

The Water Resources Discipline (WRD) Instrumentation Committee (ICOM) funded a project in the Indiana District, beginning in October 2000, to guide the adaptation of hydroacoustic current meters for discharge measurements in shallow, wadeable streams. SonTek/YSI designed the FlowTracker to be used for making discharge measurements in wadeable streams using a standard USGS wading rod. During the last 4 years, OSW worked with SonTek/YSI to provide guidance on standard USGS discharge-measurement methods and algorithms. WRD and SonTek/YSI personnel also conducted a number of field and laboratory tests of the FlowTracker.

Tow-tank tests of the FlowTracker

In April 2002, two FlowTrackers were tested in a tow-tank at the USGS Hydraulics Laboratory at Stennis Space Center, Mississippi. FlowTrackers were tested at various tow-cart speeds in order to determine their accuracy. These FlowTrackers met Price AA and the manufacturer's specified accuracy limits for most tow-tank runs (http://hydroacoustics.usgs.gov/reports/SEMpaper.pdf).

In November 2002, 31 FlowTrackers were tested in a tow-tank at the USGS Hydraulics Laboratory at Stennis Space Center, Mississippi to ascertain the performance of a large batch of instruments. FlowTrackers were tested at eight tow-cart speeds, ranging from 0.10 to 2.99 feet per second (ft/s). Unfortunately, data analysis indicated various problems related to the test procedures. These problems included acoustic interference caused by operating instruments simultaneously, residual currents in the tow-tank, and possible test-equipment-induced noise. Testing hydroacoustic instruments in a tow-tank is a difficult process and the USGS and other organizations still are experimenting on how to properly conduct these tests. A revised tow-tank test plan (http://hydroacoustics.usgs.gov/downloads/flowtracker.field.test.pdf) was drafted based on the November 2002 test experience. In March 2003, new tests were conducted in the tow-tank based on the revised test plan. Additional tests of the FlowTracker also were conducted in a jet tank at the Hydraulics Laboratory. Data from both these tests currently are being analyzed.

Acoustic Doppler Velocimeters (ADV), of which the FlowTracker is a special adaptation, have been tested and shown to be an accurate instrument. ADV's commonly are used in laboratory and field investigations in hydraulics. A list of selected papers published in peer-reviewed journals that relate to testing and evaluation of ADV's is provided in the "Selected References to ADV Evaluations" section at the back of this memorandum. The results of these and other papers provide confidence in the underlying technology that is used in the FlowTracker for making velocity measurements.

FlowTracker results in low backscatter environments

Field tests at 29 sites in 2001 and 5 sites in 2002-03 have shown that the discharge-measurement algorithms used by the FlowTracker are correct. For the 2002-03 field tests, FlowTracker discharge measurements were within 5 percent of discharges measured with Price AA or pygmy meters, with mean velocities ranging from 0.48 to 1.9 feet per second (ft/s), mean depths ranging from 0.7 to 2.1 ft, and measured discharges ranging from 12 to 120 cubic feet per second (ft^3/s). Whereas FlowTracker measurements compared favorably with mechanical current meter measurements, all measurements were made in streams with few boundary effects, and in streams that carried enough suspended backscatter material to produce adequate FlowTracker signal-to-noise ratios (SNR). Data from FlowTracker measurements made in the last 6-9 months have indicated potential data-quality problems in streams with low suspended backscattering material.

SonTek/YSI indicates that the SNR should be greater than 10 decibels (dB) for optimal data quality (SonTek FlowTracker Operation Manual, Section 1.4.1), but FlowTrackers may collect reliable data when the SNR is lower. Field and laboratory data analyses have indicated that velocity data are unreliable when the SNR is below 4 dB.

In June 2003, SonTek/YSI released firmware version 2.4. **It is recommended that all FlowTrackers be upgraded to firmware version 2.4 by contacting SonTek/YSI.** This firmware version includes changes that may increase data quality in some low backscatter environments. Information on obtaining the firmware upgrade can be obtained from http://www.sontek.com/e/0307a/ftupgrade.html or by contacting SonTek/YSI by email at support@sontek.com or by phone at (858) 546-8327.

In July 2003, SonTek/YSI made a hardware upgrade available for FlowTrackers that involves a new high-sensitivity receiver component. The manufacturer states that this upgrade can improve the SNR by 5 to 10 dB, which may dramatically improve the capability to work in low backscatter environments. OSW has not yet tested FlowTrackers equipped with this upgrade, but has plans for testing in the next 6-12 months. The hardware upgrade is available from SonTek/YSI and is standard in all FlowTrackers shipped since July 15, 2003.

FlowTracker results in streams with potential boundary effects

Recently reviewed FlowTracker discharge measurements indicate numerous boundary effect problems. A boundary effect occurs when the sampling volume for the FlowTracker includes some solid, stationary boundary such as a cobble or boulder in the stream. These problems generally are more common in streams with rough beds and at shallow depths. The volume of water used by the FlowTracker to make velocity measurements (called the sample volume) is approximately 0.25 cubic centimeters in size and is located 10 centimeters (about 4 inches) away from the center transmitting transducer on the FlowTracker (figure 1). If the FlowTracker sample volume includes or is near a solid boundary, the velocity data will be corrupted and biased low. The low bias is caused by the FlowTracker measuring a zero velocity from the solid, stationary boundary for at least some part of the sample volume.

Guidelines for use of FlowTrackers in making discharge measurements

FlowTracker users should take the following actions when making discharge measurements:

1. Under appropriate conditions and use as described below, the FlowTracker can be used in place of the mechanical Pygmy and Price AA meters for wading discharge measurements. The same procedures and polices for use of the mechanical meters apply to the use of the FlowTracker; these include:
    - Measurement site selection -- the measurement section should be within a straight reach, where streamlines are parallel. The streambed should be relatively uniform and free of numerous boulders, debris, and heavy aquatic growth. The flow should be relatively uniform and free of eddies, slack water, and excessive turbulence.
    - Velocity sample time – under normal measurement conditions, each point velocity measurement should be sampled for a minimum of 40 seconds. Under extreme flow conditions, such as rapidly changing stage, a shorter sample time may be used to lessen the time needed to complete the discharge measurement.
    - Location of velocity observations in each vertical – at depths below 1.5 feet, the 0.6-depth method should be used; at depths between 1.5 and 2.5 feet when a non-logarithmic velocity distribution may be present and the 0.8 depth sample location would be more than 2 inches from any boundary, the two-point method should be used; and at depths greater than 2.5 feet, the two-point method should be used. If a non-logarithmic velocity profile is discovered when using the two-point method, the three-point method should be used.

2. Prior to each field trip, or about once per week, perform a FlowTracker ADVCheck (FlowTracker Operation Manual Section 6.5.4). The ADVCheck should be logged to a file and archived. The name of the ADV check file should be written on the measurement note sheet. Perform FlowTracker field diagnostic procedures (FlowTracker Operation Manual Section 3.3.2) prior to starting every measurement.

3. Monitor the FlowTracker SNR readings during the measurement for SNR readings that are less than 4 dB. The FlowTracker will display a warning at the end of a velocity measurement if the SNR for any beam is less than 4 dB. If the SNR is below 4 dB, try moving to a different measurement section where backscatter may be higher. If a section with an acceptable SNR cannot be located, the FlowTracker should not be used to make a discharge measurement.
4. Avoid measurement sections with abrupt changes in bed topography. These changes can result because of such things as large rocks or cobbles in the measuring section. Abrupt changes in bed topography may cause boundary effects leading to inaccurate velocity measurements. During the measurement, velocities should be monitored for unrealistically low velocities, and also for unusually large SNR values (a solid boundary should cause an increase in the SNR). Be aware of the location of the FlowTracker sample volume when measuring. The sample volume typically is 10 centimeters (about 4 inches) from the center transmitting transducer (figure 1). Avoid placing the sample volume within 2 inches from any solid boundary. Although this recommended placement does not mean that the FlowTracker cannot be used closer to boundaries, nevertheless, extra care should be taken in those situations.
5. Pay close attention to the flow angle reported by the FlowTracker. The wading rod (with FlowTracker attached) always should be held perpendicular to the tagline, so that the pulse generated by the transmitter (see figure 1) is parallel to the tagline. Ideally, the tagline should be set up in the cross section to be measured such that flow is perpendicular to the tagline.

   Flow angle, as calculated by the FlowTracker, is defined as the direction of flow relative to the x-direction of flow, so that

   $$FlowAngle = \arctan\left(\frac{Vy}{Vx}\right)$$

   where, Vy is the velocity in the y-direction (parallel to the tagline) and Vx is the velocity in the x-direction (perpendicular to the tagline) used to calculate discharge.

   The flow angle calculated by the FlowTracker can result from two sources: (1) the flow is not perpendicular to the tagline, and (2) the flow is perpendicular to the tagline but the wading rod is not being held correctly relative to the tagline, as described above. Regarding (1), some small angles and variation in the flow angle at a site is not unusual. However, if large fluctuations of flow angles are reported, measurements should be made at another section with more uniform flow. Regarding (2), holding the FlowTracker such that it is skewed at any angle relative to the tagline will result in a measurement of velocity that is biased low. Small angles do not result in significant biases, but because of these biases, users should be careful to minimize this error. If the FlowTracker is held such that it is skewed at an angle of approximately 8 degrees from the tagline, the measured velocity may be in error by as much as 1% (assuming that flow is perpendicular to the tagline).

   Large variations in flow angles may be indicative of poor or inconsistent alignment of the wading rod or poor site selection for the measurement.

6. Each FlowTracker measurement is stored in a binary file (.WAD extension) that a user can download to the computer and, using FlowTracker software, extract four files containing the

measurement data. These files include a summary of the measurement (.DIS) with average subsection velocities and SNR readings, and a "raw" data file (.DAT) that lists 1-second velocities and SNR readings. The effect of unrealistic velocities may not be apparent in the average subsection velocities in the .DIS file. Thus, users should review the 1-second velocity and SNR data in the .DAT file if any of the following results are observed:

- Average subsection SNR readings in the .DIS files are less than 10;
- .DIS file average subsection velocities or SNR readings appear to be inconsistent across the measurement section or unrealistic for site conditions;
- SNR readings are observed to fall below 4 dB any time during a discharge measurement;
- The .DIS file shows unrealistic subsection velocity spikes;
- The .DIS file shows subsection boundary variable values of 3 (poor);
- The mean standard error of velocity for the measurement shown in a DIS file exceeds 5 percent of the mean velocity for the measurement; or,
- There is any reason to suspect data-quality problems (such as the presence of irregular bedforms or other solid boundaries that could interfere with the sample volume).

The FlowTracker software contains a velocity spike filter (number of spikes filtered is displayed in the .DIS file); however, the spike filter may not remove all bad or questionable velocity data from the subsection average. Furthermore, boundary variables of 1 (best) or 2 (good) do not necessarily mean that boundaries did not cause velocity biases in the measurement data. Users should refer to the FlowTracker Operation Manual Section 1.4 and become familiar with the detailed descriptions of SNR's, standard error of velocity, boundary variables, and velocity spike filtering.

OSW is making available a program called DatView, written by Mike Rehmel of the Indiana District, to facilitate the rapid review of FlowTracker data contained in the .DAT file. At present, this program is considered Beta software – but appears to be stable. The program allows users to load FlowTracker .DAT files and examine plots of measurement velocities and SNRs. An example of a plot generated using DatView for a measurement with low SNRs and associated velocity spikes is attached (figure 2). DatView can be obtained at http://hydroacoustics.usgs.gov/download/DatView.exe.

Low SNR readings and velocity spikes can degrade the FlowTracker measurement quality. For this reason, users should consider downgrading the quality of measurements made in low-backscatter environments.

Summary

Test data collected to date indicate that FlowTrackers are accurate instruments for making wading discharge measurements in many stream environments. If a FlowTracker is used outside of its designed operating environment, data can be compromised resulting in inaccurate measurements. Until OSW completes field and laboratory testing, users of FlowTrackers should make comparison measurements with Price AA current meters in various stream environments per OSW memorandum regarding Acoustic Doppler Velocimeter, dated October 4, 2001. A test plan for FlowTracker comparison measurements can be obtained at http://hydroacoustics.usgs.gov/downloads/FlowTracker.field.test.pdf.

OSW requests that any FlowTracker users share results of their experiences and other information regarding FlowTracker use. Please send information to Mike Rehmel, Indiana District, (msrehmel@usgs.gov), 317-290-3333 ext. 158 or to the USGS Hydroacoustics Work Group (hawg@simon.er.usgs.gov). OSW is interested in receiving information regarding measurement comparisons, problems identified with the instrument or software, possible hardware or software enhancements, and other important issues to users. Field and laboratory tests of these instruments are continuing and test results will be communicated in future memorandums, by the OSW Hydroacoustics Web pages (http://hydroacoustics.usgs.gov/), and through the Acoustics mailing list.

Questions concerning the information presented in this memorandum should be directed to Kevin Oberg (kaoberg@usgs.gov, 217-344-0037 ext. 3004) or Mike Rehmel (msrehmel@usgs.gov, 317-290-3333 ext. 158). Specific questions concerning the DatView program should be directed to Mike Rehmel.

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Distribution Code: A,B,CD,OSW Staff all, District SW specialist, and FO

Selected References to ADV Evaluations

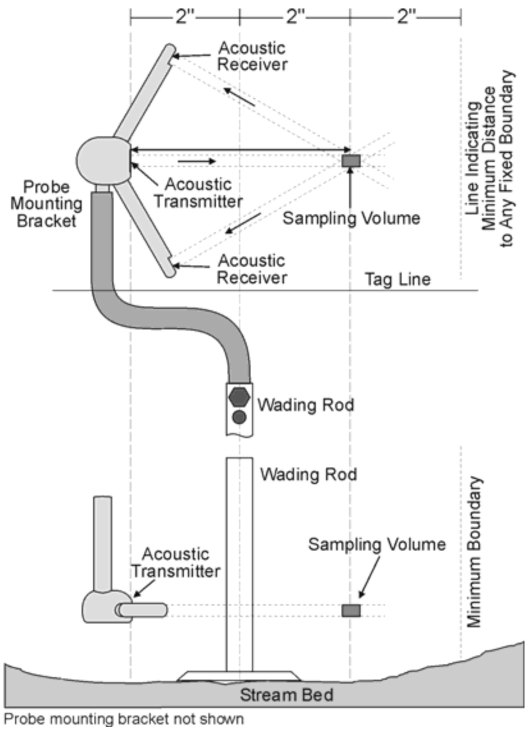
Kraus, N. C., Lohrmann A., and Cabrera R., 1994, New acoustic meter for measuring 3D laboratory flows: Journal of Hydraulic Engineering, v. 120, p. 406-412.

Snyder, W.H., and Castro, I. P., 1999. Acoustic Doppler Velocimeter Evaluation in Stratified Towing Tank: Journal of Hydraulic Engineering, v. 125, no. 6, p. 595-603.

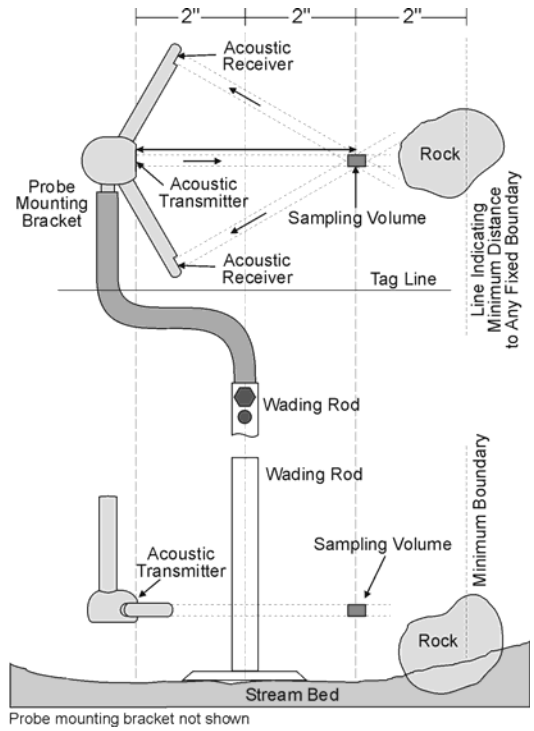
Song, T., and Graf, W. H., 1996. Velocity and turbulence distribution in unsteady open-channel flows: Journal of Hydraulic Engineering, v. 122, no. 3, p. 141-154.

Voulgaris, G., and Trowbridge, J. H., 1998, Evaluation of the Acoustic Doppler Velocimeter (ADV) for Turbulence Measurements: Journal of Atmospheric and Oceanic Technology, v. 15, no. 1, p. 272-289.

Figure 1.—Schematic showing FlowTracker sampling volume and proximity to a fixed boundary in the stream



Ideal FlowTracker measurement conditions



FlowTracker measurement illustrating conditions with potential for interference from a solid boundary

Figure 2.—Example Plot of FlowTracker .DAT File Using DatView