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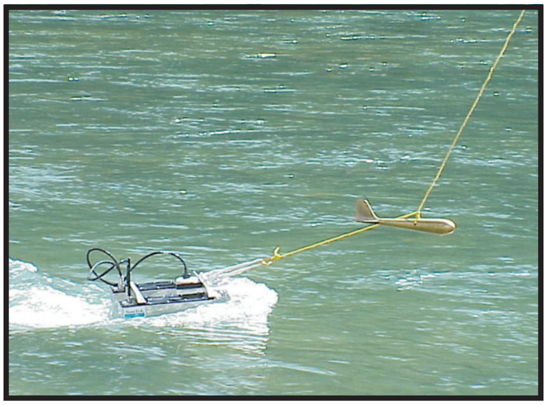
Quality-Assurance Plan for Discharge Measurements Using Acoustic Doppler Current Profilers



Scientific Investigations Report 2005-5183

U.S. Department of the Interior
U.S. Geological Survey

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By Kevin A. Oberg, Scott E. Morlock, and William S. Caldwell

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Gale A. Norton, Secretary

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Cover:
Left—Bow-mounted acoustic Doppler current profiler (ADCP) mounting bracket and ADCP on U.S. Geological Survey work boat (photograph by Paul Baker, U.S. Geological Survey [see fig. 4]).
Bottom right—Tethered acoustic Doppler current profiler (ADCP) boat used for making discharge measurements (photograph by Jeff Woodward, Environment Canada [see fig. 5]).
Top right—Temporary bank-operated cableway for making acoustic Doppler current profiler (ADCP) measurements with a tethered ADCP boat [photograph by Brian L. Loving, U.S. Geological Survey (see fig. 6)].

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Abbreviations used:

ADCP	acoustic Doppler current profiler
DC	direct current
DGPS	differential global positioning system
DOI	The Department of the Interior
EMF	electromagnetic field
GPS	global positioning system
HAWG	Hydroacoustics Work Group
kHz	kilohertz
LAN	local area network
MHz	megahertz
NWIS	National Water Information System
OSW	Office of Surface Water
ppt	parts per thousand
USB	Universal Serial Bus
USGS	U.S. Geological Survey
WRD	Water Resources Discipline

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Abstract

This report describes the quality-assurance measures implemented by the U.S. Geological Survey (USGS) for discharge (streamflow) measurements using acoustic Doppler current profilers (ADCPs). The report is an update of a 1995 quality-assurance plan for ADCPs and addresses the many changes in ADCP technology and procedures since 1995. An ADCP is an electronic instrument used to measure water velocity, water depth, boat velocity, and discharge in rivers by means of underwater acoustic signals. ADCPs have been used by the USGS to measure streamflow in rivers and estuaries since 1985. Techniques for the measurement of discharge and for assuring the quality of the data have been developed and documented by the USGS Office of Surface Water (OSW). The OSW supports ADCP use through training classes, Web pages on the use of ADCPs, software and hardware testing, and the Hydroacoustics Work Group.

Quality-assurance measures include selection of measurement locations, use of suitable deployment platforms, performing diagnostic and moving-bed tests, configuration of the ADCP, techniques for the collection and review of ADCP discharge measurements, and instrument tests. During discharge measurements, proper boat control and speed is critical to ADCP data quality. A minimum of four transects should be made in reciprocal pairs and the four transect discharges averaged to obtain the measured discharge for normal flow conditions. Procedures are described for streams where the flow is changing rapidly. Edge distances must be measured with a distance-measuring device or tagline. Following the discharge measurement, all ADCP files collected on the field computer should be backed up on non-volatile storage media. Tests of each ADCP should be conducted after an ADCP is first acquired, after factory repair, after firmware or hardware upgrades, and at some periodic interval. Each USGS office must also develop an office ADCP quality-assurance plan that includes procedures specific to the office ADCP models, users, and measurement sites.

ADCP data collected in the field should be reviewed as soon a practical in the office. All measurement data should be transferred to an office server within 2 work days of returning to the office from the field, and archived within a directory structure similar to that used for other electronically collected data. Approximately every 3 years, ADCP measurement, documentation, and data-archival procedures will be reviewed during an OSW Surface-Water Technical Review.

Introduction

The acoustic Doppler current profiler (ADCP) is an acoustic instrument used to measure water velocities, boat velocities, and water depths (fig.1). Water-velocity measurements are made by transmitting sound at a known frequency into the water and measuring the Doppler shift, or change in sound frequency, from signals reflected off particles in the water. ADCPs also can measure water depths, and when deployed from a moving boat, can measure the velocity of the boat. The capability of ADCPs to measure water

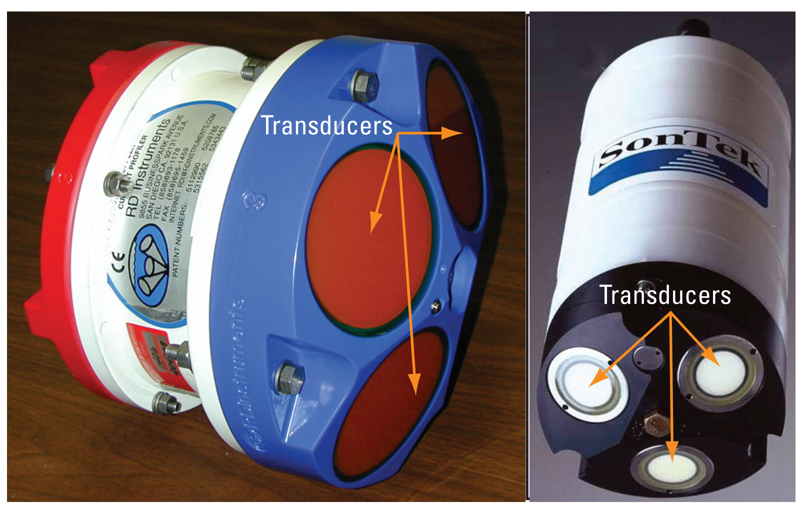


Figure 1. Two acoustic Doppler current profilers commonly used by the U.S. Geological Survey to measure streamflow. (Left photograph by Kevin Oberg, U.S. Geological Survey and right photograph by SonTek/YSI.)

velocity, depth, and boat velocity allows them to be used to measure discharge in rivers and estuaries. In this report, the term ADCP is used to refer to a class of acoustic Doppler instruments that can be used to measure velocity profiles and compute discharge from a moving platform, rather than any particular brand of ADCP, unless otherwise indicated.

The U.S. Geological Survey (USGS) has used ADCPs to measure velocity and discharge (streamflow) in rivers and estuaries since 1985 (Simpson, 2002). Simpson and Oltmann (1993) published a description of a system for the measurement of discharge in real time based on an ADCP. Simpson (2002) contains much useful information about the method and application of ADCPs for discharge measurement. The first ADCPs used by the USGS in the 1980s had depth and measurement precision limitations that limited their applicability to rivers and estuaries with depths greater than 11.5 ft (Simpson and Oltmann, 1993, p. 5). In 1992, the USGS began purchasing new ADCP models that were more precise than the earlier models and could be used in stream depths of 5 ft or greater. Because of the wider applicability of these new ADCPs, their use by the USGS became widespread by the late 1990s. ADCPs used by the USGS now include models with a variety of configurations, frequencies, and features.

The primary advantages of making discharge measurements using the ADCP as compared with point velocity meters, such as the Price AA current meter (Rantz and others, 1982), are that in most situations (1) the time required to complete a measurement is reduced, an advantage for personnel safety and for making measurements in unsteady-flow conditions; (2) the ADCP allows for data to be collected throughout most of the water column and cross section rather than at discrete points; (3) the ADCP is deployed at the water surface appreciably reducing the chance of snagging by debris, another safety advantage; (4) the instrument can be boat-mounted; thus, eliminating the installation, maintenance, and liability of costly manned cableways; (5) complex flow regimes, such as vertical bi-directional flow, can be accurately identified and measured; and (6) many parameters are available for analyzing measurement quality. The primary disadvantages of using the ADCP, compared with point velocity meters, are the high initial cost of an ADCP (costs range from approximately $12,000 to 19,000 in 2005); complexity, requiring some understanding of the physics, electronics, and system software prior to use; and the frequent changes in ADCP technology.

Documenting the standards, policies, and procedures for the collection, processing, storage, and analysis of streamflow data collected with ADCPs is important for ensuring the quality and reproducibility of the data. Although ADCPs are commonly used in the USGS in the accomplishment of its mission, as with any technology or methodology, it is critical that strict measures be implemented to ensure the quality and reproducibility of the data throughout the USGS. Lipscomb (1995) published the first quality-assurance plan for discharge measurements using broadband ADCPs. Many advances in ADCP technology and practice have occurred since 1995. These advances include the development of new ADCP software, the introduction of ADCPs from other manufacturers, new ADCPs with different configurations and operating modes, and the development of new deployment methods including unmanned tethered and remote-controlled boats. Because of these advances, and because of experience gained by the USGS from widespread use of ADCPs, it has become necessary to create a new ADCP quality-assurance plan (QA plan).

Purpose and Scope

The purpose of this QA plan is to document the standards, policies, and procedures to be used by USGS personnel for the collection, processing, storage, and analysis of streamflow data using ADCPs. The objectives stated by Lipscomb (1995), which also apply to this report, are to ensure the following:

1. Field and office procedures associated with the use of ADCPs adhere to applicable USGS policies and standards governing the collection, analysis, and reporting of surface-water data.

2. Personnel who collect and analyze the data are adequately trained in proper and acceptable ADCP operational procedures.

3. All activities related to the collection, analysis, and reporting of data collected using ADCPs are reviewed regularly for accuracy, completeness, and conformance to USGS standards.

4. Any deficiencies discovered during review are addressed immediately and corrective action is taken.

The scope of this new QA plan has been expanded to address developments in ADCP technologies and methods of use subsequent to Lipscomb (1995). This report focuses on discharge-measurement procedures and quality-assurance issues common to ADCPs. At present (2005), ADCP hardware, firmware, and software undergoes nearly continuous development. USGS offices are encouraged to develop and document instrument- or office-specific QA plans for all ADCPs in use by that office. Resources created by the USGS Office of Surface Water (OSW) and described in the next section can be used by USGS offices to develop instrument-specific QA plans.

Office of Surface Water Hydroacoustics Support

The OSW supports the application of hydroacoustic instruments used for hydrologic and hydraulic measurements. This support includes the following activities relative to hydroacoustics instrumentation:

- Organize, develop, and deliver training,
- Assist users with hydroacoustic instrumentation and

techniques,

- Develop methods for the application of hydroacoustic instruments for streamflow and hydraulic measurements,
- Develop instrument/software testing and quality-assurance procedures,
- Test hydroacoustic instruments, software, and methods,
- Share information on the above items with USGS users, and
- Represent the USGS in ADCP activities involving other agencies and organizations.

The coordination and support for hydroacoustics is part of OSW's continued support of new technology for USGS programs. The following resources have been developed by OSW for USGS users of hydroacoustics instruments, including ADCPs:

- Technical Memorandums—OSW prepares and publishes technical memorandums designed to provide ADCP users with technical recommendations and policies.
- Training—Presently (2005), the OSW provides four training classes for hydroacoustic instruments and techniques, three of which pertain to the measurement of streamflow using ADCPs.
- Hydroacoustic Web Pages—OSW, with help from the Hydroacoustics Work Group (see below), maintains a set of Web pages (*http://hydroacoustics.usgs.gov/*) on hydroacoustics. These pages include OSW memorandums, training-class information and schedules, reports on the use of hydroacoustic instrumentation, and access to software recommended for use by USGS personnel.
- Hydroacoustics Work Group (HAWG)—The HAWG is sponsored by the OSW to assist in providing operational guidance to users of acoustic instruments used for hydrologic measurements. The HAWG includes USGS staff who have a wide range of experience covering many aspects of data collection and analysis with acoustic instruments from various regions of the U.S. The HAWG also includes representatives from Environment Canada and the South Florida Water Management District.
- Acoustics Mailing List – OSW maintains an electronic mailing list on hydroacoustics, called the Acoustics List. This list allows list members to ask questions about hydroacoustics, share information about hydroacoustic applications, and to disseminate important information regarding quality-assurance practices, training, and other matters. Information on subscribing to this list can be obtained at *http://hydroacoustics.usgs.gov/*.
- Software—OSW has entered into agreements with manufacturers to test and release software for some ADCPs, to ensure consistency in software use, and to reduce the use of software versions that may adversely affect data quality. These software packages are available to USGS users at *http://hydroacoustics.usgs.gov/*.
- Surface-Water Reviewers—The OSW ensures that at least one person with expertise in hydroacoustics is available to serve on OSW Surface-Water Technical Review Teams.

Training

ADCP systems are becoming easier to operate; however, a rudimentary knowledge of acoustical physics, knowledge of ADCP operation, the manufacturers' discharge-measurement software, and boating techniques are necessary for proper operation and data collection. Various forms of training are available for USGS personnel; formal training classes, including short courses and workshops and self-organized training.

Formal Training

USGS personnel collecting and reviewing ADCP data for streamflow measurements are required to complete the USGS training class, *Measurement of Streamflow using ADCPs* (U.S. Geological Survey, 2002b). This 5-day class is designed to take the user through the progressive steps needed to configure the ADCP and to collect and analyze ADCP measurement data. In order to become more familiar with the measurement procedures and techniques, prospective students are strongly encouraged to participate in collecting an ADCP discharge measurement prior to attending the class. Students are required to complete two post-training discharge measurements using ADCPs and have them reviewed by an instructor in order to successfully complete the class. Class information, outlines, and schedules can be found on the USGS Hydroacoustic Web pages.

USGS personnel requiring advanced instruction may attend the training class, *Advanced ADCP Applications*. This 5-day class provides instruction on ADCP theory, ADCP water modes and bottom modes, integration of differential global positioning systems (DGPS) and echo sounders with ADCPs, discharge measurements using DGPS, collection of velocity data, and velocity vector processing. This class is recommended for personnel who make use of DGPS with ADCPs.

A refresher class on the use of ADCPs for streamflow measurements is also available, *Review of ADCP Discharge Measurement Data*. This 3-day class is designed to provide instruction on using ADCP software to review streamflow-measurement data. The following topics are covered during the class: (1) review of basic principles of ADCP operation, (2) USGS policy on use of ADCPs, (3) ADCP direct commands, (4) review of basic procedures for streamflow measurement, and (5) using ADCP software to playback and review ADCP discharge measurements.

The Department of the Interior (DOI) requires that all USGS boat operators be certified by attending a DOI-approved motorboat operators training course before operating a USGS boat or vessel and then be re-certified every 5 years. If a manned boat is used for ADCP deployment, USGS boat operators must be trained and become experienced in boat-maneuvering techniques that may be required for valid ADCP discharge measurements under all river and weather conditions.

Self-Organized Training

Successful completion of the required class, *Measurement of Streamflow using ADCPs*, should be considered a "first step" in the learning process for ADCP operation. Users are responsible for learning about individual aspects of the specific instruments they will be using and for keeping up to date regarding software and firmware, OSW policies and guidelines, and technological developments. Much of this information is made available by way of the USGS Acoustics Mailing List (*http://hydroacoustics.usgs.gov/list_info.html*). ADCP users should become familiar with the user manuals for each ADCP they will be using. Users also are encouraged to make use of other vendor-specific resources, such as technical information bulletins, documents describing theory, and other documentation.

Users of ADCPs for streamflow measurements should stay current with USGS polices and guidelines regarding the use of ADCPs. Therefore, it is strongly recommended that users:

- Frequently visit the USGS Hydroacoustic Web pages (*http://hydroacoustics.usgs.gov/*) ;
- Subscribe to the USGS Acoustics Mailing List (*http://simon.er.usgs.gov/mailman/listinfo/acoustics* or *http://hydroacoustics.usgs.gov/*) ; and,
- Attend hydroacoustics workshops and other meetings sponsored by the HAWG or OSW.

Simpson's (2002) report is a valuable resource for ADCP users. This report describes ADCP operating techniques, fundamental ADCP theory, ADCP discharge-measurement theory, vessel mounts, and operating techniques required for ADCP measurements. Reading and reviewing the report is an excellent means of reinforcing material taught in formal training classes.

General Office Documentation

Miscellaneous information that should be documented by offices using ADCPs includes, but is not limited to:

- Logs of ADCP instrument calibration checks (annual instrument checks or checks of a newly acquired instrument);
- Logs of electronic distance-measurement device calibration checks; and,
- For each ADCP, a "history" log that includes model and frequency, acquisition date, firmware/hardware upgrade descriptions and dates.

This information can be in paper format; however, electronic files containing this information should be created because these files can be archived in the event of paper-copy loss. An example ADCP history log is included in appendix A.

Each office using ADCPs must develop an office ADCP QA plan. The ADCP QA plan should be easily accessible by office personnel; for example, the plan could be made available on an internal office Web page. The ADCP quality-assurance information should be part of the office surface-water quality-assurance plan. In order to keep the ADCP information readily available to users, however, it is recommended the ADCP portion of the plan be a separate section of the plan (such as an addendum or appendix). The ADCP QA plan may reference this report, OSW memorandums, and USGS reports but should also include office-specific information including:

- ADCP archival procedures, file naming conventions, and the archival directory structure;
- Important information specific to individual ADCP models;
- ADCP instrument calibration check sites and documentation procedures;
- Training documentation procedures;
- A list of ADCP resources, including memorandums, reports, and Web pages;
- The identification of responsible persons regarding ADCPs (in an office with multiple ADCP operators, designation of a lead person responsible for overall ADCP operations is recommended); and,
- Individual site information (for example, an ADCP transect-collection strategy for a station with extreme flow variability).

Checklists for pre-measurement preparation, discharge-measurement procedures, post-measurement procedures, and office procedures; where necessary, these checklists should be instrument-specific.

Data Archiving

An important part of a good quality-assurance program is the archival of data collected. Hubbard (1992) stated that it is USGS policy that all original data that are published or that support published scientific analyses shall be placed in archives. Hubbard (1992) defined original data as unaltered data acquired from the sensor and converted to conventional (engineering) units in a form and format suitable for entry into the USGS National Water Information System (NWIS) (Bartholoma and others, 2003). Hubbard refers to "electronic archiving" and defines it as follows:

> *Electronic archiving–The systematic process of removing from the active, on-line data base original data and data that require minimum access, retaining it indefinitely, and providing the capability of reading it or returning it to the active data base.*

The information in this section primarily deals with electronic archiving. The USGS has not developed nationally consistent procedures for the permanent archival of electronic data, such as that collected using ADCPs, including the archival media nor archival methods. OSW, however, has prepared a technical memorandum providing guidance for electronic archival of discharge measurement data collected electronically (U.S. Geological Survey, 2005).

The USGS Water Resources Discipline (WRD) has issued a policy memo (U.S. Geological Survey, 1999), WATER RESOURCES DIVISION MEMORANDUM NO. 99.33, titled "Preservation of Original Digital Field-Recorded Time-Series Data". This memorandum states *"It is WRD policy that original hydrologic time-series data field-recorded in digital formats and used in automatic digital computation of hydrologic records be preserved indefinitely in electronic digital format"*. Plans are currently (2005) in progress for creating permanent and standardized archival mechanisms to be included in future versions of NWIS.

In addition to archiving all of the measurement data, discharge-measurement summary data for each measurement should be entered into the NWIS database. If a means of electronically transferring the data to the database is available, it should be utilized, otherwise, the data must be manually entered and checked.

Pre-field Office Procedures

Before going into the field, certain office procedures are recommended in order to avoid delays in the field and to ensure complete and accurate data collection. These pre-field office procedures include ensuring that ADCP software and firmware updates recommended by OSW have been installed or are being used, inspection and bench testing the ADCP, and assembling ancillary equipment for use with the ADCP.

Software and Firmware Procedures

Upgrades to both software and firmware associated with ADCPs are common. Many of these upgrades result in minor improvements to the software or firmware and do not substantively affect the quality of discharge measurements made with the instrument. Nevertheless, software and firmware changes can be major, and, therefore, appreciably affect discharge-measurement results. Therefore, ADCP users must ensure that the most recent OSW-approved software and firmware will be used for data collection and processing. The OSW tests firmware and software revisions for ADCPs before approving them for USGS use. Information regarding recommended software and firmware is usually made available by means of OSW Technical Memorandums, the USGS Acoustics Mailing List , and the OSW Hydroacoustics Web pages. Recommended ADCP firmware updates and software versions are available for download from the Hydroacoustics Web pages (*http://hydroacoustics.usgs.gov/*).

Before an ADCP is taken to the field, the most recent OSW-approved software should be installed on the primary and any backup field computers. A copy of the software also should be kept on a storage media separate from the field computers, such as a CD-ROM or memory card, in the event of damage or loss of the primary field computer.

Equipment Inspection and Testing

A pre-field inspection checklist is recommended to ensure that all procedures are followed and that all necessary equipment is available and functioning for the field trip. An example of a pre-field inspection checklist is shown in appendix A. The ADCP, cables, connectors, batteries, mounts, and DGPS or echo sounders that will be integrated with the ADCP in the field should be inspected for any irregularities. The ADCP should be connected to the field computer, and communications with the ADCP established using the ADCP data-collection software. If radio modems are to be used for communications (tethered and remote-controlled boat deployments), the communications should be established using the radio modems. If a DGPS or echo sounder will be connected to the ADCP in the field, then the DGPS and/or echo sounder should be connected with the ADCP to ensure that they properly function with the ADCP and the ADCP data-collection software. If problems are encountered during any system check, the problems should be resolved by: (1) consulting the necessary technical documentation, (2) calling an OSW staff member familiar with ADCPs, (3) calling the vendor technical support unit, or some combination of these three options.

Tethered and remote-controlled boat deployments, tethered and remote-controlled boat hulls, fins, structural members and compartments/hatches should be inspected. Remote-controlled boat deployments, motors, servos, and the radio controller should be inspected and tested before going into the field.

Assembling Ancillary Equipment

A toolkit should be assembled for the ADCP with tools and any spare parts that may be difficult to obtain in the field (such as fuses and special wrenches). The toolkit should always be kept with the ADCP. An adequate supply of the OSW-approved ADCP discharge-measurement notes should be taken to the field. The discharge-measurement form (9-275-I) can be ordered in the same way as other measurement and note forms, but is also available from OSW's Hydroacoustics Web pages. Computer data-storage media (such as flash-memory card or CD-ROM) with sufficient storage space for making temporary backup copies of all field data files also should be available. Other ancillary equipment used when making ADCP discharge measurements are listed in table 1. An example ADCP toolkit that includes some of this equipment is shown in figure 2.

If radio modems are utilized for ADCP communications, the cable for connecting directly to the ADCP should be taken to the field. Experience has shown that an ADCP connected through radio modems will occasionally not communicate with the field computer. This problem is often resolved by using a direct cable to establish communications and "reset" the ADCP for modem use. If a second pair of radio modems is available, they should be taken as a backup.

Any site-specific information, such as maximum water depths and velocities from previous measurements, can be used as a guide for developing configuration files for the measurement sites. Notes about measuring conditions and locations from previous ADCP discharge measurements should be reviewed prior to the field trip.

Field Procedures

ADCP field measurement procedures are documented in:

- Simpson (2002); this report describes ADCP boat deployments, instrument setup, site selection, and proper discharge-measurement techniques;
- OSW Technical Memorandum 2002.02 (U.S. Geological Survey, 2002b); this memorandum provides specific policy and technical guidance for making ADCP field measurements; and,
- The USGS class, *Measurement of Streamflow using ADCPs.*

Because ADCP measurement procedures are well documented in the above resources, a detailed discussion of all procedures will not be included here. Extensive review of ADCP data collected over the last 8 years, however, has revealed common and often reoccurring problems that result from incorrect procedures or not following guidelines and policies. Thus, certain aspects of ADCP measurement procedures will be summarized and emphasized in this section of the report.

Site Selection

It is important to select appropriate measurement cross sections for streamflow measurements. Many ADCP measurement problems can be solved by moving to a better measurement section. The guidelines provided in USGS Water-Supply Paper 2175 (Rantz and others, 1982, p. 139) should be followed when using an ADCP, except for those guidelines that relate to depth and velocity requirements for current-meter measurements. Rantz states:

"The first step in making a conventional current-meter measurement of discharge is to select a measurement cross-section of desirable qualities. If the stream cannot be waded, and high-water measurements are made from a bridge or cableway, the hydrographer has no choice with regard to selection of a measurement cross-section. If the stream can be waded, the hydrographer looks for a cross-section of channel with the following qualities:

1. Cross-section lies within a straight reach, and streamlines are parallel to each other.

Table 1. List of ancillary equipment to be included in acoustic Doppler current profiler (ADCP) toolkit for use with ADCPs when making streamflow measurements.

[USB, Universal Serial Bus]

Equipment	Function	Required or Optional
Laser rangefinder or other distance measurement tool	Measure shore distances	Required
Thermometer	Measure water and air temperatures	Required
Compact flash card / USB memory stick	Field backups of data	Required
ADCP field notes	Note keeping	Required
Vendor-supplied ADCP tools	Service / repair ADCP	Required
Salinity/Conductivity Meter	Measure salinity	Required[1]
Wind speed meter	Obtain estimate of wind speed	Optional
Hand-held radios	For use in tethered-boat measurements	Optional
Digital multimeter	Troubleshoot electronics	Required

[1]Required for ADCP measurements in estuaries and coastal streams.

2. Velocities are greater than 0.5 ft/s (0.15 m/s) and depths are greater than 0.5 ft (0.15 m).

3. Streambed is relatively uniform and free of numerous boulders and heavy aquatic growth.

4. Flow is relatively uniform and free of eddies, slack water, and excessive turbulence.

5. Measurement section is relatively close to the gaging-station control to avoid the effect of tributary inflow between the measurement section and control and to avoid the effect of storage between the measurement section and control during periods of rapidly changing stage.

It will often be impossible to meet all of the above criteria, and when that is the case, the hydrographer must exercise judgment in selecting the best of the sites available for making the discharge measurement. If the stream cannot be waded and the measurement must be made from a boat, the measurement section selected should have the attributes listed above, except for those listed in item 2 concerning depth and velocity."

General guidelines for selection of an ADCP measurement section are listed below.

- Desirable measurement sections are roughly parabolic, trapezoidal, or rectangular. Asymmetric channel geometries (for example, deep on one side and shallow on the other) should be avoided if possible (Simpson, 2002), as should cross sections with abrupt changes in channel-bottom slope. The streambed cross section should be as uniform as possible and free from debris and vegetation or plant growth.

- Measurement sections with velocities less than 0.30 ft/s should be avoided if it is possible to do so, and an alternative measurement location is available. Although measurements can be made in low velocities, boat speeds must be kept extremely slow (if possible, less than or equal to the average water velocity)

Figure 2. Example toolkit of ancillary equipment for use with acoustic Doppler current profilers (ADCPs) when making streamflow measurements. (Photograph by John M. Shelton, U.S. Geological Survey.)

requiring special techniques for boat control (Simpson, 2002).

- Depth at the measurement site should allow for the measurement of velocity in two or more depth cells at the start and stop points near the left and right edges of water.
- Sites with very turbulent flow, for example, evidenced by standing waves, large eddies, and non-uniform flow lines, should be avoided. This condition is often indicative of non-homogenous flow, a condition that violates one of the assumptions required for accurate ADCP velocity and discharge measurements.
- Measurement sections having local magnetic fields that are relatively large as compared to the Earth's magnetic field should be avoided. Large steel structures, such as overhead truss bridges, are a common source for these large local magnetic fields and may result in ADCP compass errors.
- When using DGPS, avoid locations where multi-path interference is possible (signals from the satellites bounce off structures and objects such as trees along the bank or nearby bridges or buildings) or where reception of signals from GPS satellites is blocked.

It may be possible to make valid measurements in sections that violate one or more of the above guidelines, but whenever possible, locate and use a better measurement section.

Instrument Deployments

Every measurement site has unique features that dictate the type of ADCP deployment platform. Site features may include hydraulic characteristics such as water depth and access considerations such as the presence of boat ramps, bridges, or cableways. The three types of ADCP deployment platforms are manned boats, tethered boats, and remote-controlled boats. This section provides recommendations for deployment platform mounts, waterproof enclosures, and radio-modem telemetry.

Manned Boats

ADCPs typically are mounted on either side of manned boats, off the bow, or in a well through the hull. The ideal mounting location for an ADCP is a well through the hull midway between the gunwales and approximately three-fifths of the distance from the bow to the stern. Boat and ADCP operators, however, are often reluctant to install a well in many of boats that are commonly used for river discharge measurements. Advantages and disadvantages for mounting locations on manned boats are listed in table 2.

The ADCP should not be mounted in close proximity to any object containing ferrous metal or sources of strong electromagnetic fields, such as portable generators, in order to minimize ADCP compass errors. A good rule of thumb is that an ADCP should not be mounted any closer to a steel object than the largest dimension of that object. This is a rule of

Table 2. Advantages and disadvantages of acoustic Doppler current profiler (ADCP) mounting locations on manned boats.

Mounting Location	Advantages	Disadvantages
Side of boat	Easy to deploy	Moderate chance of directional bias in measured discharges with some boats and flows
	Mounts are easy to construct and are adaptable to a variety of boats	Possibly closer to ferrous metal (engines) or other sources of electromagnetic fields (EMF)
	ADCP depth measurement can be easily obtained	Moderate-low risk of damage to ADCP from debris or obstructions in the water
		Susceptible to roll-induced bias in ADCP depths
Bow of boat	Minimizes chance of directional bias in measured discharges	Increased risk of damage to ADCP from debris or obstructions in the water
	Mounts relatively easy to construct	More difficult to measure ADCP depth
	Usually far from ferrous metal or electromagnetic fields	Less susceptible to pitch/roll-induced bias in ADCP depths, except at high speeds or during rough conditions (waves)
Well in center of boat	Protected from debris and obstructions	Often requires special modifications to boat
	Accurate depth measurements possible	
	Least susceptible to pitch/roll-induced bias in ADCP depths	

thumb, however, and there are large variations in the magnetic fields generated by different metals. Even stainless steel varies appreciably in the amount of ferrous material contained in the steel.

ADCP mounts for manned boats should:

1. Allow the ADCP transducers (fig. 1) to be positioned free and clear of the boat hull and mount;
2. Hold the ADCP in a fixed, vertical position so that the transducers are submerged at all times while minimizing air entrainment under the transducers;
3. Allow the user to adjust the ADCP depth easily;
4. Be rigid enough to withstand the force of water caused by the combined water and boat speed;
5. Be constructed of non-ferrous parts;
6. Be adjustable for boat pitch-and-roll; and,
7. Be equipped with a safety cable to hold the ADCP in the event of a mount failure.

Versatile ADCP mounting brackets are illustrated in figure 3, a side-mounted ADCP on an 18-ft long work boat, and in figure 4, a bow-mounted ADCP on 16-ft work boat. Additional photographs of ADCP mounts are available in Simpson (2002, p. 58-69) or on the USGS Hydroacoustics Web pages.

Tethered Boats

A tethered boat can be defined as a small boat (usually less than 5 ft long) attached to a rope, or tether, that can be deployed from a bridge, a fixed cableway, or a temporary bank-operated cableway. The tethered boat should be equipped with an ADCP mount that meets all of the specifications outlined in the previous section on manned boats. The tethered boat should also contain a waterproof enclosure capable of housing a power supply and wireless radio modem for data telemetry. A second wireless radio modem attached to the field computer enables communication between the ADCP and field computer without requiring a direct cable connection. The radio modems should reliably communicate with the ADCP using the ADCP data-acquisition software; have a rugged, environmental housing; operate on a 12-volt direct current (DC) power supply; and, have at least 38,400 baud data-communication capability to maximize ADCP data throughput (Rehmel and others, 2002). Rehmel and others (2002) describe the development of a prototype tethered platform, a project to refine the platform into a commercially available product, and tethered-platform measurement procedures.

Tethered ADCP boats have become a common deployment method (fig. 5). Certain considerations need to be made when making tethered ADCP boat measurements. Tethered boats are used in a variety of settings, but primarily from the downstream side of bridges for convenience. Bridge piers can cause excessive turbulence during high streamflow, especially if debris accumulations are present on the piers and the piers are skewed to the flow. The effect of bridge pier-induced turbulence may be reduced by lengthening the tether to increase the distance between the bridge and the tethered boat. Attention should be paid to the cross section to ensure that there are no large eddies that could cause flow to be non-homogeneous. Possible alternatives to measuring off the downstream side of bridges include bank-operated cableways or having personnel on each bank with a rope attached to the platform, pulling it back and forth across the river. Bank-operated cableways may be as simple as a temporary “rope and pulley” apparatus (fig. 6) or may involve the use of a small temporary cableway with a motorized drive for towing the tethered boat back and forth across the stream. Recently (2004), remote-controlled rovers have been developed for cableways. These rovers can be carried from one streamflow-gaging station to another and, once mounted on the cableway, can be used to winch up the tethered boat and drive the boat back and forth at a user-controlled speed.

When the water velocity is slow (usually less than 0.5 ft/s), it may become difficult to control the tethered boat. This lack of control may be exacerbated by wind, which may push the boat in an undesirable direction. Boat handling can be improved by attaching a floating sea anchor to the back side of the boat, to increase the effect of the current and its pull on the tether. Make sure that this anchor is far enough behind the boat so as to not disturb the flow and potentially bias the velocity measurements. An example of a sea anchor deployed on a tethered boat is shown in figure 7.

When the water velocity is fast (usually greater than 5 ft/s), it is not uncommon for a tethered boat to be pitched upward at the bow. This increased pitch is caused by increased vertical tension on the tether in faster flows, hull dynamics, and an incorrect setting of the angle for the bail, for those boats equipped with a rigid bail. The bail connects the tether to the boat and can be either a rigid design or a more flexible rope bail. Large pitch angles may introduce some bias in depth measurements and should be minimized as much as possible. Experience in handling tethered boats has shown that adding a sounding weight on the tether near the location where it is tied to the boat (see fig. 5) will help decrease the pitch angle. In addition, increasing the length of the tether helps reduce the pitch angle.

The tether line should be visible from the water surface to minimize the risk of collision with river traffic. Orange plastic flags tied along the tether will enhance its visibility. The operator should also be capable of releasing the tether quickly in case the boat becomes entangled in debris or collides with river traffic. Do not wind the tether around the hand to hold the boat as this action is a safety hazard. Standard safety practices, site-specific traffic safety plans, and the local highway traffic regulations should be followed.

For tethered and remote-controlled boats, it is possible to lose control of the boat because of a system component failure. For example, a boat tether or tether attachment point could break. It is recommended that ADCP operators using tethered- and remote-controlled boat deployments have a contingency plan for retrieving the boat in the event of a failure that causes a loss of boat control. An example of a contingency plan would be to carry a small manned boat that could be quickly and safely launched to retrieve the tethered or remote-controlled boat.

Remote-Controlled Boats

Unmanned, remote-controlled ADCP boats allow the deployment of ADCPs where deployment with either a manned boat or tethered boat may not be feasible or ideal. Similar to (but smaller than) manned boats, a remote-controlled boat has self-contained motors and a remote-control system for maneuvering the boat across the river. Unlike the tethered boat, the remote-controlled boat has no rope

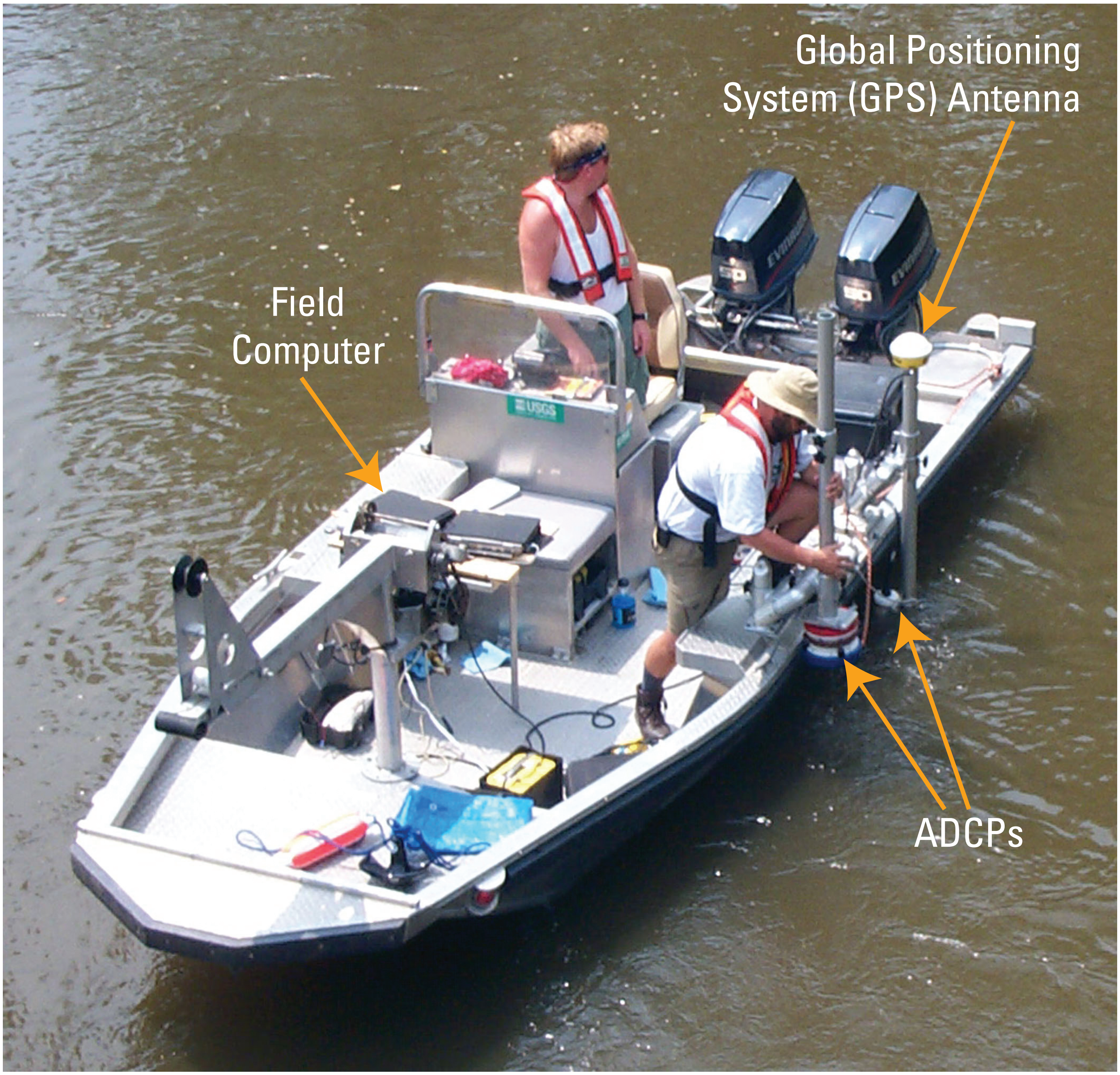


Figure 3. Side-mounted acoustic Doppler current profiler (ADCP) mounting brackets on U.S. Geological Survey work boat. (Photograph by Michael S. Rehmel, U.S. Geological Survey.)

Figure 4. Bow-mounted acoustic Doppler current profiler (ADCP) mounting brackets and ADCP on U.S. Geological Survey work boat. (Photograph by Paul Baker, U.S. Geological Survey.)

(tether) restraints. Although remote-controlled boats have an increased risk of equipment loss because of potential loss of boat control, they provide the ability to launch a boat without a boat ramp and to collect data away from bridge effects (for example, upstream of a bridge) or at sites where no bridge or cableway is present.

A remote-controlled boat ADCP mount should meet all mount specifications listed for manned boats. The remote-controlled boat also should contain a waterproof enclosure capable of housing a power supply, a radio modem, and the control radio. Radio modems are used for data telemetry between the remote-controlled boat and field computer; the radio modems should have the capabilities described for tethered boat deployments.

The same operational guidelines regarding speed and maneuvering for manned boats also apply to remote-controlled boats. Proper control of a remote-controlled boat requires practice. The operator should be familiar with remote-controlled boat operation prior to using this deployment technique in high flows. Regular maintenance of the boat and control radios is critical to ensure reliable operation.

Pre-Measurement Field Procedures

The following sections describe the field procedures for use prior to ADCP measurements. These procedures include instrument diagnostic checks and configuration, and moving-bed tests.

Instrument Diagnostic Checks

After the ADCP is mounted and communication between the ADCP and field computer is established, the instrument must be checked to ensure all components are operating properly. Instrument diagnostic tests should be performed and the results electronically stored on the field computer. Diagnostic tests should include system information (includes information such as system firmware and hardware configuration), the beam transformation matrix, electronics diagnostic tests, internal system tests, and sensor verification tests. Software for executing diagnostic tests for some ADCPs is available on the USGS Hydroacoustics Web pages. If software or diagnostic test information is not available for a specific instrument, the user should contact the manufacturer for guidance. The results of diagnostic tests should be backed up in the field and archived in the office with the associated discharge-measurement files. The file names of the test files should be documented on the ADCP discharge-measurement note form (appendix A). It is recommended that complete diagnostic tests be made prior to every discharge measurement. It is usually prudent to conduct the test from a stationary boat in relatively still water, for example, near the shore. Some of the tests conducted require little or no water motion relative to the ADCP.

ADCPs have built-in temperature sensors to measure water temperature at the transducer face. The ADCP must compute the speed of sound correctly to accurately measure velocities, depths, and compute discharge. Temperature is

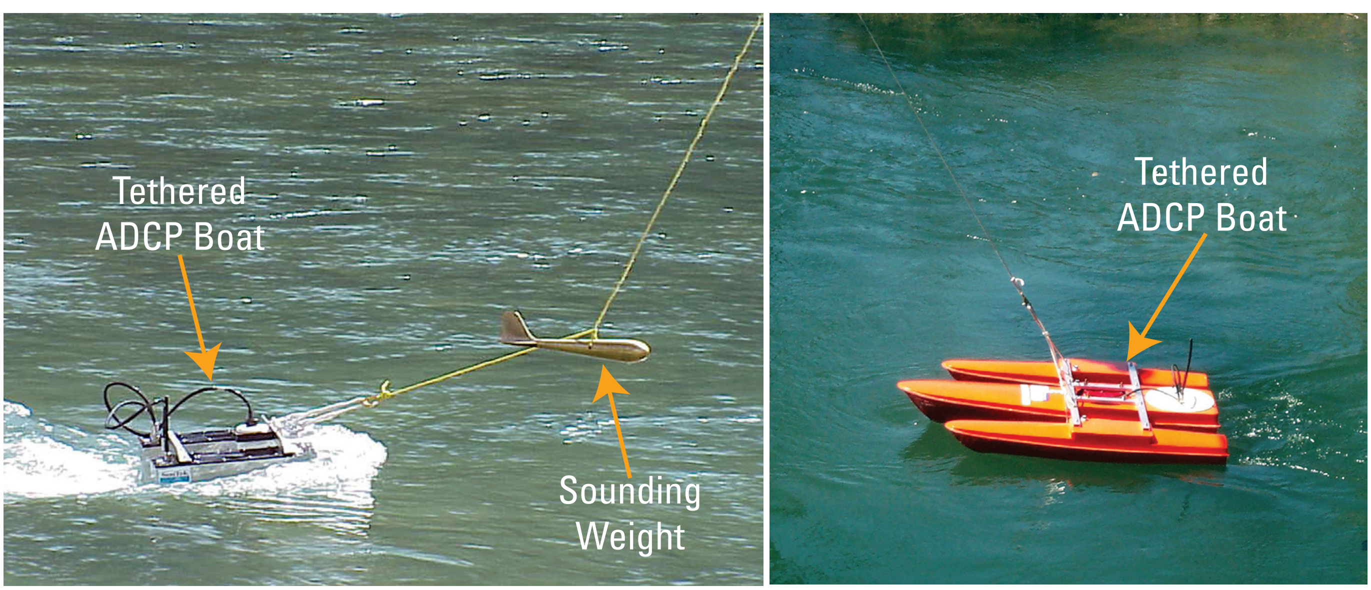


Figure 5. Examples of tethered acoustic Doppler current profiler (ADCP) boats used for making discharge measurements. (Left photograph by Jeff Woodward, Environment Canada and right photograph by Geoffrey D. Cartano, U.S. Geological Survey.)

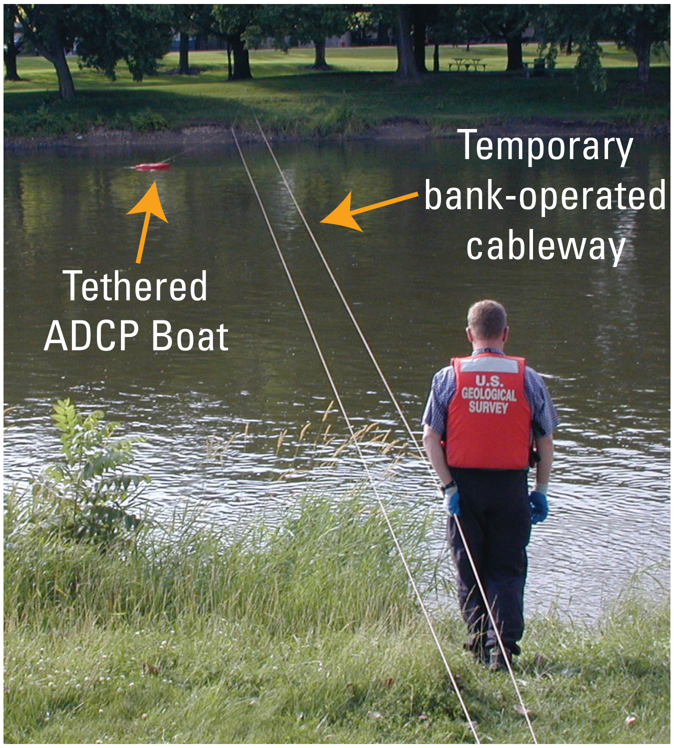


Figure 6. A temporary bank-operated cableway for making acoustic Doppler current profiler (ADCP) measurements with a tethered ADCP boat. (Photograph by Brian L. Loving, U.S. Geological Survey.)

the most important term in the equation used to compute the speed of sound (Urick, 1983, p. 113). An error of 5° C in the temperature measurement will cause a 2-percent bias error in the measured discharge. Thus, the temperature measured by the ADCP should be compared with an independent temperature measurement made adjacent to the ADCP. This check should be performed prior to every discharge measurement and the results recorded on the measurement note sheet. If the temperature measured by the ADCP temperature sensor differs consistently from the independent temperature measurement by 2° C or more, or if the ADCP temperature sensor has failed, the ADCP should not be used to make discharge measurements until the temperature sensor is repaired and checked. In the event that a discharge measurement is necessary and another ADCP is not readily available, it may be possible to enter a temperature manually for use in the speed of sound calculations. This action is not recommended as standard practice, however, and it may decrease the accuracy of the discharge measurement.

Salinity is another important term in the speed of sound equation. Salinity values generally range from 0 parts per thousand (ppt) for freshwater to 35 ppt for water from the open ocean. When measuring in waters where the salinity is greater than zero, such as in estuaries, the salinity should be measured near the transducer face and recorded on the field note sheet. It should be noted that the salinity value used for the transect should reflect an average salinity for the section to be measured at the approximate depth of the ADCP transducers. The salinity value may then be entered into the ADCP data-collection software prior to data collection and adjusted as necessary during playback and processing. Salinity should be measured for every transect in locations where salinity varies over time. Salinity may also vary from bank to bank.

Prior to the start of the discharge measurement, the clock internal to the ADCP should be checked, set to the correct time, and noted on the ADCP measurement note sheet. In most cases, the ADCP clock should be set to agree with the recorder time at the streamflow-gaging station. Checking and setting the correct time is of particular importance when using the discharge measurements to calibrate or check the calibration of fixed acoustic current meters installed at streamflow-gaging stations, or when measuring at sites where the flow is unsteady.

Calibrating the internal magnetic compass is encouraged for all ADCP measurements, but

Figure 7. Tethered acoustic Doppler current profiler boat with a sea anchor attached (from Environment Canada, 2004). (Photograph by Clare Bowden, Environment Canada).

is mandatory when using DGPS. The instrument-specific procedures for calibrating the compass of the ADCP being used should be followed. The USGS has written a small program for some ADCPs that steps the user through the compass calibration process. This program, known as CompCal, is available on the USGS Hydroacoustics Web pages. The following guidelines should be followed for successful compass calibrations:

1. No ferrous material should be located in the vicinity of the ADCP. Ferrous material may adversely affect the performance of the internal magnetic compass.

2. If the instrument reports a total compass error, this error should be should be less than 1 degree when evaluated after calibration. If the error exceeds 1 degree, the calibration procedure should be repeated. If after several attempts, the total compass error cannot be reduced to less than 1 degree, the compass error should be noted on the field sheet. The discharge measurement can then be made, but special attention should be paid to potential compass errors (for example, directional bias and irregular ship track). If the instrument does not report a numerical error, the instrument should report an “excellent” rating for the horizontal calibration parameter.

3. Pitch-and-roll changes must be minimized with certain ADCPs equipped only for a single-tilt calibration process. In such situations, the standard deviation of the pitch-and-roll should be less than 1 degree, and, ideally, 0.5 degree or less, during the calibration and evaluation process. For other ADCPs, pitching and rolling the instrument is encouraged during the calibration, but only the rating of the horizontal calibration is of major concern.

4. For best results, maximum rotation velocity should be 5 degrees per second or less.

Instrument Configuration

The ADCP must be configured by a trained user, reflecting the hydrologic conditions at the site, to optimize the data quality (Lipscomb, 1995). ADCP configuration parameters that must be set include the blanking distance, water mode (if applicable), depth cell (bin) size, and profiling range. Configuration parameters are specific to the kind of ADCP being used (narrowband or broadband) and the manufacturer and model; thus, detailed descriptions of configuration parameters for all situations are beyond the scope of this report. Twelve general recommendations for configuration parameters are given below.

1. The depth of the ADCP (vertical distance from the water surface to the center of the transducer faces) must be measured accurately, recorded in the ADCP discharge-measurement notes, and entered into the configuration file. Schematics with dimensions of commonly used ADCPs are shown in appendix B. The pitch-and-roll of the boat when the depth is measured should be similar to the pitch-and-roll during the discharge measurement. If the depth of the ADCP changes during the measurement, the depth must be re-measured, noted, and the configuration file modified with the new depth. For example, when measuring fast flows or a river where there is appreciable wave action, the ADCP depth may be increased after the first transect or two in order to prevent the ADCP from coming out of the water.

2. The user will need to know the maximum water depth of the measurement section so the proper number of bins is used to reach the bottom.

3. Most ADCP data-collection software contains an automated method to configure the ADCP. The automated methods are dependent upon user-supplied information about site characteristics, such as maximum water depth, bed-material characteristics, and expected maximum water and boat speeds. Where these methods are available in ADCP data-collection software, it should be used to configure the ADCP for discharge measurements (U.S. Geological Survey, 2003). The commands generated by this software utility, however, should be checked prior to the start of the measurement.

4. For manual configuration of an ADCP, the most up-to-date OSW guidelines for the instrument should be used. If guidelines are not available, the user should use manufacturer recommendations for the unit. It is advisable, however, to seek advice from OSW.

5. Whenever possible, the ADCP should be configured to collect single-ping water data. Collection of single-ping data allows possible data-quality problems to be more easily identified than multi-ping data. Collection of single-ping data is not possible for all ADCPs, but even for such profilers, smaller averaging intervals are generally desirable.

6. All configuration files associated with a discharge measurement must be backed up in the field and later archived along with all other electronic files associated with the measurement.

7. The ADCP operator should verify that the salinity to be used for the measurement is correct. A default salinity value of zero is used with some ADCP data-collection software, whereas in other software, the default salinity value is set to 35 ppt, the average salinity for water in the open ocean.

8. The extrapolation method for the top and bottom unmeasured zones must be specified. Often, the appropriate extrapolation method cannot be determined until

after the measurement, during post-processing. Experience with previous data collected at a site may be used to guide the selection of the extrapolation method. In the absence of any other information, the one-sixth (0.1667 power coefficient) power-law extrapolation method is a good assumption for most steady-flow sites. The extrapolation methods should be evaluated and, if necessary, changed during post-processing.

9. File names for the data files collected (also called deployment names) should follow a uniform, documented convention developed by each office involved in ADCP operation. Examples of documented conventions are given in OSW Technical Memorandum 2005.08 on archival of electronic discharge-measurement data (U.S. Geological Survey, 2005).

10. The ADCP measurement note sheet contains fields for describing ADCP configuration commands. These fields should be completed prior to data collection in order for the user to review the configuration file setup and make any necessary changes.

11. Any changes made to the ADCP configuration during a measurement must be documented on the measurement note sheets, so it is clear that changes were made and the transects to which these changes apply.

12. A trial transect should be made across the river for sites where few or no previous ADCP discharge measurements have been made. Information gleaned from the trial transect should be recorded on the discharge-measurement notes. A trial transect is useful for determining characteristics of the proposed measurement section such as:

    - Maximum water depth and the overall cross-section shape,
    - Maximum water velocity and its location in the cross section,
    - Flow uniformity and the effects that hydraulic structures, such as bridges, piers, islands, may have on the flow,
    - Unusual flow conditions such as reverse or bi-directional flow,
    - Bank shapes, and,
    - Start-and-stop locations on the left and right banks, where a minimum of two depth cells with valid velocity measurements can be measured. It is recommended that buoys for marking these start and stop points be used in order to aid in obtaining consistent edge estimates.

Moving-Bed Tests

ADCPs can measure the boat velocity using a technique called bottom tracking, which computes the Doppler shift of acoustic pulses reflected from the streambed. This technique assumes that the streambed is stationary; however, sediment transport on or near the streambed can affect the Doppler shift of the bottom-tracking pulses. In such situations, reflections of bottom-tracking pulses from highly concentrated near-bed sediments are difficult to distinguish from reflections from the bed. These near-bed sediments are typically being transported in the downstream direction. If bottom tracking is affected by sediment transport, the measured boat velocity will be biased in the opposite direction of the sediment movement. A stationary boat in the stream would appear to be moving upstream (fig. 8). This bias in the boat velocity will result in measured water velocities and discharges that are negatively biased (measured velocities and discharge are less than the true velocities and discharge).

OSW policy (U.S. Geological Survey Office of Surface Water Technical Memorandum No. 2002.02 (U.S. Geological Survey, 2002b) requires that a moving-bed test be made prior to making any discharge measurement. At least one transverse location within the measuring section of the river should be identified where the potential for bed movement is greatest. Although the location of maximum potential bed movement cannot easily be predicted, it commonly occurs in the region of maximum water velocity. Moving-bed conditions may be measured even in streams where the bed is stationary. Sediments being transported near the bed may affect the bottom-tracking pulses.

It may not be necessary to do a moving-bed test for every discharge measurement, if water velocities are low (less than 1 ft/s) throughout the range of discharges expected or the site typically has a moving bed and DGPS is regularly used to make the discharge measurement. Users can demonstrate that moving-bed tests are not necessary on a site-by-site basis, however, users must demonstrate this by documenting moving-bed tests for the range of expected flows at the site. After a low-velocity measurement site has been documented as not having a moving bed, periodic moving-bed tests must still be made during medium and high flows or when an instrument with a higher acoustic frequency is used. After documenting that a site routinely has moving-bed problems (from low to high flow), periodic moving-bed tests should be made at low flows to verify that DGPS is still needed because bottom-track measurements are typically less prone to errors. Sediment transport characteristics can vary greatly for the same discharge, depending on the hydrograph shape, source of runoff, and season of the year. These variations can cause a moving bed to be detected at locations and discharges where it was not previously detected or a moving-bed condition may no longer exist at locations and discharges where it was previously measured.

There are two acceptable methods for performing a moving-bed test. The first method requires that the boat with the

ADCP be held in a stationary position while recording ADCP data for 10 minutes, using bottom track as the boat-velocity reference. When a moving-bed condition is present, a stationary boat will appear to have moved upstream (fig. 8). The error caused by the moving bed can be estimated by dividing the distance of the apparent boat motion in the upstream direction by the duration of the test in seconds. This computation will provide an estimate of the moving bed detected by the bottom-tracking technique. This moving-bed velocity can then be divided by the average water velocity and the moving-bed velocity, and multiplied by 100 to yield the percent bias error for a water-velocity measurement at this stream location. In the example shown in figure 8, the distance traveled was approximately 80 ft over a 10-minute (600 seconds) period. The estimated moving-bed velocity is 0.13 ft/s. If the mean velocity for the discharge measurement was 5.0 ft/s, the percent bias error in the water-velocity measurement would be estimated to be 2.6 percent.

When it is not possible to safely anchor in the stream because of boat traffic, drift, or other hazardous conditions, it is often difficult to hold the boat stationary at the desired location in the measurement section. Boat movement in the upstream or downstream direction will introduce errors in the moving-bed test when using this first method. A technique for helping the boat operator determine whether the boat is moving excessively in the upstream or downstream direction during a moving-bed test is illustrated in figure 9. The boat operator selects two distinguishable reference points on shore that are separated by a considerable distance from one another (100 ft or more). Examples of distinguishable reference points include telephone or power poles or large trees that can be easily distinguished from other nearby trees. Bridges, bridge piers, and navigation buoys also can be used as reference points when making a moving-bed test as aids for maintaining an approximately stationary position. If it is determined that the boat changed position appreciably in the upstream or downstream direction, this change should be noted on the field note sheet.

A more accurate method for estimating the errors introduced by a moving bed can be determined if a DGPS

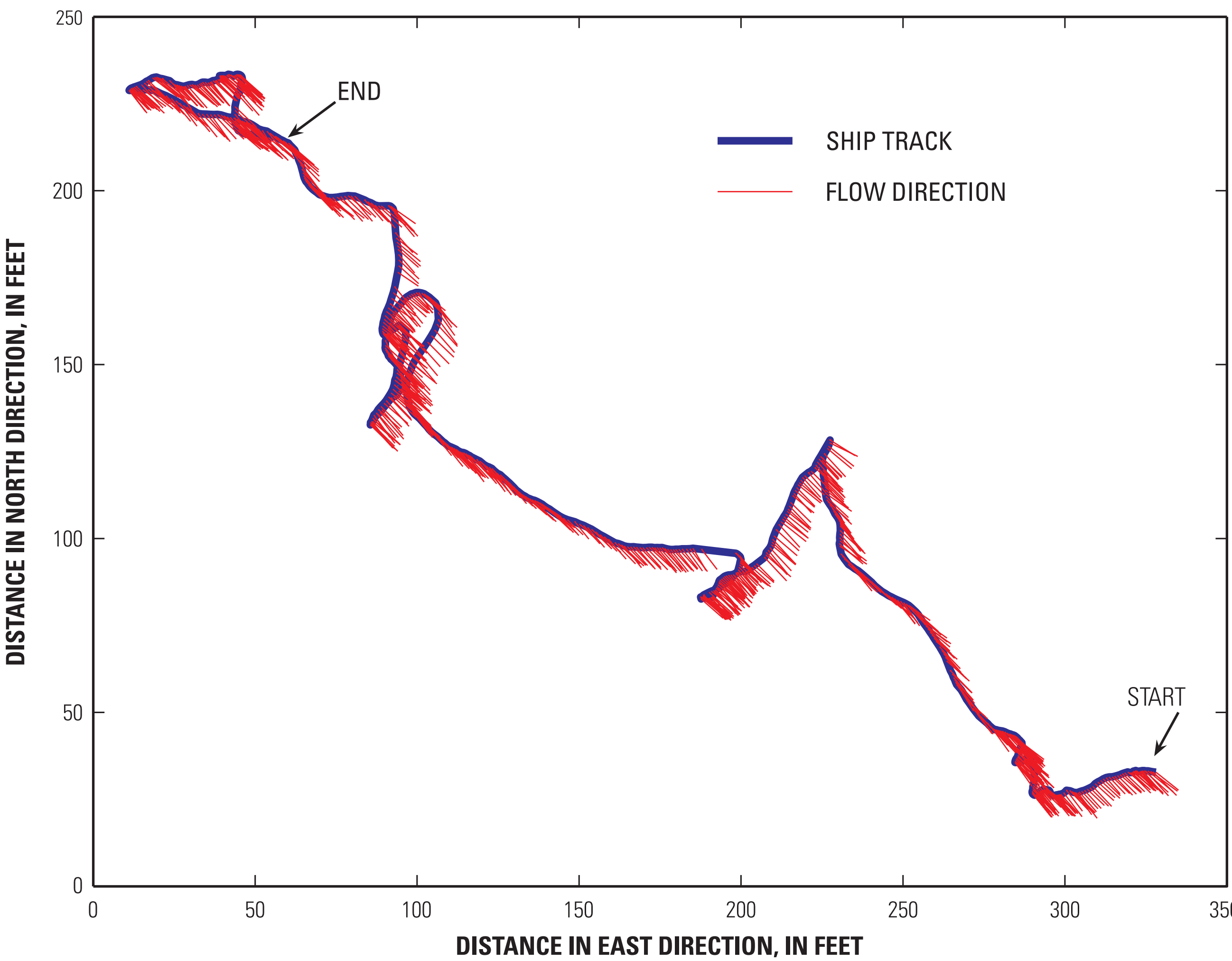


Figure 8. Example of a moving bed measured with a 1,200-kilohertz acoustic Doppler current profiler on the Mississippi River at Chester, Illinois.

is available for use and is interfaced with the ADCP and the data-collection software. This second method also requires that the ADCP boat be held in a stationary position and a data file recorded for at least 10 minutes. Either bottom tracking or DGPS can be used for the boat-velocity reference. It is often easier during data collection to use DGPS as the reference so that the boat operator can use the ship track display as a means to assist in holding the boat in an approximately stationary position. After the moving-bed test is complete, compare the boat track using ADCP bottom track as reference with the boat track using DGPS as the reference. If the bottom-track boat velocity data indicate apparent upstream movement that the DGPS data do not indicate, a moving bed is present. The error caused by the moving bed can be computed in the same manner as described above in the first method, except that the distance in the upstream direction indicated by bottom tracking should be corrected by the distance actually traveled in that direction, as indicated by DGPS.

If a moving bed is observed, a DGPS that provides a NMEA-0183 output (National Marine Electronics Association, 2002) should be used instead of bottom tracking to compute boat velocity. The DGPS unit must be capable of horizontal position accuracies of 3 ft or less. If a DGPS unit is used, the internal ADCP compass must be calibrated, and an accurate estimate of local magnetic variation must be obtained and used to process the discharge measurement. ADCP operators that use or anticipate using DGPS for ADCP measurements are encouraged to attend the OSW class *Advanced ADCP Applications.*

Streams with high sediment concentrations of fines and sand being transported on or near the streambed also may cause inaccuracies in ADCP water-depth measurements, and, therefore, an inaccurate discharge. It may be necessary in such conditions to use a depth sounder to measure the water depth. The bed-load transport rate or sediment concentration that makes necessary the use of a depth sounder have not been quantified; future guidance on this topic will be provided by OSW as experience is gained. If a depth sounder is used, it is important that the depth sounder be properly calibrated as part of the pre-measurement field procedures. For proper calibration techniques, the user is referred to the bar check procedures in the U.S. Army Corps of Engineers, Engineering Design Manual on hydrographic surveying (U.S. Army Corps of Engineers, 2002).

If the moving-bed velocity exceeds 2 percent of the mean velocity for the discharge measurement, DGPS should be used. However, if the moving-bed test was made using a tethered boat, a manned boat that was anchored in the stream, or if the boat operator was able to keep the boat accurately on station throughout the moving-bed test, DGPS should be

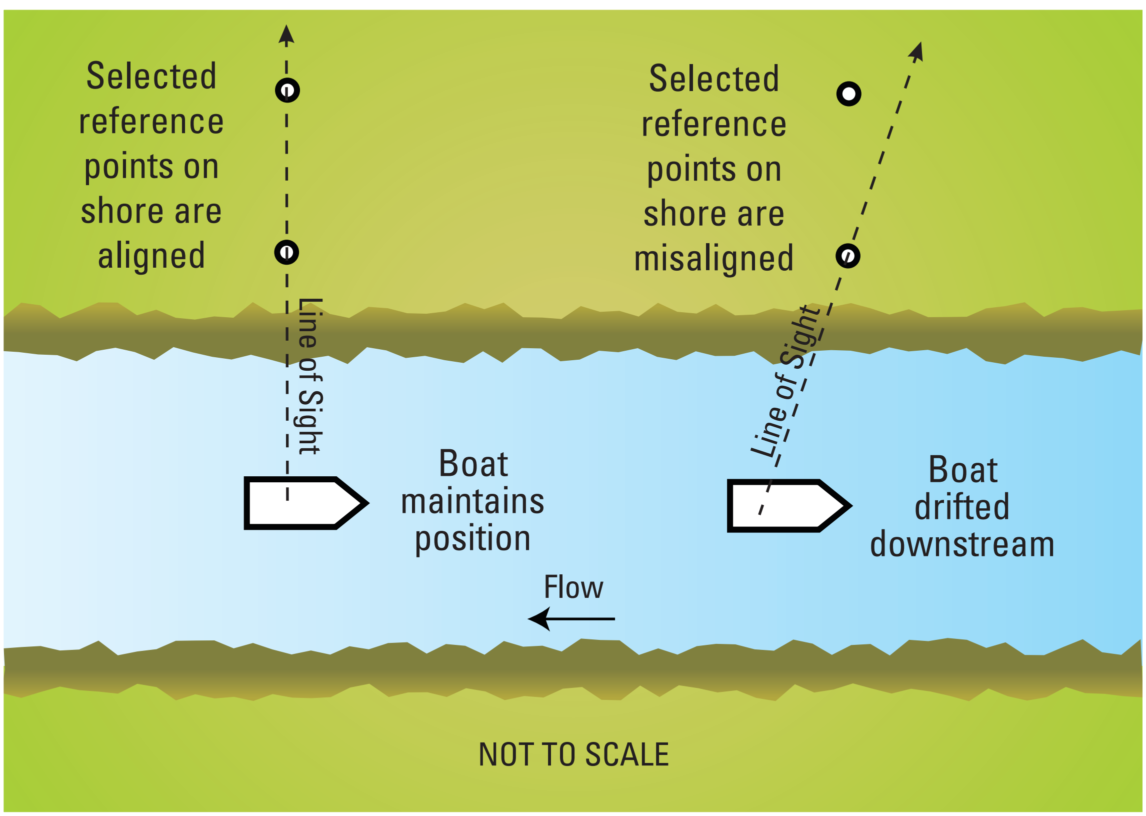


Figure 9. Method for verifying that upstream/downstream boat movement is minimized during an acoustic Doppler current profiler moving-bed test. (Modified from Environment Canada, 2004).

used when the moving-bed velocity exceeds 1 percent of the mean velocity for the discharge measurement. If a moving-bed condition is present and a DGPS is unavailable and alternate measurement methods (such as mechanical current meter) are not practical, multiple moving-bed tests at different locations across the measurement section can be made prior to making the ADCP measurement. Estimates of water-velocity bias from the moving-bed tests should be applied using a mid-section technique to correct the discharge in each subsection represented by the moving-bed test. If this correction is attempted, it should be accurately documented. The quality of discharge measurements made with a known moving bed should be carefully evaluated and downgraded if the moving-bed correction technique or lack thereof introduces sufficient potential error.

The OSW is developing additional methods for correcting discharges measured in the presence of moving beds. When development is completed, these methods will be made available by means of technical memorandums and other publications.

Discharge-Measurement Procedures

For discharge measurement, a minimum of four transects (two in each direction) will be made under steady-flow conditions unless site and flow conditions make this requirement unpractical. The measured discharge will be the average of the discharges from the four transects. If the discharge for any of the four transects differs by more than 5-percent from the measured discharge, and there is no critical data-quality problem that can be identified and documented, a minimum of four additional transects will be obtained and the average of all eight transects will be the measured discharge. In the past when using DGPS, it was considered acceptable to average reciprocal transects and then compare the average to the average of all four passes when applying the 5-percent rule; however, experience has shown that properly configured DGPS-based measurements should be able to meet the same criteria as bottom-track-based measurements and no further distinction should be made. If the discharge for one or more transects is not within 5 percent of the average and there is a critical data-quality problem that can be identified and documented (a tow boat approaching the section, a sudden change in discharge because of a lockage, appreciable data lost because of computer problems, and other factors), the transect deviating from the mean may be replaced with an additional transect. Reciprocal transects should be always made to reduce potential directional biases. Directional biases occur when the discharges measured for transects from the left bank to the right bank are consistently either greater than or less than discharges measured for transects made from the right bank to the left bank.

Measurements of rapidly changing flows (sometimes referred to as unsteady flows) present special considerations. Unsteady flows can be caused by upstream dam or lock regulation, tidal effects, downstream backwater effects, flood waves, or other conditions. It may be necessary to use individual transects as discrete measurements of discharge if the flow is changing rapidly. If possible, however, pairs of reciprocal transects should be averaged together as one measurement of discharge to reduce the potential of directional bias. The justification for using a single transect or pairs of transects for discharge measurements should be documented and stored with the discharge measurement or applicable station analysis files. Another consideration for unsteady flows, specifically bi-directional flows, is the assignment of a positive or negative sign to the discharge measurement. The ADCP software may or may not assign flow direction correctly and the sign also can depend on which edge is designated “left” or “right;” thus, the operator should note the direction of flow during each transect, according to accepted convention for a particular site.

When making ADCP discharge measurements, the ADCP operator should continuously monitor the data. If a critical data-quality problem is observed during a transect, the transect may be terminated. Potential critical data-quality problems can include:

a) Use of an operating mode inappropriate for the site;

b) Configuration errors such as an insufficient number of depth cells to profile to the channel bed;

c) Appreciable area with invalid or missing data;

d) Unusual boat or water velocities, such as ambiguity errors (See Simpson, 2002, p. 19-21 for explanation of ambiguity errors);

e) Excessive boat speed; and,

f) Inadvertent early termination of the transect.

If a transect is terminated, the reason should be documented on the ADCP discharge-measurement note sheets. The discharge from the transect should not be used in the computation of measurement discharge. If the problem was related to undesirable measurement section characteristics, a new measurement section should be located and noted on the measurement note sheets. If the terminated transect was not the first transect in a measurement series, the boat should be returned to the side the terminated transect was started from and a new transect should be started. Therefore, the transects are run in reciprocal pairs.

Average boat speed for each transect normally should be less than or equal to the average water speed. At some sites, it may be necessary to move the boat across the channel using a non-ferrous tag line in order to meet this requirement. Other methods for moving the boat slow enough to be equal to or less than the water speed include the use of push poles, paddles, low-speed trolling motors, or tethered boats (a tethered boat deployed from a hand-operated cableway or bridge can be moved slowly across the channel). In certain conditions, it may not be possible to keep the boat speed less than the water speed. If it is not practical or safe to keep the boat speed less than or equal to the average water speed, additional transects may need to be made or the measurement quality may need to be downgraded. The reason for maintaining a boat speed that is higher than the average water speed should be documented on the ADCP measurement note sheets. When using DGPS, it is especially important to keep the boat speed as low as practical because errors in the compass readings are additive and increase with boat speed. Rapid boat course changes should be avoided whether bottom track or DGPS is used for boat velocity; the key element in boat operation during the measurement is to do everything slowly and smoothly. Simpson (2002) discusses proper boat operation for ADCP measurements in detail. His remarks on boat operation should be heeded (Simpson, 2002, p. 122). He said *"Be a smooth operator! The BB-ADCP discharge-measurement system will give more consistent results if rapid movements and course changes are kept to a minimum. Smooth boat motion is more important than a straight-line course."*

Because ADCPs cannot measure near the channel edges, it is necessary to estimate discharge in the near-shore unmeasured zones using the ADCP discharge-measurement software. In order to ensure the accuracy of near-shore discharge estimates, the distances from the edge of water to the starting and stopping point of each transect must be measured using a distance-measurement device (such as a laser or optical rangefinder), tagline, or some other accurate measurement device. The calibration of distance-measurement devices should be checked periodically by measuring the distance to targets at a known distance; the results of these tests should be recorded in an office log. Various types of laser and optical rangefinders, accuracy and limitations, and test results can be found on the OSW Hydroacoustics Web pages. Placing marker buoys at the start and end points of transects is recommended where possible. Use of marker buoys enhances the data collection by ensuring more consistent edge estimates and by measuring in approximately the same section for all passes. When measuring in channels with vertical walls at the edges, start and stop points for transects should be no closer to the wall than the depth of water at the wall to prevent acoustic interference from the main beam or side lobes impinging on the wall. For example, if the depth at a vertical wall is 10 ft, transects should start/stop at least 10 ft away from the wall. In order to obtain an accurate velocity for estimating the discharge in the near-shore zones, the boat should be held nearly stationary from 5 to 10 seconds at the beginning and end of each transect. Accurate edge discharge estimates also require the ADCP operator to select the correct edge-shape coefficient for the type of edge (sloping or vertical). The edge shapes should be recorded on the ADCP discharge-measurement notes.

When using a tethered boat, special methods are required to measure edge distances. Distance marks on the bridge handrail or guardrail may be used to measure edge distances (fig. 10). If the tethered boat is too far away from the bridge to accurately use distance marks for measuring edge distances, laser rangefinders having a compass and inclinometer and a "missing line mode" capability may be used. Missing line mode calculates a horizontal distance between two points, given a range, heading, and vertical angle measured for each point. Edge distance may be measured by selecting the shore and the transect start or end point while using this mode (Rehmel and others, 2002).

When using a remote-controlled boat at some sites, edge distances may be measured using the same techniques as with tethered boats. At other sites where edge distances cannot be measured using these techniques, it may be necessary to have someone in line with the measurement section to measure the distance from the near-shore edge of water to the starting point and the distance from the ending point to the edge of water on the far shore.

All information on the ADCP measurement note sheets must be filled out in the course of the measurement, either prior to, during, or immediately after the measurement. The ADCP operator should note any conditions that potentially could affect the measurement, including estimated wind speed and direction, bi-directional or unusual flow patterns, excessive waves, or passing boats. Use of an ADCP does not negate long-standing, USGS guidelines and policies regarding measurement documentation, such as recording reference gage heights before, after, and, if needed, during the discharge measurement. An example of a completed ADCP discharge-measurement note sheet is shown in figure 11.

Post-Measurement Field Procedures

An assessment of the discharge measurement should be made after completion of the transects composing the measurement. A thorough review of all measurement data often is not practical in the field, but a cursory review of the measurement should be made in order to assign a preliminary quality rating to the measurement and to make certain that there are no critical data-quality problems with specific transects. If all transects were collected at the same measurement section, the transect widths and discharges in the measured (middle) and unmeasured (top, bottom, and edge) sections should be consistent. If transect widths or discharges are not consistent with the other transects, the transect data should be scrutinized to determine if a critical data-quality problem occurred (examples of critical data-quality problems are listed in the Discharge-Measurement Procedures section).

If a critical data-quality problem is identified, the data from that transect should not be used in the computation of discharge. A new transect should be collected, starting from the same side as the discarded transect, if flow conditions have remained steady. If the flow has changed, a new transect series should be collected (a minimum of four transects if the flow is stable when the new transects are collected). It is emphasized that a transect should be discarded only if a critical data-quality problem is identified and documented on the field note sheet.

The measured discharge should be plotted on the rating curve for that streamflow-gaging station and the percent difference from the stage-discharge rating computed. Rantz and others (1982, p. 346) state *"If the discharge measurement does not check a defined segment of the rating curve by 5 percent or less, or if the discharge measurement does not check the trend of departures shown by recent measurements, the hydrographer is normally expected to make a second discharge measurement to check his original measurement."* Rantz (1982, p. 346-7) then describes procedures for making check discharge measurements with mechanical current meters. For ADCPs, the following steps should be followed when making a check measurement.

1. Start as if making a completely new discharge measurement.
2. Turn the ADCP off and then power it back on.
3. Re-measure the ADCP depth.
4. Perform a diagnostic test.
5. Calibrate the compass and evaluate the compass.
6. Re-run the software for configuring the ADCP.

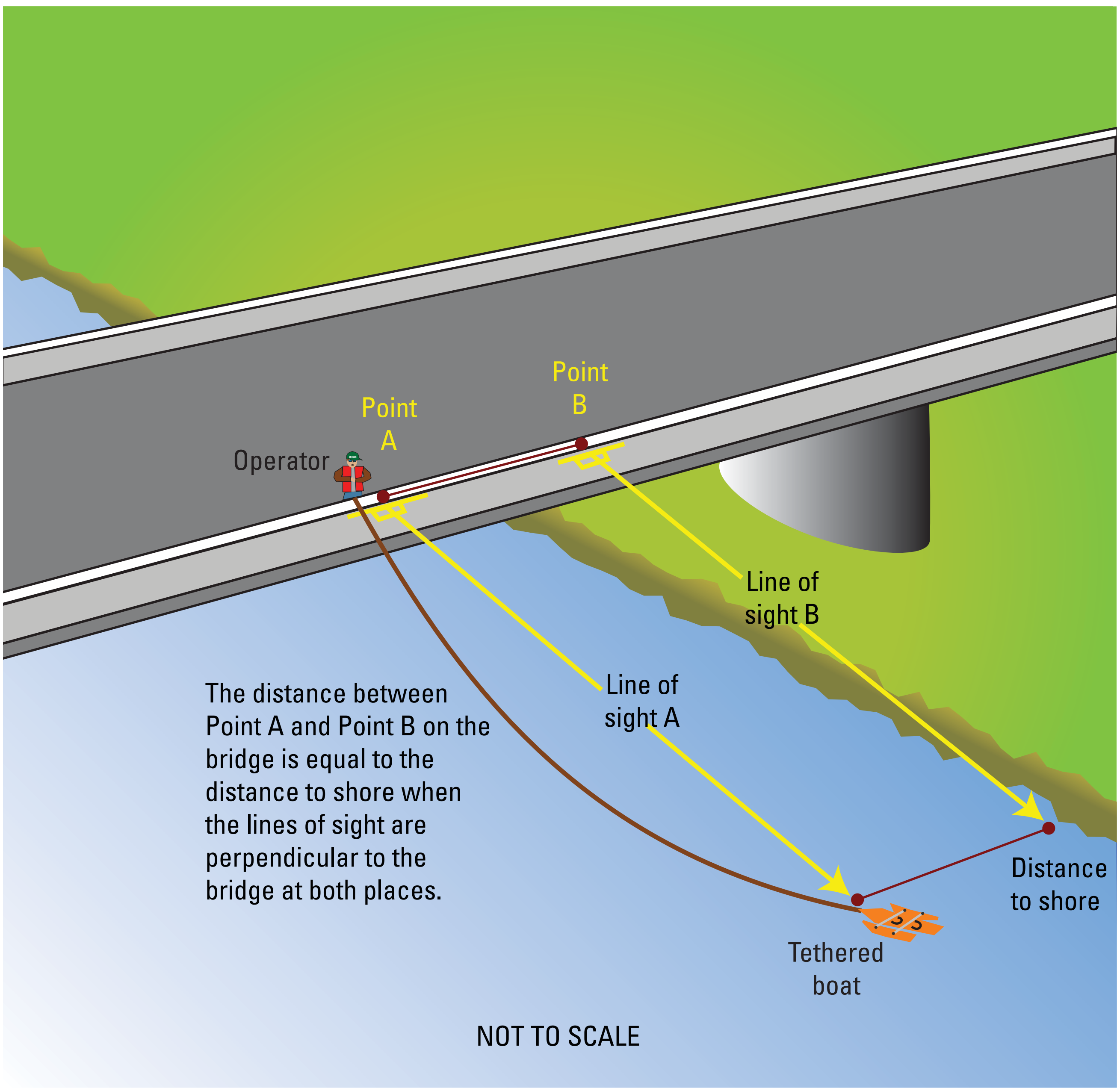


Figure 10. Measuring edge distances when using a tethered acoustic Doppler current profiler boat for discharge measurements (modified from Environment Canada, 2004).

7. If available, and conditions permit, consider making the measurement using a different mode and/or in a different cross-section location.

8. Adhere to the following steps of the discharge-measurement checklist in appendix A: (a) prepare for discharge measurement, (b) make discharge measurement, and (c) playback discharge measurement.

The measured discharge from the check measurement should then be plotted on the rating curve and the percent difference from the stage-discharge rating computed in the field.

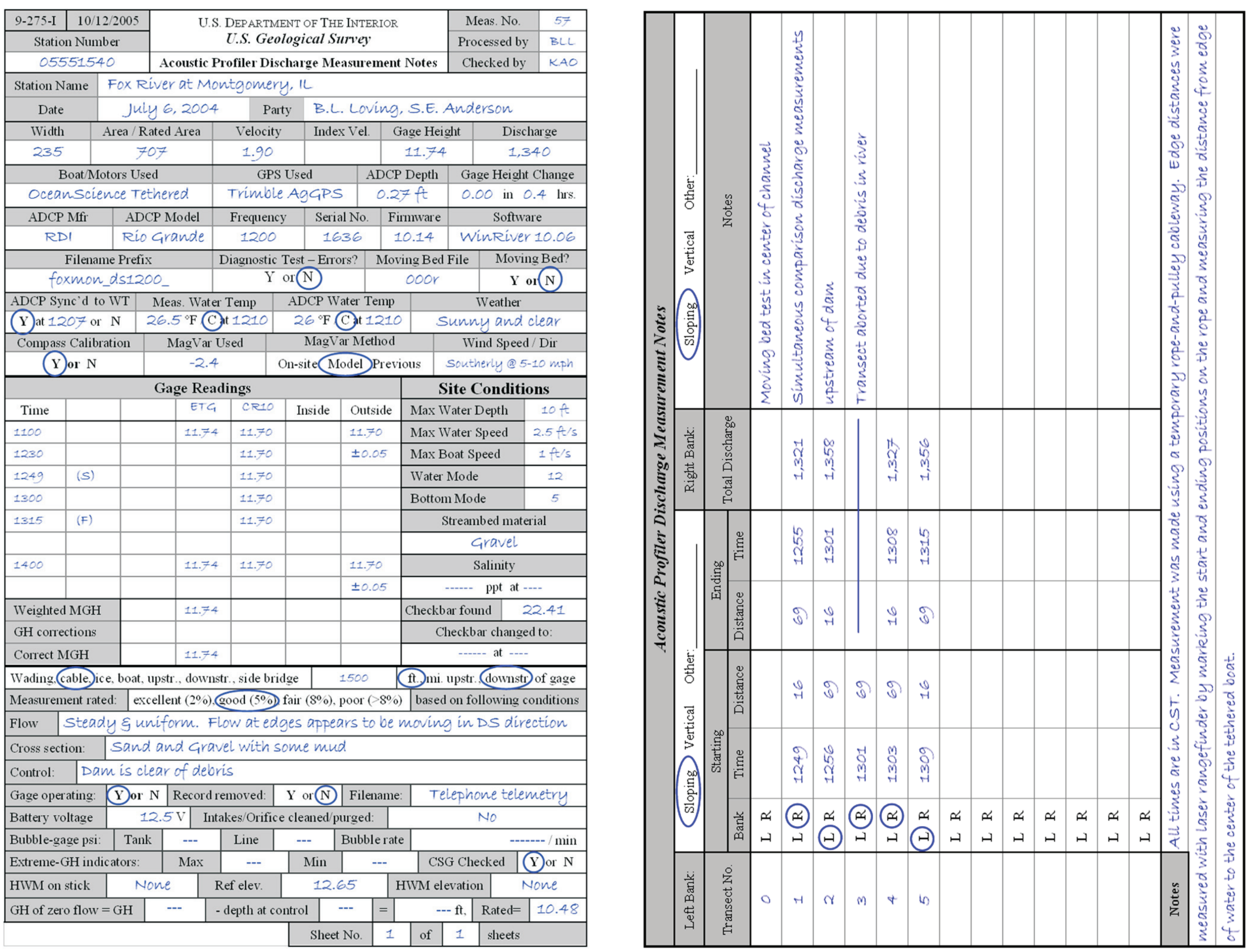
Site-specific conditions, such as turbulence, eddies, reverse flows, surface waves, moving bed, high sediment concentration, and proximity of the instrument to ferrous objects, should be noted under the appropriate sections on the ADCP measurement note sheet and used in assigning a quality rating for the measurement (Lipscomb, 1995).

All of the files in a discharge-measurement series should be identified uniquely. Immediately after completion of a measurement, all files including raw data files, configuration files, instrument test files, compass calibration files, and any electronic measurement forms should be backed up on a non-volatile media such as CD-ROM, flash-memory cards, or USB drives and stored separately from the field computer. The purpose of this backup is to preserve the data in the event of loss or failure of the field computer.

The ADCP should be dried after use and stored in its protective case for transport. When working in estuaries and other salt-water environments, the ADCP should be rinsed off with fresh water and dried prior to storing the ADCP for transport. Failure to dry the ADCP may result in corrosion of the ADCP connectors, mounting brackets, and any ADCP accessories stored in the protective case. This is especially important when working in saltwater environments.

Review of Measurements and Field Techniques

The ADCP and associated accessories (DGPS, vertical depth sounders, electronic rangefinders) should be inspected upon return from the field to determine their condition.



9-275-I	10/12/2005	U.S. Department of the Interior *U.S. Geological Survey*		Meas. No.	57
Station Number				Processed by	BLL
05551540		Acoustic Profiler Discharge Measurement Notes		Checked by	KAO
Station Name	Fox River at Montgomery, IL				
Date	July 6, 2004	Party	B.L. Loving, S.E. Anderson		

Width	Area / Rated Area	Velocity	Index Vel.	Gage Height	Discharge
235	707	1.90		11.74	1,340

Boat/Motors Used	GPS Used	ADCP Depth	Gage Height Change
OceanScience Tethered	Trimble AgGPS	0.27 ft	0.00 in 0.4 hrs.

ADCP Mfr	ADCP Model	Frequency	Serial No.	Firmware	Software
RDI	Rio Grande	1200	1636	10.14	WinRiver 10.06

Filename Prefix	Diagnostic Test – Errors?	Moving Bed File	Moving Bed?
foxmon_ds1200_	Y or (N)	000r	Y or (N)

ADCP Sync'd to WT	Meas. Water Temp	ADCP Water Temp	Weather
(Y) at 1207 or N	26.5 °F (C) at 1210	26 °F (C) at 1210	Sunny and clear

Compass Calibration	MagVar Used	MagVar Method	Wind Speed / Dir
(Y) or N	-2.4	On-site (Model) Previous	Southerly @ 5-10 mph

Gage Readings							Site Conditions	
Time			ETG	CR10	Inside	Outside	Max Water Depth	10 ft
1100			11.74	11.70		11.70	Max Water Speed	2.5 ft/s
1230				11.70		±0.05	Max Boat Speed	1 ft/s
1249	(S)			11.70			Water Mode	12
1300				11.70			Bottom Mode	5
1315	(F)			11.70			Streambed material	
							Gravel	
1400			11.74	11.70		11.70	Salinity	
						±0.05	------ ppt at ----	
Weighted MGH			11.74				Checkbar found	22.41
GH corrections							Checkbar changed to:	
Correct MGH			11.74				------ at ----	

Wading, (cable), ice, boat, upstr., downstr., side bridge	1500	(ft.), mi. upstr., (downstr) of gage
Measurement rated:	excellent (2%), (good (5%)), fair (8%), poor (>8%)	based on following conditions
Flow	Steady & uniform. Flow at edges appears to be moving in DS direction	
Cross section:	Sand and Gravel with some mud	
Control:	Dam is clear of debris	

Gage operating:	(Y) or N	Record removed:	Y or (N)	Filename:	Telephone telemetry
Battery voltage	12.5 V	Intakes/Orifice cleaned/purged:	No		
Bubble-gage psi:	Tank ---	Line ---	Bubble rate	------- / min	
Extreme-GH indicators:	Max ---	Min ---	CSG Checked	(Y) or N	
HWM on stick	None	Ref elev.	12.65	HWM elevation	None
GH of zero flow = GH ---	- depth at control ---	= --- ft,	Rated=	10.48	
		Sheet No. 1	of 1	sheets	

Acoustic Profiler Discharge Measurement Notes

Left Bank: (Sloping) Vertical Other:____ Right Bank: (Sloping) Vertical Other:____

Transect No.	Starting: Bank	Starting: Time	Starting: Distance	Ending: Distance	Ending: Time	Total Discharge	Notes
0	L R						Moving bed test in center of channel
1	L (R)	1249	16	69	1255	1,321	Simultaneous comparison discharge measurements
2	(L) R	1256	69	16	1301	1,358	upstream of dam
3	L (R)	1301	69	—	—	—	Transect aborted due to debris in river
4	L (R)	1303	69	16	1308	1,327	
5	(L) R	1309	16	69	1315	1,356	
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						

Notes: All times are in CST. Measurement was made using a temporary rope-and-pulley cableway. Edge distances were measured with laser rangefinder by marking the start and ending positions on the rope and measuring the distance from edge of water to the center of the tethered boat.

Figure 11. Example of completed acoustic Doppler current profiler discharge-measurement note sheets.

Deployment platforms and mounts also should be inspected. Damage or undue wear to any instrument components, deployment platforms, or mounts should be corrected as soon as possible. The ADCP, all accessories, platforms, mounts, and field computers should be prepared for redeployment and stored in an appropriate location. All batteries should be recharged immediately to facilitate rapid reuse.

All measurement files should be moved from the field computer or field backup media to a permanent storage location for archival and backup within 2 working days of returning to the office. Field computers used to collect ADCP data should have local area network (LAN) capability to facilitate the process of transferring the measurement data to an office server.

Discharge measurements should be reviewed in detail by the person that made the measurements as soon as practical after completion of ADCP field measurements. Checking ADCP discharge measurements should adhere to USGS policy for current-meter discharge measurements as outlined in USGS, Surface Water Branch Memorandum 61.78 (U.S. Geological Survey, 1961). The memorandum states: *"you are authorized to modify the past general practice of checking all current meter discharge measurements to the extent warranted in your district, providing adequate safeguards are established and maintained."* Therefore, the current policies in effect in USGS offices should be followed for ADCP discharge measurements as well as current-meter discharge measurements.

Important aspects of ADCP discharge-measurement reviews are listed below.

- The discharge-measurement note sheets should be complete, clear, and legible.

- All electronic data files associated with the measurement should be backed up in the field and archived on an office server.

- The number of transects collected should be appropriate for the flow conditions and satisfy OSW policy. Transects should be collected in reciprocal pairs.

- Configuration files should be checked for errors, appropriateness for the hydrologic conditions, and for consistency with field notes. ADCP depth, salinity, edge distances, edge shapes, extrapolation methods, and ADCP configuration parameters shown on the field notes should match those in the configuration file.

- A moving-bed test using proper technique should be performed prior to the discharge measurement, recorded, archived, and noted on the ADCP measurement note sheets. If a moving bed was detected, DGPS should be utilized. If DGPS was not used, the measured discharges should be adjusted for the moving bed and the measurement quality should be downgraded.

- The average boat speed for the measurement should not have exceeded the average water speed unless it was impractical or unsafe to do so, and the reason documented in the field notes or station file. Boat pitch-and-roll should not be excessive. Excessive boat speed or pitch-and-roll may justify downgrading the measurement quality.

- The measured edge distances recorded on the ADCP measurement note sheet should match those electronically logged with each transect. The correct edge shape should be selected and 5-10 seconds of data collected at transect stop/start points while the boat was held stationary. If subsectioning was used to correct problems with edges, then the subsectioning should be clearly documented on the note sheets. If a vertical wall(s) were present, then the start and/or end points for the transect should be located such that the distance from the wall(s) is equivalent to the water depth at the wall or greater.

- There should not be excessive loss of ensembles/profiles. The loss of more than 10 percent of ensembles/profiles in one or more transects may necessitate downgrading the measurement quality, especially if the missing data are concentrated in one part of the measured cross section. When the missing ensembles/profiles always occur in the same part of the cross section, the measurement quality should be downgraded, even when less than 10 percent of the ensembles/profiles are missing.

- When more than 25 percent of the depth cells in one or more transects are marked invalid or missing, the quality of the measurement may need to be downgraded. This degradement is not necessary, however, if the distribution of the missing depth cells is more or less uniform throughout the water column and/or the cross section measured.

- The extrapolation method for the top and bottom discharges should be reviewed. If review of the data shows the need for a different extrapolation method than that chosen for use in the field, the extrapolation method should be corrected and the reasons documented on or attached to the measurement note sheet. Wind and horizontally stratified density currents are common causes for profiles that do not fit well by means of the 1/6th power-law extrapolation method. In these situations, it is usually necessary to use different extrapolation techniques for the top and bottom areas and (or) to limit the portion of the profile used for the selected method.

- Measurement computations, including mean discharge and measurement gage height, must be correct.

It may be necessary for the person who collected the data or the reviewer to change some configuration parameters. In rare circumstances, it may be necessary to subsection a transect in order to provide a more accurate estimate of the edge discharge (for example, when there is excessive boat movement in the data used to estimate the edges). Changes to configuration parameters may include correcting the ADCP depth, salinity, or the extrapolation method for top or bottom. If the measurement reviewer makes changes, these changes should be discussed with the person who made the measurement. Any changes to the configuration parameters and the reasons for the changes must be documented on (or attached to) the ADCP measurement note sheets.

Problems identified during the review process should be viewed as an opportunity for improving future measurements. If the measurement section had undesirable characteristics (undesirable measurement section characteristics are described in the Site Selection section), future measurements should be made at a more appropriate measurement section. If boat-operation technique problems are identified, these problems should be discussed with the boat operator so they are not repeated during future measurements. If the ADCP and the data-collection software could have been more accurately configured, this problem also should be discussed with the field crew.

Approximately every 3 years, OSW personnel or their designees (Surface-Water Technical Review Team) will review (if applicable) each office's procedures for ADCP measurements, documentation, and data archival during OSW's technical review of the surface-water program for that office (Lipscomb, 1995). This review will include an evaluation of site selection, suitability of configuration files, measurement completeness and accuracy, documentation of instrument diagnostic tests and moving-bed tests, and archival of data files. The review will evaluate the maintenance procedures followed by each office to ensure that the most current firmware and software upgrades have been implemented, and that the instrument and peripheral equipment are being maintained properly. In addition, the review will evaluate the office ADCP QA plan to ensure that it complies with OSW policies and that the plan has been implemented and followed. The appropriate office personnel will immediately address recommendations by the Surface-Water Technical Review Team.

USGS offices that are new to ADCP use, desire ADCP data reviews more frequently than approximately every 3 years, or have issues with quality assurance that need to be addressed are encouraged to contact the OSW for assistance.

Office surface-water reviews have revealed that the most common problems related to ADCP data quality are:

a) No moving-bed test made or documented;

b) Discharge measurements not adjusted or downgraded when a moving-bed condition is present;

c) Excessive boat velocity (appreciably greater than mean water velocity);

d) Edge distances estimated, not measured;

e) Poor data-archival procedures;

f) Incorrect extrapolation method;

g) No diagnostic ADCP test;

h) ADCP time not properly set;

i) Poor field notes; and

j) ADCP depth not measured or incorrectly set.

Recommendations on how to address these problems are given throughout this report. ADCP users should pay special attention to these problems when planning ADCP data-collection efforts, collecting data, processing and archiving data, and developing office quality-assurance plans.

Instrument Tests

Each ADCP used by USGS offices must be tested: (1) when the ADCP is first acquired; (2) after factory repair and prior to any data collection; (3) after firmware or hardware upgrades and prior to any data collection; and (4) at some periodic interval (for example, annually).

The purpose of an instrument test is to verify that the ADCP is working properly for making accurate discharge measurements. Various methods for testing ADCP accuracy include tow-tank tests, flume tests, and comparing ADCP discharge measurements with discharges from some other sources, such as conventional current meters. Each of these methods has limitations as discussed by Oberg (2002).

A good evaluation of the instrument and common sources of bias in ADCPs can be made by traversing a long (1,200 – 2,500 ft) course at a constant compass heading and speed while simultaneously recording both DGPS and ADCP data. Then, traverse a course of the same length at a heading approximately 180 degrees from the previous pass. This procedure is repeated for a total of four times (eight passes altogether) while rotating the ADCP 45 degrees between each pair of courses. Rotating the ADCP helps to identify potential problems related to transducer misalignment. The ratio of the straight-line distance traveled (commonly called the distance made good) as measured by means of bottom tracking with the ADCP and the straight-line distance traveled as measured by means of DGPS can then be computed. This ratio is referred to as the bottom track to GPS ratio. Experience to date (Oberg, 2002) has shown that when the bottom track to GPS ratio is less than 0.995, ADCP measurements most likely have a negative bias error, and when the bottom track to GPS ratio is greater than 1.003, the ADCP most likely has a positive bias error. A value for the bottom track to GPS ratio of 0.995 corresponds to a -0.5 percent error in bottom-track velocity measurements. A value for the bottom track to GPS ratio of 1.003 corresponds to a +0.3 percent error in bottom-track velocity measurements. Well-calibrated Rio Grande ADCPs should have bottom track to GPS ratios of approximately 0.998 or

0.999; however, as this test is performed on more ADCPs, these bias-error criteria may change.

Although the bottom track to GPS ratio can be used to quantify bias errors caused by transducer misalignment, the full ADCP discharge-measurement functionality cannot be tested using the above procedure because bottom-track, not water-track measurements, are tested. The above procedure, however, will identify beam-alignment errors, which have been shown to be a major source of bias errors in ADCP discharge measurements. Bias errors are a major concern regarding measurement accuracy because these errors cannot be reduced. A form for documenting the distance tests is shown in appendix A.

It is suggested (but not required) that the annual instrument check described by Lipscomb (1995) be done, although some modifications to Lipscomb's procedure are recommended. This instrument check may be made annually at a site where the ADCP-measured discharge can be compared with a known discharge derived from some other source, such as the rating discharge from a site with a stable stage-discharge rating. The discharge obtained from the ADCP must be within 5 percent of the known discharge. If done, the instrument check should be fully documented and archived in a log, and also documented (see appendix A, USGS ADCP Instrument History Log form) and archived electronically. Additional recommendations for the annual instrument check are listed below.

1. Where possible, checks should not always be performed at the same site, so that a range of hydrologic conditions are reflected in the tests, and so that any inherent biases associated with a particular site are minimized.

2. If the rating discharge from a site with a stable stage-discharge rating is the comparison measurement and the ADCP measurement departs from the rating discharge by more than 5 percent, it is possible that a rating shift has resulted. Another measurement with a second ADCP or conventional discharge measurement should be made to check the validity of the rating before drawing definitive conclusions regarding the ADCP instrument test.

3. If the ADCP is equipped with more than one water- or bottom-tracking mode, it is desireable, though not required, to periodically conduct these tests using the different modes.

Summary

The acoustic Doppler current profiler (ADCP) is an electronic instrument that uses underwater acoustic signals to measure water velocity, water depth, boat velocity, and discharge in rivers. The U.S. Geological Survey (USGS) has been using ADCPs to measure river streamflow since 1985. This report describes the quality-assurance measures implemented by the USGS for discharge measurements using ADCPs; this report is an update of a 1995 quality-assurance plan for ADCPs. Use of both narrowband and broadband ADCPs by the USGS are described in this report.

The USGS Office of Surface Water (OSW) supports ADCP use through training classes, Hydroacoustic Support Web pages, software testing, and the Hydroacoustic Work Group. The OSW class *Measurement of Streamflow using ADCPs* is required before a user can operate an ADCP or review ADCP data. Users must stay current with USGS policies on ADCP use by consulting the USGS Hydroacoustics Web pages, subscribing to the USGS Acoustics Mailing List, attending hydroacoustics workshops, or taking additional USGS classes on ADCP use.

Pre-field office procedures for ADCPs include ensuring that the user has the most recent OSW-approved ADCP software and firmware, inspecting the ADCP, deployment platform, and ADCP accessories (such as differential global positioning systems (DGPS)) that will be used in the field. Field data-collection considerations include selecting an ADCP measurement section with desirable characteristics and selecting an ADCP deployment platform; deployment platforms include manned boats, unmanned tethered boats, or unmanned, remote-controlled boats. Prior to starting an ADCP discharge measurement, instrument self tests should be performed and logged, and the ADCP should be configured for the measurement with a configuration file that is matched to the hydrologic conditions at the measurement site. A moving-bed test should be performed, and if a moving-bed condition is determined, a DGPS should be used for boat tracking rather than ADCP bottom tracking.

During discharge measurements, proper boat control and speed is critical to ADCP data quality. A minimum of four transects should be made in reciprocal pairs and the four transect discharges averaged. If flow is changing too rapidly for four transects to be representative, then a single transect might constitute one discharge measurement, but, if possible, the discharge from reciprocal pairs of transects should be averaged to minimize directional bias. Edge distances must be measured with a distance-measuring device or tagline. Following the discharge measurement, all ADCP files collected on the field computer should be backed up on non-volatile storage media.

ADCP data collected in the field should be reviewed as soon a practical in the office by the person that made the measurements and, ideally, by a second qualified person. All measurement data should be transferred to an office server within 2 days of returning to the office, and archived within a directory structure similar to that used for other electronically collected data. All archived data should be backed up annually on stable archival media with a long storage life.

Each ADCP should be checked when an ADCP is first acquired, after factory repair, after firmware or hardware upgrades, and at some periodic interval. Many of the potential errors in an ADCP can be checked by traversing a course on

a large body of water and computing the ratio of the distance made good measured by the ADCP to the distance made good measured by a DGPS. Annual instrument checks may be made at a site where the ADCP-measured discharge can be compared with a known discharge.

Miscellaneous information that should be documented by offices using ADCPs includes, logs of ADCP and electronic distance-measuring device calibration checks, and a history log of ADCP upgrades. Each office must also develop an office ADCP QA plan that includes procedures specific to office ADCP models, users, and measurement sites. Approximately every 3 years, ADCP measurement, documentation, and data-archival procedures will be reviewed during an OSW Surface-Water Technical Review. Surface-water reviews have identified common ADCP data-quality problems that ADCP users should pay special attention to when planning ADCP data-collection efforts, collecting data, processing and archiving data, and developing office quality-assurance plans. Staff in the OSW provide technical assistance and consultation regarding the use of ADCPs for discharge measurements and other applications in support of the mission of the USGS.

Acknowledgments

This revision of the USGS QA plan for ADCPs was originally begun by the USGS Southeastern Region Hydroacoustics Committee (SRHC). Members of the committee took responsibility for preparing various sections of this report, revising sections from the previous quality-assurance plan (Lipscomb, 1995), or obtaining information necessary for this report. The SRHC is acknowledged for their efforts in initiating the first draft of this report. Members of the SRHC who worked on this report include Larry Bohmann, Mark Dickman, John Erbland, Anthony Gotvald, Kevin Hubbs, Mitchell Murray, John Shelton, Mark Stephens, John Storm, and Shaun Wicklein.

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APPENDIX A –Acoustic Doppler Current Profiler Streamflow-Measurement Forms

The forms presented in this appendix have been developed by the U.S. Geological Survey (USGS) for use in making streamflow measurements with acoustic Doppler current profilers (ADCPs) and for assuring the quality of the data collected by ADCPs. The forms are shown separately on the following pages to facilitate duplication and use by USGS personnel. These forms may be obtained from the USGS Hydroacoustics Web pages at *http://hydroacoustics.usgs.gov/*.

Pre-Field checklist of equipment for discharge measurements with acoustic Doppler current profilers (ADCPs).

This checklist should be used as a guideline for field preparation. Other equipment may be necessary for the sites and conditions that may be encountered in the field.

Equipment Available	Equipment List
	Basic ADCP Equipment
	• ADCP with attachments; bolts and nuts
	• ADCP cable(s)
	• Field computer with appropriate software
	• Screen shade/rain protection for field computer
	• Spare 12 V Battery with appropriate wiring assembly
	• Power inverters and power strips, if needed
	• Laser rangefinder, or some other distance measurement device
	• Battery charger
	• ADCP measurement toolkit (see table 1)
	• Field note sheets
	• Safety line for ADCP
	Boat Deployment
	• ADCP mount
	• Marker buoys
	Tethered / Remote-controlled (RC) Boat Deployment
	• Tethered boat and harness / RC boat
	• Long rope for use as tether for tethered boat
	• Radio modems and cables
	• Small 12V-9A batteries and charger
	• Boat repair kit
	• Sea anchor (for slow velocities)
	• Weight for tether (for fast velocities)
	• Hand-held walkie-talkie type radios
	DGPS Deployment
	• DGPS and power/data cables
	• DGPS antenna and cable
	• Pole for mounting DGPS antenna over ADCP
	• 12 V DC Battery
	• Spare Fuses
	Echo Sounder
	• Echo sounder and associated cables
	• Mounting bracket for echo sounder
	• 12 V DC Battery

Form for documenting history of beam-angle tests, comparison discharge measurements, diagnostic tests, and firmware upgrades.

USGS ADCP Instrument History Log

Model:		**Serial Number:**		**Office Location**	
Frequency:		**Purchase Date:**			

Task codes: BAT = Beam-angle test (distance course); CQM = comparison discharge measurement; DT = Diagnostic test; FU = Firmware upgrade; RTM = Returned to manufacturer for repair; RFM = Received from manufacturer

Date	Person	Task	Comments and Description of Work Performed

Checklist for making acoustic Doppler current profiler (ADCP) discharge measurements.

Done	Discharge Measurement Tasks
	Setup ADCP and Other Equipment
	• Attach ADCP to mount
	• Attach safety line to ADCP
	• Connect ADCP / GPS / field computer
	• Connect power to field computer and ADCP and other equipment
	• Verify communication
	Deploy ADCP, Perform Diagnostic Test, and Calibrate Compass
	• Turn off all automated field computer tasks/power saver settings
	• Put ADCP in the water
	• Configure ADCP (using configuration wizard, if available) using best estimates for water depth, water and boat speed, and bed conditions.
	• Locate appropriate measurement section / collect trial transect if needed
	◆ Select measurement site with uniform flow, no rapid drop-offs
	◆ Minimize unmeasured area
	◆ Determine maximum profiling depth
	• Measure and record water temperature and compare to ADCP measured temperature
	• Measure and record salinity and if not zero
	• Measure and record ADCP depth
	• Perform and document diagnostic test
	• Perform and document compass calibration procedure
	• Check and set ADCP clock time to be synchronized with datalogger clock
	Prepare for discharge measurement
	• Update configuration of ADCP using software tools available
	◆ Update depth of ADCP
	◆ Enter salinity; if required
	◆ Enter magnetic variation, if known
	• Fill out all field sheet with configuration and other information
	• Perform moving-bed test
	◆ Anchor or hold position next to a reference point for 10 minutes
	◆ Record data in a rawdata file
	◆ Use GPS if a moving bed is present
	• Establish start/stop points
	◆ Need minimum of two depth cells with “good” velocity on each edge
	◆ May use buoys, pilings, poles, or other reference
	Make discharge measurement
	• Position boat at starting edge-of-water (two ‘good’ depth cells)
	◆ Begin recording data
	◆ Measure and record distance to shore
	• Hold position for minimum of 10 velocity measurements
	• Drive boat across the river
	◆ Boat speed should be less than or equal to the water speed
	◆ Be a smooth operator
	• Approach ending shore slowly
	◆ Hold position for minimum of 10 velocity measurements
	◆ Stop recording
	◆ Measure and record distance to shore
	◆ Repeat four times (or more)
	◆ All four transects must be within 5 percent of the mean discharge; except for unsteady flow
	Playback discharge measurement
	• Evaluate data in field, looking for potential problems in the data
	• Make temporary backups before leaving the site

Acoustic Doppler current profiler (ADCP) beam-angle test form

9/7/2005	U.S. DEPARTMENT OF THE INTERIOR ***U.S. Geological Survey***	Processed by	
	Acoustic Profiler Beam Alignment Test Form	Ck'd by	

Location			
Date	, 20_____	Party	

Mfgr:	Model	Freq.	Serial	Firmware	Software

ADCP Depth	Filename Prefix	Diagnostic Test File	Test Errors?
			Y or N

Boat/Motors Used	ADCP Water Temp	Measured Water Temp.
	°C at	°C at

GPS Used	Moving Bed Test File	Moving bed
		Y or N

Site Conditions		Describe measurement location	
Max Water Depth			
Max Water Speed			
Max Boat Speed		Weather	
Water Mode			
Bottom Mode		Salinity	
Streambed material		ppt at	ppt at
Other Commands			

Beam Orientation	Heading	Filename or number	Field BT/GT	Final BT/GT	Notes
USGS Standard			0.995 to 1.003		
Comments					

Sheet No.		of		sheets

9/7/2005	U.S. DEPARTMENT OF THE INTERIOR ***U.S. Geological Survey***	Processed by	
	Acoustic Profiler Beam Alignment Test Form	Ck'd by	

Location			
Date	, 20_____	Party	

Mfgr:	Model	Freq.	Serial	Firmware	Software

ADCP Depth	Filename Prefix	Diagnostic Test File	Test Errors?
			Y or N

Boat/Motors Used	ADCP Water Temp	Measured Water Temp.
	°C at	°C at

GPS Used	Moving Bed Test File	Moving bed
		Y or N

Site Conditions		Describe measurement location	
Max Water Depth			
Max Water Speed			
Max Boat Speed		Weather	
Water Mode			
Bottom Mode		Salinity	
Streambed material		ppt at	ppt at
Other Commands			

Beam Orientation	Heading	Filename or number	Field BT/GT	Final BT/GT	Notes
USGS Standard			0.995 to 1.003		
Comments					

Sheet No.		of		sheets

Form for making acoustic Doppler current profiler (ADCP) discharge measurements.

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U.S. DEPARTMENT OF THE INTERIOR
U.S. Geological Survey
Acoustic Profiler Discharge Measurement Notes

Meas. No.
Processed by
Checked by

Station Number
Station Name
Date , 20 ____ Party

Width	Area / Rated Area	Velocity	Index Vel.	Gage Height	Discharge

Boat/Motors Used	GPS Used	ADCP Depth	Gage Height Change
			in hrs.

ADCP Mfr	ADCP Model	Frequency	Serial No.	Firmware	Software

Filename Prefix	Diagnostic Test – Errors?	Moving Bed File	Moving Bed?
	Y or N		Y or N

ADCP Sync'd to WT	Meas. Water Temp	ADCP Water Temp	Weather
Y at ____ or N	°F / C at	°F / C at	

Compass Calibration	MagVar Used	MagVar Method	Wind Speed / Dir
Y or N		On-site Model Previous	

Gage Readings

Time	Inside	Outside

Weighted MGH
GH corrections
Correct MGH

Site Conditions
Max Water Depth
Max Water Speed
Max Boat Speed
Water Mode
Bottom Mode
Streambed material
Salinity ppt at
Checkbar found
Checkbar changed to: at

Wading, cable, ice, boat, upstr., downstr., side bridge ft., mi. upstr., downstr. of gage
Measurement rated: excellent (2%), good (5%), fair (8%), poor (>8%) based on following conditions
Flow
Cross section:
Control:
Gage operating: Y or N Record removed: Y or N Filename:
Battery voltage V Intakes/Orifice cleaned/purged:
Bubble-gage psi: Tank Line Bubble rate / min
Extreme-GH indicators: Max Min CSG Checked Y or N
HWM on stick Ref elev. HWM elevation
GH of zero flow = GH - depth at control = ft, Rated=
Sheet No. of sheets

Acoustic Profiler Discharge Measurement Notes

Left Bank:	Sloping Vertical Other:________________				Right Bank:	Sloping Vertical Other:________________
Transect No.	Starting			Ending		Total Discharge	Notes
	Bank	Time	Distance	Distance	Time		
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
	L R						
Notes							

APPENDIX B – Acoustic Doppler Current Profiler (ADCP) Schematics

Schematics of commonly used bottom-tracking ADCPs are shown in the figures below. These schematics are provided as a means to easily reference the distance from the centerline of the transducers on the ADCP to important reference points on the pressure case.

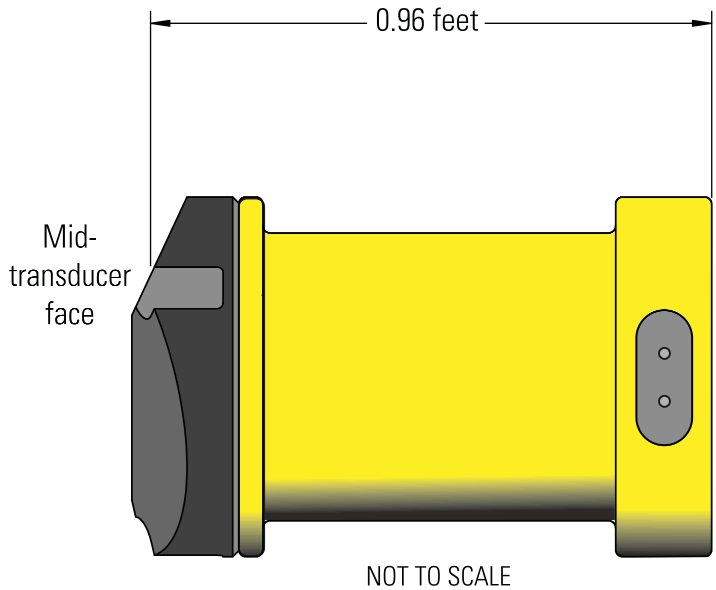

Figure B-1. Distance between top cap and center of transducers for SonTek/YSI 1,000, 1,500, 3,000 kilohertz (kHz) acoustic Doppler profilers (ADPs).

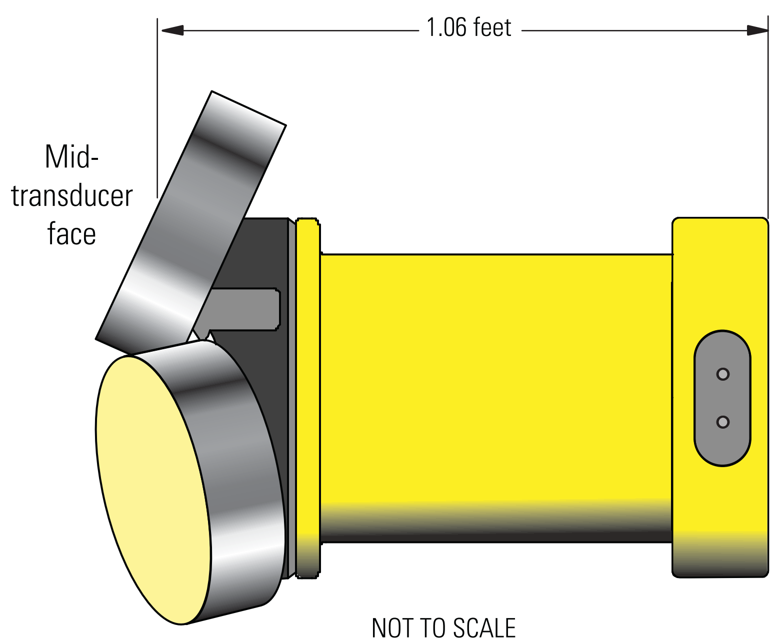

Figure B-2. Distance between top cap and center of transducers for SonTek/YSI 500 kHz acoustic Doppler profiler (ADP).

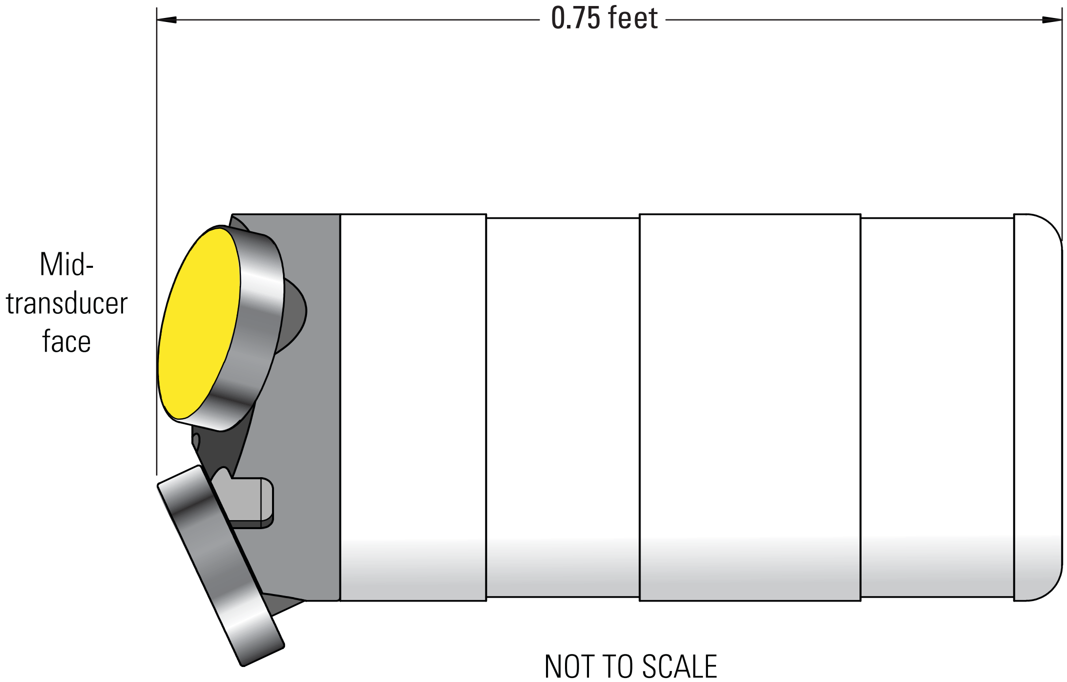

Figure B-3. Distance between top cap and center of transducers for SonTek/YSI 1,500 kHz mini acoustic Doppler profilers (ADPs) with small transducers.

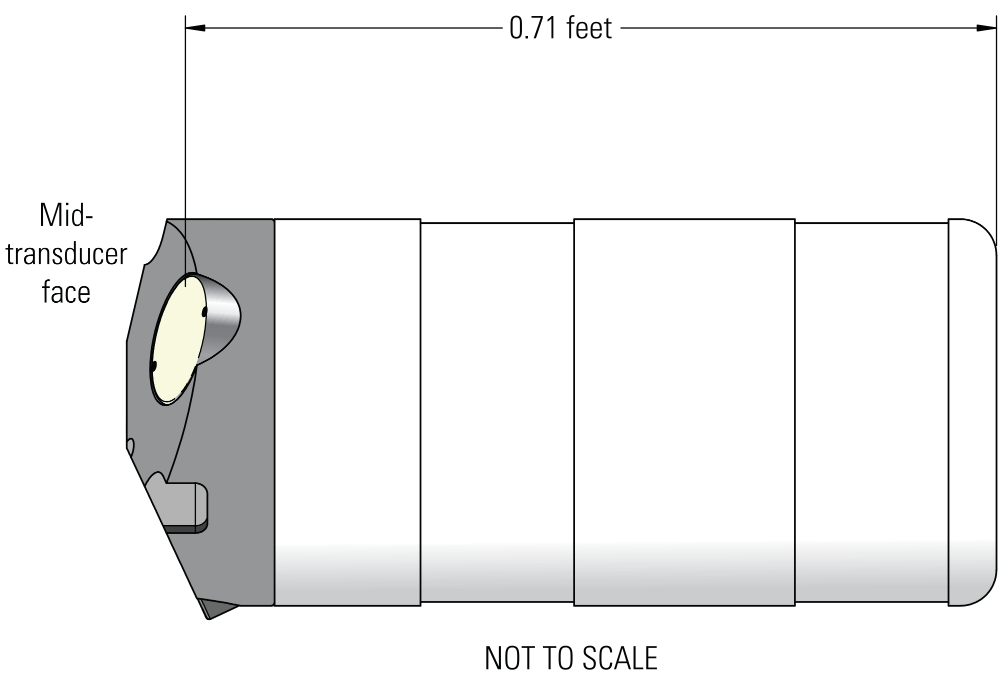

Figure B-4. Distance between top cap and center of transducers for SonTek/YSI 3,000 kHz mini acoustic Doppler profilers (ADPs) with small transducers.

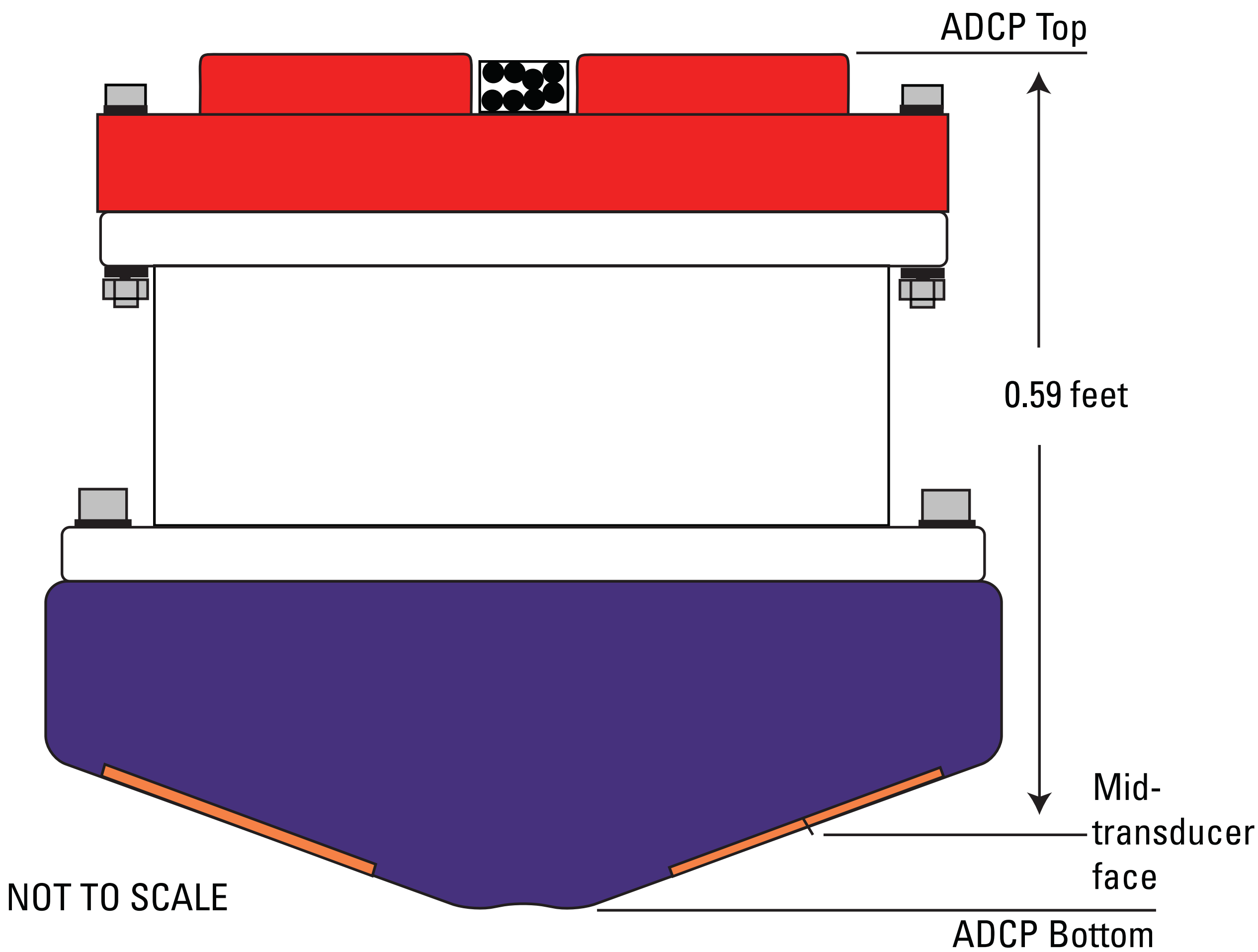

Figure B-5. Distance between top cap and center of transducers for RD Instruments Rio Grande acoustic Doppler current profiler (ADCP). (Modified from Environment Canada, 2004).

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USGS

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